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Preface

Sustainable Development Goals (SDG) adopted by United Nations in 2015 called for action by 2030 to end poverty, balance economic growth with social empowerment, and take climate-appropriate actions to save the planet. In the same year, the Paris Agreement on Climate Change required the nations to set their Nationally Determined Contribution to reduce Global warming.

As the world population grows and the impact of climate change becomes more severe, the demand for sustainable buildings and infrastructure has also increased. Moreover, durable and resilient structures are crucial aspects of sustainable construction. The resilient and durable structures which can withstand the vagaries of natural disasters reduce the need for frequent interventions of repairs and replacements, thereby reducing the resources required for maintenance.

To crystalise the way forward in the construction industry, The Indian National Group of The International Association for Bridge and Structural Engineering (ING-IABSE) has hosted this International Congress, on the theme “Engineering for Sustainable Development” in New Delhi on September 20-22, 2023.

The primary goal of the IABSE Congress is to provide a platform for policymakers, engineers, scientists, industrial partners and practitioners to present and discuss the latest developments and state-of-the-art, relevant to durability, sustainability and resilience. The congress covers various topics related to innovative materials, structural performance & design, construction methods & management, and some outstanding structures.

We are pleased to present the proceedings report of two-page extended abstracts that have undergone a rigorous review process by the members of the scientific committee from more than 35 countries. The Congress Proceeding includes more than 210 papers that have passed the stringent scrutiny out of nearly 500 submitted abstracts, which are being presented in six parallel halls aggregating to 36 sessions during the Congress. In addition, there are eight keynote lectures by eminent academicians, engineers and Government functionaries. We would like to extend our sincere thanks and appreciation to all the session speakers, and convey our special thanks to the keynote speakers for their invaluable contribution and knowledge sharing.

We also would like to express our thanks to the core members of the Scientific Committee, members and the Chair of the Organizing Committee Mr. PVVSS Ravi Prasad, President of IABSE, Dr. Tina Verjum, Executive Director of IABSE, Mr. Chep Uytiepo, Publications and Communications Manager of IABSE, Ms. Brindarica Bose, IABSE HQ staff, and the secretarial staff of ING-IABSE for their valuable contribution in the final culmination of the Congress Proceedings.

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Table of contents

Sr. No.	Title	Author/Co-Author/ Presenter	Page no.
	Keynote		
1	Sustainable Development Pathways to Address Climate Change	*Leena Nandan*	
2	Engineering Solutions for Sustainable Development	*S S Chakraborty*	22
3	Changing Climate and Sustainability of Built Environment	*Petr Hajek*	23
4	Sustainable Development Goals and The Debate of Demolition Versus Conservation in A Developing Economy	*Arun Menon*	24
5	Upgrade & Retrofit of Existing infrastructure & How It Contributes to Sustainability to Extend the Service Life of Structures	*David MacKenzie*	25
6	Code of Practice for Sustainable Structures	*Helena Gervasio*	26
7	Approach to Sustainability in Built Environment	*Sanjay Pant*	27
8	New initiatives to Sustainable infrastructure Growth in India	*Anurag Jain*	
	Session 1: Sustainability in Transportation Structures		
9	New modular construction method for multi-span concrete bridges with reduced material consumption	*Franz Untermarzoner*, Michael Rath, Johann Kollegger*	29-30
10	The Practice of Forensic Structural Engineering in IABSE Member Countries: preliminary review of Survey 2022	*Fabrizio Palmisano, Laurent Rus, Karel Terwel*	31-32
11	Lessons in Remote Infrastructure: Connecting People and Landscape to Promote Economic Vitality & Create Social Value	*Poul Ove Jensen, Kasper Svanberg, Jesper Henriksen, Tine Holmboe, Catherine Merlo*	33-34
12	Towards Attaining SDG in Design and Construction of Highway Bridges - A Critical Review	*Naresh Kumar Sinha*	35-36
13	Designing on existing bridges: A paradigm of sustainability applied to civil engineering	*Javier Torrico Liz, Jose Romo*	37-38
14	Long-Term Sustenance Issues with Cables for Cable-Supported Bridges	*Amitabha Ghoshal, Partha Roy*	39-40
	Session 2: Case Studies in Sustainable Materials, Technology and Practices		
15	Innovative bridge structures recently built in Poland	*Jan Biliszczuk, Wojciech Lorenc, Maciej Kożuch, Marco Teichgraeber*	42-43

16	Design of Multi-span Cable Stayed Bridge at Ambhora, near Nagpur, Maharashtra	*Nirav V. Mody, Dr. Harshavardhan Subbarao, HKS Durga Jithendra Bhattiprolu*	44-46
17	Seismic demand assessment for 20km long Elevated Expressway in Chattogram, Bangladesh	*Engr. Sabbir Siddique, Engr. Faria Sharmin*	47-49
18	Independent Design Checking of Brahmaputra Bridge, Guwahati - Sharing Experience Lessons Learnt	*Alok Bhowmick,Gurpreet Singh Raja*	50-51
19	Structure of the new movable railway bridge on Pamban Island	*Alberto Curbelo, Ginés Ladrón de Guevara, José Luis Sánchez, Ángel Cabria, Andrés González*	52-53
20	Case study using Non-Linear Finite Element Analysis for Assessment of Slutchers Lane bridge.	*Jithu G Francis, Sreejith Parayil, Abani Kumar Satapathy*	54-55
	Session 3: Analysis, Research and Standardisation		
21	Experimental study on dynamic characteristics of rubber sand mixtures	*Zhen Li, Bruno Briseghella, Junqing Xue, ZhengxianYang, Fuyun Huang, Alessandro Contento*	57-58
22	Gap filler to eliminate the hole play between base plate and channel bolts installed in anchor channels to sustain higher seismic loads	*Christoph Mahrenholtz, Sven Giesenbauer, Akanshu Sharma, Gopal Vutha, Kusum Saini*	59-60
23	Sandwich panels with bio-based core of wood fibre insulation	*Eric Man Pradhan, Jörg Lange, David Izabel, Thibault Renaux, Valérie Huet*	61-62
24	Experimental and Analytical Investigations on The Shear Capacity of Prestressed Concrete Bridges	*Christian Dommes*, M.Sc.; Univ.-Prof. Dr.-Ing. Josef Hegger*	63-64
25	The Evolution of the Indian Standard IS 1893 Focusing on Base Shear Values of Seismic Forces for a Forty-Three-Storey Reinforced Concrete High-Rise Building Using the Response Spectrum Method	*Samard Buddee*	65-67
26	Influence of Train Composition on Crack Propagation at Structural Components of Welded Railway Bridges	*Dorina Siebert*, Christina Radlbeck, Martin Mensinger*	68-69
	Session 4: Climate Change Adaptation and Disaster Resilience		
27	Addressing Climate Resiliency in Long Span Bridges through Early Stage Aerodynamic and Climate Engineering Consulting	*Guy L. Larose, Theresa Erskine, Rahul Rajendran, Suresh Kumaresan*	71-72

28	Climate Change: Latest on the Wind Speed at the Coastal Regions of India	*Rahul PS, Cini Anoop, Suresh Kumar K*	73-74
29	Functional Seismic Resilience of Reinforced Concrete Building Conforming to Indian Standards	*Mohammad Rafiq Joo, Ravi Sinha*	75-76
30	Influence of Design Practices and Climate Change Effects on the Seismic Fragility and Life-Cycle Cost of Highway Bridges	*Mohamed Mortagi, Jayadipta Ghosh*	77-78
31	Understanding Social Engineering and Disaster Resilience of the Rural Roads Sector for Sustainable Development	*Shailly Gupta*, Mukesh Chander Gupta*	79
32	Modular Steel Panel Bridges for Optimal Emergency Response to Distressed Bridges on National Highways in India.	*Lt Gen S Ravi Shankar*	80
	Session 5: Sustainability in Built Environment		
33	Construction Materials and Green House Gas Emissions in India	*Dr. Chandrasekaran Balaji Venkateswaran M.E. Ph.D.*	82-83
34	Material Selection for Minimum Carbon Footprint in Structural Design	*Martin Rettinger*, Melissa Meyer*	84-85
35	Experimental Analysis on The Sustainable Effects of Magnetic Water in Self-Compacting Concrete with Partial Replacement of Constituent Materials	*Mallikarjun Kaspa*, VLD Prasad Reddy*	86-87
36	Water transport properties and Life Cycle Assessment of low-grade fly ash based cementitious materials	*Manoj Kumar, K V Harish*	88-89
37	Different strategies for setting requirements to sustainability	*Randi Muff Christensen*	90-91
38	Steel Fibre Reinforced Concrete for Sustainable Construction	*Summer Shahzad, Kasperi Pirttikoski, Sébastien Wolf*	92-93
	Session 6: Heritage Structures		
39	Methods for ensuring the sustainability of steel heritage bridges	*Pavel Ryjáček, Vojtěch Stančík, Jakub Vůjtěch, Jiří Litoš, Martin Pospíšil, Jan Kudláček, Miroslav Sýkora*	95-96
40	Revitalization of the historical bridge over the Mala Panew river in Ozimek - the oldest chain suspension grey cast iron river-crossing on the European continent	*Mariusz Maślak, Marek Pańtak, Michał Pazdanowski*	97-98
41	Femtosecond pulse laser cleaning for the preservation of the Sydney Harbour Bridge	*Julia Branda,b , Andrei V. Rodeb, Steve Maddenb, Alison Waina, Penelope L. Kingc, Meera, Mohand, Waruna Kaluarachchid, Julia Ratnayaked, Ludovic Rappb*	99-100

42	Conservation of caves cut in volcanic breccia, Jogeshwari, Mumbai	*Vikram Pawar, Kimaya Keluskar, Malini Rajlakshmi*	101-102
43	How an Architectural Gem from 1900 Became Building of the Year 2020 Alter Wall 2-32 at the Heart of Hamburg-Germany	*Oskar H. Pekoll*	103-104
44	Femtosecond pulse laser cleaning of Makrana marble and semi-precious stones for the preservation of the Holy Samadh	*Julia Brand, Steve Madden, Andrei Rode, Ludovic Rapp, Alison Wain*	105
	Session 7: Sustainability in Transportation Structures		
45	Bridge Management Analytics Focused on Sustainability and Economic Growth	*Sachidanand Joshi, Atharvi Thorat, Harshali Dehadray, Mayuri Tundalwar*	107-108
46	Sustainability and innovation in design of major bridge substructures	*Thomas Löhning, Flemming Pedersen, Uffe Graaskov Ravn, Kahini Kundu*	109-110
47	Halsafjorden Suspension bridge on floating foundation. Design and CO2 emission.	*Ketil Aas-Jakobsen, Assad Jamal, Joar Tistel*	111-112
48	A comparison of the resource efficiency of different reinforcement concepts motivated by tunnel segments	*Marion Decker, Clemens Proksch-Weilguni, Johann Kollegger*	113-114
49	Environmental assessment ofroad construction projects in India: A novel approach	*Abhiram Shukla, Harshal Tikam*	115-116
50	Innovative Box Girder Having Footpath at Bottom of Boxgirder by Cantilevering Soffit Slab	*Arun K V, Dr. Beena K P*	117-118
	Session 8: Case Studies in Sustainable Materials, Technology and Practices		
51	Innovative solution for an Extrodosed bridge over river Beas in Hilly Terrain of Himalayas	*Nirav V. Mody, Dr. Harshavardhan Subbarao, Shaik Mohammed Rizwan*	120-122
52	Development of Extraordinary Suspension Bridge Solutions for Sulafjord in Norway	*Svein Erik Jakobsen, Inger Kroon, Ketil Aas-Jakobsen, Per Norum Larsen, Kristin Nessa, Assad Jamal, Joar Tistel, Gunnar Egset*	123-124
53	Innovation in the Design and Construction of Temburong Bridge, Brunei	*Sammy Yip,Naeem Hussain, Paresh Vishnoi*	125-126

54	Mechanisms for New Lifting Railway Bridge on Pamban Island In Tamil Nadu, India	*Jose Luis Sanchez Jimenez, Angel Luis Cabria Calleja, Andres Gonzalez Guerrero, Gines Ladron de Guevara Mendez, Alberto Curbelo Diaz*	127-128
55	Wind Tunnel Testing and Aerodynamic Consulting for Indian Bridges Today	*Guy L. Larose and Pierre-Olivier Dallaire, Rahul Rajendran and Vishnu,Raveendranathan*	129-130
56	Case Study of Rochdale Canal Bridge Assessment using Non-Linear Finite Element analysis	*Sai Anoop Aditya Voleti*, Sreejith Parayil, Abani Kumar Satapathy*	131-132
	Session 9: Analysis, Research and Standardisation		
57	Proposed Seismic Design Methodology for Steel Pier-Pile Integrated Structure Considering Dynamic Soil-Pile Interaction and Ductility Performance of Elongated Members	*Shreya Thusoo*, Takayuki Omori, Fukutaro Umebayashi*	134-136
58	A longitudinal isolation system with elastoplastic cables forsingle-tower cable-stayed bridges	*Zhang Shichun, Guan Zhongguo*	137-138
59	Seismic Analysis of Integral Abutment Bridge - Comparison of Framed Abutment with Fixed Base and Hinged Base	*Biswa Kumar Balla, Sudip Shrestha*, Shreenij Maharjan*	139-140
60	Effect of Bridge Foundation Stiffness on The Dynamic Behavior of Bridge Structure	*Minh Tran Quang, Hélder S. Sousa, Binh Nguyen Duc, José C. Matos, Ana Margarida Bento, Tiago Ferradosa, Huan X. Nguyen*	141-142
61	Study on Mechanical Properties of a Negative Poisson's Ratio Structural Bridge Block	*Xuhui Zhang, Xun Wu, Shanguo Jiang*	143-144
62	Thermal Performance of Sandwich Wall Panels with Core Insulating Material	*Sooriya lakshmi. N, Dr. Jane Helena.H, Sherila.B*	145-146
	Session 10: Digital Initiatives (BIM, Artificial Intelligence, 3D Printing)		
63	Humanism through artificial intelligence?	*Baris Wenzel*	148-149
64	MINIMASS: a new approach for low-carbon, low-cost 3D printed concrete beams	*Andy Coward, Jesper Harrild Sørensen*	150-151
65	Material efficient WAAM Steel Construction Details	*Maren Erven, Jörg Lange*	152-153
66	A Holistic Digital Design Approach for a Metro Project in Portugal	*Jose R. Duarte, Filipa Duarte, Bruno Fernandes, Zeljka Devedzic, Johann Stampler, Blaz Mulavec*	154-155

67	3D Printed Sandwich Structural Decks of Dual Corrugate Sheet with Mid Shear Layer (DCMSL) as Core Profile	*K Kamal*	156-157
68	Machine Learning Based Optimization Techniques for Predictive Strength of High Performance Concrete: Enhancing Sustainable Development	*Lukesh Parida, Sumedha Moharana, Sourav Kumar Giri*	158-160
	Session 11: Sustainability in Built Environment		
69	Effect of Slenderness on the Designof FRP reinforced Concrete Columns	*Ahmed Usama Syed*, Arndt Goldack*	162-163
70	Disruptive change in mineral building materials - high-performance prefabricated elements made of UHPC for circular buildings	*Michael Olipitz*	164-165
71	Mapping structural engineering strategies for sustainable development	*Karel Terwel, Roy Crielaard*	166-167
72	Mechanical behavior and load-bearing capacity of components made from sustainable lime-paper material	*Stefan Reich, Christian Pfütze*	168-170
73	Replacement of gypsum plasterboard with sustainable secondary raw material composition	*Christian Pfütze, Stefan Reich*	171-173
74	Sustainability by Integration of Existing Structures into new Infrastructures	*Grischa Dette, Ed. Züblin AG, Jörg Munack*	174-175
	Session 12: Heritage Structures		
75	Bridges as Built Heritage: Preservation, Reimagination, Transformation	*Poul Ove Jensen, Jesper Henriksen, Tine Holmboe, Catherine Merlo*	177-178
76	Conservation discourses in technical education, India	*Dr Bidhan Chandra Roy, Vikram Pawar*	179-180
77	Influence Of Residual Stresses on Mechanical Properties of Structural Steels Subjected to Laser Ablation Treatment	*Jiawei Tu, Anna Paradowska, Andrei Rode, Ludovic Rapp, Steve Madden, Meera Mohan, Gwénaëlle Proust*	181
78	Improving of (energy) performance of existing (heritage) buildings	*Geralt Dr. Siebert*	182-183
79	Preservation of heritage masonry structures: Assessing compatibility of consolidative treatments on Fired Clay Bricks	*Tejyas D. Singh, Swathy Manohar*	184-185
80	Lime-Red Mud Binders for Repair of Heritage Structures and for Co2 Sequestration	*V S Athira, Shipin Prakash, Swathy Manohar, Shaurya Suman*	186-188
	Session 13: Sustainability in Transportation Structures		
81	Sustainable development requires risky decisions - problematic 300ton overweight transport passing a bridge	*Mikołaj Miśkiewicz, Andrzej Kozakiewicz, Lukasz Pyrzowski, Bartosz Sobczyk*	190-191

82	Sustainable Design and Construction of Bridge Case Study of Design of Arch Bridge in Nepal Using Multi-Criteria Decision Analysis	*Shreenij Maharjan*, Biswa Kumar Balla, Sudip Shrestha*	192-193
83	Sustainable Bridges Past and Future Reflections on A European Project 2003 - 2007	*Lennart G Elfgren*	194-195
84	Research on Concrete Box Girder Bridge Widening Based on Spatial Grid Model	*Chenglin Sun**	196-197
85	Adoption of Stainless Steel in Bridge Construction for Safety and Sustainability	*Nirmalya Bandyopadhyay, Amitabha Ghoshal*	198-199
86	Underground Metro: A Solution for Sustainability	*Vinay Gupta*	200-201
	Session 14: Case Studies in Sustainable Materials, Technology and Practices		
87	Construction of the Multi-span Cable Stayed Bridge at Ambhora, near Nagpur, Maharashtra	*Nirav V. Mody, Dr. Harshavardhan Subbarao, HKS Durga Jithendra Bhattiprolu*	203-205
88	First time Use of Lead Rubber Bearing for Seismic Isolation of a continuous Bridge in India - a CASE STUDY	*Shilpi Srivastava, Sanjay Jain*	206-207
89	Double-Decker - Nagpur Metro Flyover with Spine & Wing Superstructure	*Sachin More*, Manoj T. P.*	208-209
90	Study of A Monumental Stair Susceptible to Excessive Vibrations Due to Human Movements	*Mehdi Setareh*	210
91	Designing World Tallest Statue for Wind: Statue of Unity	*Cini Anoop, Rahul P S, K Suresh Kumar*	211-212
92	488 University Avenue - Toronto: Redefining possible in the vertical expansion of buildings	*Bujar Morava, Shayne Love, David Liang*	213-214
	Session 15: Analysis, Research and Standardisation		
93	Research on creep and shrinkage effects of steel-concrete-Ultra-High Performance Concrete (UHPC) composite structure under different construction methods	*Deng guomin,Shi shudong, Ma xiaogang, Zhang dawei, Guo songsong, Liu chao*	216-217
94	Butt-jointed reinforcement bars in the longitudinal joints of tunnel segments: Experimental investigation	*Clemens Proksch-Weilguni*, Marion Decker, Johann Kollegger*	218-219
95	Bridge Cables Non-Destructive Testing	*Daniel C. Ruff, Hans Eirich*	220-221
96	Seismic Performance of Rigid-Frame Suspension Composite Bridges	*Cheng Peng *, Zhang Xuejian, Liu Xiaoxian,Yin Yonggao*	222-223
97	Numerical Modeling of Rigid Frame Suspension Composite Bridge	*Chenfei Wu *, Zhou Wenrui, Liu Xiaoxian,Yin Yonggao*	224
98	In-Plane Behavior of Strengthened Unreinforced Masonry Infill Walls: Experimental and Numerical Study	*Jaya Kumar Bhaskar, Dipendu Bhunia*	225-226

Session 16: Special Session: Existing Bridges - Our Vital Responsibility in BIM Environment

99	Digital Bridge Schwindegg (Germany): Ab initio monitoring for sustainable lifecycle management	*Johannes Wimmer*, Thomas Braml*	228-229
100	Digitalization of bridge inventory via automated generation of BIM Models	*Rade Hajdin, Lazar Rakic, Holger Diederich, Rico Richter, Justus Hildebrand, Sebastian Schulz, Jürgen Döllner, Jennifer Bednorz*	230-232
101	Linking BrIM to BMS for Bridges Concepts	*Ketil Aas-Jakobsen, Assad Jamal, Joar Tistel*	232-233
102	GABM - EMPOWERING THE MICRO BRIDGE INVENTORY OWNERS	*Sachidanand Joshi, Atharvi Thorat, Harshali Dehadray, Mayuri Tundalwar, Dinesh Surve*	234-235
103	An Overview of the BIM Implementation on Chilean Bridges.	*Matías A. Valenzuela, Marcelo Marquez & Leonardo Roca, José Luis Seguel*	236-237
104	Extending the life of a historical Bridge through UHPFRC	*Kristian Schellenberg, Henar Martín-Sanz, Vasco Amaral*	238-240

Session 17: Sustainability in Built Environment

105	CROSFALL a Knowledge Sharing Newsletter to Create a Safer Built Environment	*ALOK BHOWMICK*	242-243
106	A Machine Learning-Based Methodology of Integrating Loading Data and Load Effect Data for Long Span Bridge Assessment	*Cong (Simon) Ye* Paresh Vishnoi,Ngai Yeung, Steve KITE*	244-245
107	The second generation of Eurocode 4	*Stephen Hicks*	246-247
108	Efficiency and Cost Effectiveness of Ground Source Heat Pump for Five Storied Office Building	*Priyanka Bhartiya*	248-249
109	Restructuring Construction Thinking for Urban Material Reuse (RECUR)	*Reza Haghani, Debra Laefer*	250-251
110	Sustainable facade constructions	*Barbara Siebert,Geralt Siebert*	252-253

Session 18: Heritage Structures, Poverty Alleviation and Social Sustainability

111	Bridge construction using decommissioned wind turbine blades as a poverty alleviation centric technology: possibilities and implementation example	*Bartosz Piątek*, Mateusz Rajchel, Maciej Kulpa, Tomasz Siwowski*	255-256
112	Mobility Architecture as a Driver of Social Sustainability Outcomes	*Poul Ove Jensen, Jesper Henriksen, Tine Holmboe, Catherine Merlo**	257-258

113	Sustainable and resilient structures	*R.Jaiprasad, Dasari Taranath*	259-260
114	Deep vision-based stone deterioration assessment of Indian heritage structures using synthetic and real-time environment	*T. Jothi Saravanan*	261-262
115	Poverty Alleviation - Habitats and Infrastructures for the Under Privileged	*Dr. Bidhan Chandra Roy, Dr. Raghuram Ekambaram*	263-264
116	Sustainability of Heritage Structures : Conservation Issues & Challenges	*NC Pal*	265-267
	Session 19: Sustainability in Transportation Structures		
117	Structural Rehabilitation of Viaduct Cernicchiara	*Francesco Fanigliulo*	269-270
118	Designs and Associated Carbon Footprint – Showcasing Mumbai Trans Harbour Link	*Anoop Singh Jangi,Lars Lundorf Nielsen*	271
119	Bridges – A Catalyst as well as a Driver for Sustainable Development	*Suman Chattopadhyay, Karthik Venkatachalam, Partha Roy, Koyya Satyanarayana*	272-273
120	Experience as Incentive: Promoting Sustainable Urban Mobility Through Bridge Design	*Jesper Henriksen, Susanne Bendsen, Tony Ao Han, Jin Wang, Tine Holmboe, Catherine Merlo*	274-275
121	Net Zero implementation on transportation projects	*Sachin, Ashwinikumar Thakur*	276
122	An update on the carbon footprint of bridges.	*Dr. David Collings, Spandan Murthy*	277-278
	Session 20: Case Studies in Sustainable Materials, Technology and Practices		
123	Cable replacement of Fernando Reig Bridge in Alcoy, Alicante	*Torrico, Javier, Hugo Corres, Javier León, Julio Sánchez, Cristina Sanz, Gemma Fernández*	280-281
124	Multi-faceted Approach to School Earthquake Safety in Westernmost Nepal	*Hari Kumar, Dinesh Joshi, Veronica Cedillos, Upama Ojha, Janise Rodgers, Heidi Stenner*	282-283
125	Underground Metro Projects-Structural Engineering Challenges	*Prof. Mahesh Tandon, Mr. Navneet Gupta*	284
126	Construction of 4-lanes Signature Bridge between Okha and Beyt Dwarka in Gujarat State	*Deepak Singla , Rajiv Ahuja*	285-286
127	83.92 m Wide Rail Over Bridge Chipiyana, Gautam Buddha Nagar, UP, India	*Satyam Gupta**	287-288

128	Optimal Solution for Shallow Tunnel at Dwarka Expressway	*Nirav V. Mody, Mangesh M. Sawant, Atul S. Kavthankar*	289-291
	Session 21: Analysis, Research and Standardisation		
129	Comparative Study of the Statistical Methods of Fragility Curve Generation	*Shakil Manandhar, Sushmita Maharjan*	293-294
130	An Evaluation of Human Bouncing Force Excitation	*Mehdi Setareh, Huy Pham*	295
131	Analysis of A Cross-Section of a Steel-Concrete Composite Beam	*Patricia Vanova, Daniel Dubecky, Michala Weissova, Vincent Kvocak*	296-297
132	The usage of Polymer-based materials in Civil Engineering	*Michala Weissova, Vincent Kvocak, Daniel Dubecky, Patricia Vanova*	298-299
133	The Smart FRP Panel for Bridge Redecking – Development and Experimental Validation of "Panel – Panel" and "Panel – Girder" Connections	*Bartosz Piątek*, Maciej Kulpa, Tomasz Siwowski*	300-301
134	Influence of endurance of stud shear connectors on the reliability of steel-concrete superstructures of road bridges	*Nikolai Kozak*, Anton Syrkov, Vladimir Bystrov, Dmitry Yaroshutin*	302-303
	Session 22: Digital Initiatives (BIM, Artificial Intelligence, 3D Printing)		
135	Integration of BIM in Bridge Management - Enhanced Predictive Functionality	*Sachidanand Joshi, Atharvi Thorat, Harshali Dehadray, Mayuri Tundalwar*	305-306
136	Restructuring Construction Thinking for Urban Material Reuse	*Reza Haghani, Debra Laefer*	307-308
137	Long-term shape sensing of bridges with automated ROI extraction of LiDAR point clouds	*Ganesh Kolappan Geetha, Sung-Han Sim*	309-310
138	Use of terrestrial 3D laser scanning technology for examination of transportation structures	*Dmitry Yaroshutin, Anton Syrkov, Nikolay Kozak, Dmitry Shestovitsky**	311-312
139	Role of Artificial Intelligence in Sustainable Bridge Design	*Saju S, Nisha G K*	313-315
140	A Robotic and Automatic Solution for Identifying Frequencies and High-Resolution Mode Shapes of Bridge Structures – An Experimental Study	*Xudong Jian*, Eleni Chatzi, Zhilu Lai*	316-317
	Session 23: Sustainability in Built Environment		
141	Development of Low-Cost Seismic Isolators Using Scarp Rubber Tyre Pads for Sustainable Disaster Mitigation	*Manish Kumar, Dhanashree Tulankar, Suhasini Madhekar*	319-320
142	Making Sustainability as Core of Engineering Education	*Shantanu Apte*	321-322
143	Sustainable development of sports stadiums	*Dr. Sven Schmedes*	323-324

144	Current Knowledge, Challenges, and Facilitating Factors from the National Survey on Sustainability in the Building and Construction Sector	*Shivam Srivastava, Chetan Hazaree, Usha Iyer-Raniga, Sudhir Misra*	325-327
145	Service-life and Sustainability of Concrete Structure in Tropical Condition	*Bishwajit Bhattacharjee*	328-329
146	A Case Study on the Performance Based Enhancement of Cementitious Systems through Sustainable Nanomaterials	*Mainak Ghosal,Arun Kumar Chakraborty*	330-331
	Session 24: Analysis, Research and Standardisation		
147	Experimental corrosion investigation of untreated suspension bridge main cables	*Kazuhiro Miyachi, Haruki Oishi, Takeshi Yajima, Moritoshi Yano*	333-334
148	The need for research and innovation to facilitate upscaling of low-carbon concrete	*Rasmus Rempling, Mats Karlsson, Ignasi Fernandez, Carlos Gil, Ingemar Löfgren, Alexandre Mathern, Jonas Magnusson, Iad Saleh, Jan Suchorzewski*	335-336
149	Opportunities in Civil Projects with Artificial Intelligence	*Alexander Kjellgren, Per Kettil, Rasmus Rempling, Mats Karlsson*	337-338
150	Structural performance assessment of post-tensioned concrete beams by embedded continuous fibre optics	*Daniel Ekström, Rasmus Rempling, Ignasi Fernandez, Carlos Gil*	339-340
151	Implementation of Controlled Flexibility as a Seismic Strategy Towards Building Sustainable Bridge Infrastructure in India	*Santanu Majumdar, Pratik Sen*	341-342
152	Performance Evaluation of Off-Site Construction Method for Mass Housing Projects using Building Information Modelling (BIM) Approach	*Ramesh Nayaka, Macharla Aravind*	343-344
	Session 25: Sustainability in Transportation Structures		
153	Structure as Symbolism: Pylons as Tools for Cultural Expression in the Asia-Pacific Region	*Poul Ove Jensen, Jesper Henriksen, Tine Holmboe, Catherine Merlo*	346-347
154	Use of Waste Plastic for Road Construction in Delhi NCR Region	*Ambika Behl, Shankh Das, Saurabh K Verma, Saurabh Chandra*	348-349
155	Indian Institution of Bridge Engineers (IIBE) for Sustainable Construction of Bridges	*Vinay Gupta*	350-351
156	Sustainable Solutions for Major River Crossings in Bangladesh	*Paul Sanders, Prof. Jørgen S. Steenfelt, Amar Bahra, James Worth, Prakash Sahoo, Quasi Mohammed Ferdous*	352-353

157	Top-Down Construction in Railway Projects: A Sustainable Solution	*Ankit Gupta, Wasim Qadir*	354
158	Planning Zoji-La tunnel for sustainable ecosystem	*Indresh Kumar Pandey*	355-356
	Session 26: Case Studies in Sustainable Materials, Technology and Practices		
159	Case Study on Re-Use of Dismantled Concrete Drain in A Highway Widening Project of India	*Runal Kanti Bhattacharyya, Monali Bose*	358-359
160	Design of Tall Railway Bridges in North Eastern States, India	*Sumantra Sengupta*	360-361
161	Residual Fatigue Strength Assessment & Rehabilitation of Rajendra Setu, Mokama, India	*Jatin Singla*, Sumantra Sengupta*	362-363
162	Design and construction staging of a 300m steel bridge renovation on a wharf	*F. de Meijier MSc, D.C. Tjepkema, F. van Dooren MSc*	364-365
163	Mumbai Trans Harbour Link - A leap over Sea	*Ekhlaq Ahmed Khan*	366-368
164	Construction of New Brahmaputra Bridge Road Works near Tezpur - An Insight	*Anupam Das*	369-370
	Session 27: Analysis, Research and Standardisation		
165	Seismic Isolation Design for Achieving Post-Earthquake Functionality	*Anoop S. Mokha*	372-373
166	Flexural Behavior of Perforated Steel Beams with Multiple Web-Corrugations and Openings	*Fayaz Ahmad Sofi, Salman Sultan, and Showket A. Kumar*	374-375
167	Effects of polyvinyl alcohol fiber on bond behavior between concrete and steel rebar	*Xuhui Zhang*, Qi Lu*	376-377
168	Studies on The Microstructure of Carbon Dioxide-Sequestered Cement Paste.	*Pranjal V. Chechani, A. Ramaswamy*	378-379
169	Image analysis of concrete surface for investigating the influence of aggregate distribution and load induced damage on the chloride permeability of concrete measured using RCPT (ASTM-C1202)	*Pankaj Mishra, Aamna Sarfaraz, Sudhir Misra, K. V. Harish*	380-381
	Session 28: Climate Change Adaptation and Disaster Resilience		
170	Failure Analysis: Shallow and Deep Causes Assessment Methodology	*Laurent Rus, Carlos Moreno, Shaikh Mohammad*, Arif Shahid, Iftekhar Ahmed, Tapas Chowdhury*	383-384
171	Climate Change Induced Carbonation of Reinforced Concrete Buildings in European Cities	*Silvia Dimova, Maria Luísa Sousa, Helena Gervásio, Guido Rianna, Emilio Bastidas-Arteaga, Maria Nogalx*	385-386
172	Embodied Energy and Urban Infrastructure: Mitigating Impact of Climate Change	*Dr. B C Roy, S Bhattacharyya*	387-388

173	Seismic Resilience Assessment of Aging Highway Bridge Considering Climate Change Effects	*Chirdeep N R, Bahurudeen A, Shivang Shekhar*	389-390
174	Seismic Hazard Evaluation and Damage Assessment of Bridges	*Rajat Dabral, Vishisht Bhaiya, Rahul Chaudhary*	391-392
175	Sustainable and Green Construction Technologies in India	*Sanjay Kumar Nirmal*	393-394
	Session 29: Case Studies in Sustainable Materials, Technology and Practices		
176	Characterization of the Site-Effects on The Local Seismic Hazard Assessment for a Long Span Suspended Bridge in Southern Chile	*Galo Valdebenito, José Luis Seguel*	396-397
177	Case Study: Implementation of UHPFRC Technology in India - Pilot Bridge Project.	*Sudeep Joshi*	398
178	Design of 102.6 m span Bridge using Ultra High Performance fiber reinforced Concrete (UHPFRC)	*Sudeep Joshi, Sayali Tatar, Pratiksha Pawar*	399
179	Construction of Underpass by Box Pushing across NH-48 near Aerocity, Delhi.	*F. de Meijier MSc, D.C. Tjepkema, Rajiv Sharma,*	400-401
180	Precast PSC Segmental Girders – An overview of failures during construction based on some case studies	*Anil K Shrivastava*	402-403
	Session 30: Analysis, Research and Standardisation		
181	Verification of reinforced concrete D-regions designed with Strut-and-Tie models by nonlinear FE-Methods	*Seyed Mohammad Javad Mohseni, Arndt Goldack*	405-407
182	Seismic Retrofitting of Multi-Storey RCC Building using Fluid Viscous Dampers and Comparing the Results Before and After the Retrofitting	*Arup Saha Chaudhuri, Md. Toshif Alam*	408-409
183	Ultrasonic pulse velocity testing for evaluation of stabilized soil in pavement structures	*Dr Vinay A, Rakshitha S*	410
184	Mechanical Performance of Ultra-High Performance Concrete for Bridge Applications	*P N Ojha, Brijesh Singh*	411-412
185	Effect of Pedestrians on Vehicular Speed and Capacity of Hilly Roads	*Chirag Nagar, Jagatpal Gusain, Ashok Kumar Sharma, Dr. Abhinav Kumar*	413-414
186	Seismic protection of built environment. The Revision of the European Standard EN 15129 on Anti-Seismic Devices	*Tobia Zordan, Renzo Medeot*	415-416
	Session 31: Special Session: New Indian Guidelines on Cable-Stayed Bridges and Extradosed Bridges		
187	A new Guideline for Design, Construction and Maintenance of Extradosed Bridges in India	*Alok Bhowmick*	418-419
188	The New IRC Guidelines for Cable-Stayed Bridges in India	*Mahesh Tandon*	420-422
189	Features of the New Indian Guidelines for the Design of Cable Supported Bridges to Resist Wind & Seismicity	*Prem Krishna, Lakshmy Parmesharan, Yogendra Singh*	423-425

190	Construction aspects of cable-stayed and extra-dosed bridges in new Indian guidelines	*V N Heggade*	426-427
191	Design and Analysis of Hybrid Cable-Stayed Bridges: A Comprehensive Study	*PVVSS Ravi Prasad, Bhushan Vishnu Nahire, Amit Kakaji Desai*	428-429
	Session 32: Case Studies in Sustainable Materials, Technology and Practices		
192	Advantage of 4th Generation Modular Joint from life cycle cost point of view A case study	*Chinmoy Ghosh, Santanu Majumdar, Arijit Ghosh*	431
193	Semi Integral Structures - Mauritius Light Rail Transit System	*Navin Kumar Chaudhary*	432-433
194	Evaluation of longitudinal forces on substructure of railway bridges due to increased axle loading and speed through full scale field investigations	*B.Arun Sundaram, Voggu Srinivas, S.Parivallal and Saptarshi Sasmal*	434-435
195	Condition Assessment and measures to Repair and Retrofit Baghajatin ROB, Kolkata	*Amit Kumar Gorai*, Abhishek Kaushik*	436-437
196	1d Consolidation of Soil at Sumari Uttarakhand Considering Variable Compressibility	*Saurav Raturi, Ayush Nautiyal, Shashank Bhatra*	438-439
197	Design and Construction Challenges-Extradosed Bridge over Hatania-Doania River in West Bengal	*Akhilesh Gupta*	440-441
	Session 33: Analysis, Research and Standardisation		
198	Flexural Behaviour of Carbon Textile Reinforced Concrete (CTRC)Panel	*Sophia Immanuel, Baskar K*	443-444
199	Classifying Failure Modes of Ultra-High-Performance Fiber Reinforced Concrete Fracture Beams Using Acoustic Emission Technique	*Chandrashekhar Lakavath, Mohit Singh, S Suriya Prakash*	445-447
200	Effect of Vertical Irregularities on Buildings in Different Seismic Zones of India	*Shrey Pradhan, Musharraf Ahmad, Praveen Baghel, Smita Kaloni, Shashank Bhatra*	448-450
201	The Sheaf: Expressive Geometry Through Collaborative Computational Design and Low-Tech Construction Methods	*Niklas Johansson, Lukas Nordström, Jonas Runberger, Alexander Sehlström*	451-452
202	Studying the effect of vertical irregularities on the seismic vulnerability of setback buildings using Linear and Non-Linear methods	*Aamna Sarfaraz*	453-454
203	Is Nonlinear Analysis Becoming a Standard Tool for Design and Assessment of Reinforced Concrete Structures?	*Jan Červenka, Jiří Rymeš, Libor Jendele, and Radomír Pukl*	455-456
	Session 34: Sustainability in Built Environment		
204	Innovative Solution to Urban Infrastructure: Special Solution to Conventional Structure Planning	*Dr. B C Roy, S Bhattacharyya*	458-459

205	A roadmap for implementing integrated asset management for sustainable water Infrastructure in India	*Harshal Tikam, Abhiram Shukla*	460-461
206	Different approach of the construction sustainability	*Corneliu Bob*	462-464
207	A sustainable roadmap for affordable housing in India. A benchmarking approach to achieve the SDGs	*Ann Francis*, Albert Thomas*	465-466
208	Life Cycle Cost Analysis and Use of Continuously Reinforced Concrete Pavement (CRCP) in the Bharatmala Pariyojana Project	*Pydi Lakshmana Rao*	467
209	Effects of Moisture Ingression in Building Envelope Through Moisture Index (MI) And Wind Driven Rain Index (WDRI)	*Harris Showkat Kangoo, Sumedha Moharana, Lukesh Parida*	468-469
	Session 35: Sustainability in Built Environment		
210	Protecting Reinforced Concrete Structures with Thermal Sprayed Zinc Anodes	*Dr. R. Sharma, M.C. van Leeuwen, Dr. F. Prenger*	471
211	Continuous Galvanized Rebar for Corrosion control in RCC structures	*Dr. R. Sharma, Dr. Frank E. Goodwin, Gary W Dallin, Dr. Rakhi Sharma*	472
212	Glass Fibre Reinforced High Volume Fly Ash Mixed Green Sustainable Concrete	*Arup Saha Chaudhuri, Somsubhra De*	473-474
213	Application of Textile Waste Fiber in Mortar Strengthening towards Upgrading the Performance of Masonry Structure	*Nikhil Ranjan, Research Scholar; Sanket Nayak, Susanta Banerjee, Sreekanta Das,*	475-476
214	Resource-efficient and climate-friendly design of concrete structures through advanced structural safety concepts	*Ramon Hingorani, Jochen Köhler*	477-478
215	The Feasibility Study of Net Zero Energy Building with Carbon Credits for Sustainable Future: A Case Study in Chandigarh	*Vishal Sharma*	479-481
	Session 36: Sustainability in Transportation Structures		
216	A synthesis of techniques and ideas to optimise the life cycle of bridges in practice	*Richard Hao, John Steele*	483-484
217	Tibetan Bridges - From Adventure to Sustainability	*Franco Clerici, Laura Lombardi, Silvia Mirabella*	485-486
218	Lightly Loaded Bridge	*Prabu Raja*	487-488
219	Modular Designs for Sustainable Railway Stations	*Mark de Melo, Kulvinder Rayat, Francis Archer, Kim Quasi, Vivek Bhushan Sood, Akash Das*	489-490
220	The Climate Action Plan and Sustainability in Construction	*Gagan Anand*	491-492
221	IABSE Congress Reports		494-497

Keynotes

Engineering Solutions for Sustainable Development

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Abstract

Sustainable engineering (SE) focuses on systems that use energy and resources sustainably, addressing economic and climate change challenges (Global extreme weather this year in July is "virtually impossible" or "new extreme" in Antarctica without climate change). A radical shift in infrastructure planning is necessary to achieve net-zero emissions. Factors such as New Developments (NDs), nature-based solutions (NbS), life-cycle analysis (LCA), whole-life carbon (WLC), sustainable materials (SM), and green construction materials enable sustainable infrastructure. The identification of skills for upcoming infrastructure engineers, intelligent and sustainable built environments, IoT, and Integrated Workplace Management Systems (IWMS) are challenges. A circular economy approach to managing LC may be a more efficient and reliable means of achieving zero emissions.

Changing Climate and Sustainability of Built Environment

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Abstract

The World is changing. Humanity faces increasing depletion of energy and material resources and an increasing number of natural disasters. Earthquakes, floods, storms, hurricanes, tornados, fires, tsunamis, volcanic events, heat and cold waves, extreme dry weather etc. are more and more frequent. The probability of natural disaster is now nearly five times higher as it was in the 1970s, because of the increasing risks due to climate change. As a consequence of natural and man-made disasters and socio-economic situations, human migration increases.

Buildings and the built environment should be better prepared for changing climatic conditions – as they should be sustainable and resilient. The energy consumed in buildings, and in general, in the construction sector, is one of the most significant sources of CO2 emissions. Considering current energy and political situation the need for energy efficiency and resilience of buildings became extremelly urgent.

Considering these development trends, it is necessary to re-evaluate and modify existing principles and methods of building design and similar techniques of construction new and modernisation of existing buildings to enhance them to guarantee comfortable and safe life for the whole population in the future. The buildings for sustainable future should be better prepared for the new conditions; they should be more resilient.

Sustainable Development Goals and the Debate of Demolition versus Conservation in a Developing Economy

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Abstract

Conservation of listed heritage buildings and infrastructure in a city or a town is typically mandated by byelaws and regulations in several states in India unless such properties are protected by central or state archaeology departments as national or state monuments under the AMASR Act (Ancient Monuments and Archaeological Sites and Remains Act). Although grading and listing may exist in some towns and cities, many heritage buildings and infrastructure are still not protected through necessary legislation. Whatever the legal status, under the growing pressures of infrastructure development and renewal in a developing economy such as ours, the debate between conservation and demolition is at an important crossroads. Application of guidelines developed in the western world (e.g., ICOMOS principles) may be debatable without due consideration of context, constraints, and aspirations in large developing economies.

What do the UN's Sustainable Development Goals (SDG) 2030 have to say about conserving and revitalizing existing infrastructure, with or without cultural (or heritage) value? What is the basis for such an approach? And what are the criteria to verify whether it is logical to conserve or to demolish and redesign and rebuild. How should we consider the tangible and intangible elements of built heritage? The current paper attempts to examine this pertinent problem, often faced by primary stakeholders, conservation professionals (architects and engineers) and lawmakers, from the key perspective of structural safety and structural rehabilitation or retrofit. In an era, when sustainability, ecological and environmental awareness and cost-effectiveness together are emerging as determinants of development, how do they impact conservation of built heritage?

Upgrade & Retrofit of Existing Infrastructure & How it Contributes to Sustainability to Extend the Service Life of Structures

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Abstract

We live in a world of ultimately limited resources and as engineers we are responsible for the most efficient use of those resources. The needs of the societies we serve change and our infrastructure is under constant pressure to adapt to new requirements. Many of these demands are about capacity and drive a desire to replace existing structures with bigger and seemingly better designs. And whereas it's always nice to start with a clean sheet when preparing a design it is an obligation upon us engineers to make the most effective use of what is already there. Only in this way can we start to tackle the sustainability challenge brought upon us by the climate emergency. There are many ways that existing infrastructure can be used and repurposed so that the changing demands can be met.

The keynote paper will address the way in which existing bridge infrastructure has been adapted and expanded to meet the requirements of greater structural capacity. It will also examine how the designer can build in scope for future development within existing structure and what are the pitfalls that occur from that initial planning stage to the future execution of the extension works. It is a challenge to second guess the technological and legislative requirements that change over the decades. Examples will be provided how such changes can be addressed and what are the key requirements for future proofing our bridges.

Code of Practice for Sustainable Structures

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Abstract

The sustainability of the construction sector is very much depending on two primordial factors: the amount of resources extracted from earth and the amount of waste that is generated due to construction and demolition activities. Therefore, the sustainability of the construction sector requires a more efficient design of structures and infrastructures, taking into account an optimized used of resources over the complete life cycle of the asset.

In this context, the 7th basic requirement of the EU Construction Products Regulation (CPR), which lays down harmonised conditions for the marketing and free movement of construction products in Europe, claims the "sustainable use of natural resources". In general, all basic requirements of CPR are assessed and/or verified according to harmonised technical specifications. However, currently, the compliance with the 7th requirement cannot be performed due to the lack of harmonised technical specifications covering the sustainable use of natural resources, thus limiting the applicability of CPR to differentiate products with enhanced sustainability performance.

In summary, a harmonised and transparent methodology for assessing the sustainability performance of structures is required to stimulate the demand for more efficient buildings and other construction works, with lower consumption of resources and other important indicators, such as low-carbon emissions.

This key note will focus on the need of a code of practice for sustainable structures, and introduces a novel approach for the sustainable design of buildings, based on the standardized procedure for the Sustainability Assessment of Construction Works, laid down by CEN TC350. The proposed approach is in line with the "limit state approach" of the European standards for structural design – the Eurocodes.

Approach to Sustainability in Built Environment

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ABSTRACT

The indiscriminate use of natural resources since the development of civilization particularly their exploitation in the last one century or so in the process of industrialization and in the pursuit of comfort-at-all-cost, has resulted in a situation of almost no return. Under the circumstances, 'Sustainability' is the mantra and saviour of civilization. The most important aspect in achieving sustainability is to address the cardinal principles of reduce, reuse and recycle with due consideration to sustainability objectives in respect to space and time. The comprehensive approach demands that, in respect to space, the approach should start from larger context globally coming finally to the scale of a building or a local built environment. Meaning thereby that an isolated building cannot be regarded as sustainable product unless it is a part of overall sustainability scenario in a larger context. Similarly, a time duration needs to be kept in mind over which the sustainability is sought to be achieved. For example, what can be sustainable for a limited period of time may prove to be otherwise on a longer span of time. At the same time, sustainability cannot be seen for a period till eternity. This is particularly true because of cost implications and likelihood of paradigm shift in materials, technologies and developmental requirements during different times. Thus, sustainability needs to be largely concentrated on a scale of our planet and human life scale of periods such as 500 years. The comprehensive approach then would require to deal with all aspects relating to siting, form and design; external development and landscape; envelope optimization; selection of appropriate materials; water and waste management; building services optimization; constructional practices including selection of appropriate technologies; and commissioning, operation, maintenance and building performance tracking. The objective is not only to ensure that the facility is built sustainably using optimum embodied energy but also requires optimum operational energy and least maintenance. The progressive thought requires that the building and built environment should not be designed only to reduce the adverse effect to the environment but should intend to cause positive effects to the environment, economy and the society at large. This discusses an approach to sustainability with a view to making appropriate decisions during conceptualization, planning, design, construction, operation and maintenance stages of the built facility. To facilitate the understanding and implementation of the approach, a Sustainability Model has been attempted which may be suitably modified, extended and detailed for better understanding and application.

Session-1

Sustainability in Transportation Structures

ID-65

New Modular Construction Method for Multi-Span Concrete Bridges with Reduced Material Consumption

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Abstract

A new construction method for post-tensioned bridges with a double-T cross-section was developed at the Institute of Structural Engineering (TU Wien). That method enables a swift production of the longitudinal girders and the deck slab. Precast deck slab elements stiffened by cross-beams are placed on top of the installed post-tensioned precast girders. The precast hollow box girders and the deck slab elements can be installed along the whole length of the bridge with cranes or a launching gantry. The combination of precast hollow box bridge girders and precast deck slab elements allows for the fast production of post-tensioned concrete bridges with a double-T cross-section in the span range from 30 m to 60 m. This method will make the erection of one span per week possible, thus achieving the same construction speed as segmental bridge construction. Compared with segmental box girder bridges, the new construction method permits a reduction of construction materials and avoids transverse joints that extend over the entire height of the finished cross-section.

Keywords: Precast deck slab element, precast hollow box girder, post-tensioned bridge, segments, sustainable, thin-walled.

1 The concept of the LT bridge construction method

1.1 Idea

Since good experience has been gained with thin-walled precast elements, a new construction method for plate-girder bridges was developed at TU Wien [1]. This construction method unites the advantages of a fast construction progress for the entire bridge structure with the quality of a bridge, which is cast using in-situ concrete.

The new construction method includes conceptual considerations of the precast segmental span-by-span erection method (with transverse joints between the segments) and the method for pre-cast girder erection by launching gantry (with girders oriented in the longitudinal direction). With this new method, a weekly cycle for producing a construction section with a length corresponding to the span can be achieved [1]. This fast construction progress is possible because only limited reinforcement laying work must be done at the installation site.

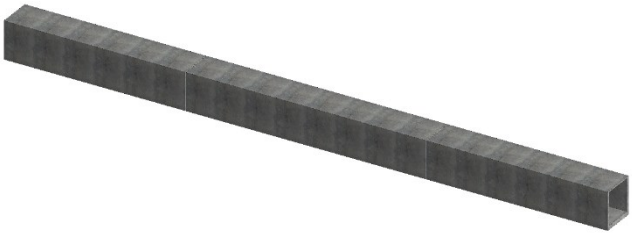
For the placing of the precast girders, a launching gantry was developed. It can move the precast girders to their final position. Moreover, the launching gantry is designed in such a way that it can also move the precast elements for the deck slab to their final position.

1.2 Description of the precast elements

1.2.1 Precast girder

The precast girder consists of several hollow box segments connected on the already finished deck slab or at an assembly area. The number of segments depends on the span length of the bridge, the maximum possible transportation length, and the allowable transport weight in the respective country. For spans up to 30 m, the longitudinal girder can be cast from one piece. In general, the precast element sizes depend on the lifting capacities available in the precast plants, which are limited to 80–100 t in Austria, for example.

An example of a precast girder is shown in Fig. 1. In this case, the girder consists of three hollow box segments. The segments are connected with an additional in-situ concrete layer on the bottom plate and bonded tendons. Before the segments are clamped together, the joints must be grouted. This precast girder belongs to a variant where unbonded tendons are anchored in a pier segment



above the support.

Figure 1. Precast girder with a length corresponding to the span length

1.2.2 Precast elements for the deck slab

The precast elements for the deck slab consist of plates, which are connected by cross-beams. Fig. 2 shows a precast element for the deck slab, which already has the entire width of the bridge in the final state. Three plates are connected by two reinforced cross-beams. The element has upstands at the cantilever ends to create a vertical formwork for the in-situ concrete layer. To create a sufficient bond between the in-situ and the precast concrete, the surface of the plates must have a certain roughness. The deck slab element is dimensioned so that it can support its dead load, an additional concrete layer, and a construction crew. Therefore, the element acts as a formwork that can be fully included in the structural analysis.



The connection between the precast girder and the precast elements for the deck slab is achieved with the shear reinforcement, which protrudes from the top surface of the hollow box segments and the reinforcement necessary for shear between the web and flanges. Almost all the reinforcement required for the final state is contained in the precast elements. Only the splice reinforcement, the upper longitudinal, and the upper transverse reinforcement must be installed at the construction site.

Figure 2. Precast element for the deck slab of a bridge with two longitudinal girders

2 References

[1] *Kollegger, J.; Untermarzoner, F.; Rath, M.:* Verfahren zur Herstellung einer Brücke aus Längsträgern und Fahrbahnplattenelementen. Austrian patent application, 2022.

ID-111

The Practice of Forensic Structural Engineering in IABSE Member Countries: Preliminary Review of Survey 2022

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Abstract

The IABSE Task Group 5.1 on Forensic Structural Engineering aims to examine and to mitigate structural failures by sharing knowledge of technical, human, and organizational causes of failures, in addition to methods and techniques in forensic investigation processes. The expertise of Forensic Engineering is yet to be worldwide recognised as a specific domain of civil engineering practice and this article amends previously published technical reports in 2012, 2014 and 2015 by former IABSE Working Group 8 following a new survey carried out in 2020-2022.

This new survey has been developed with the lessons learnt from the previous survey in 2013-2014.

A panel composed of the authors of this article (all of them members of TG 5.1) was activated to develop the new questionnaire together with a procedure composed of three stages. The main aim of this stepwise approach was to significantly improve the questions on the basis of the results of the previous step in order to avoid, at the final step, unclear responses and to limit subjectiveness as much as possible.

In the article a preliminary analysis of some sections of the third stage questionnaire is presented.

This questionnaire is composed of 36 questions divided into the following sections:

- PP: Professional Practice (6 questions);
- RG: Role of Government (9 questions);
- LI: Legal Issues/Considerations (8 questions);
- CA: Contractual Arrangements (1 question);
- HA: Hazard Assessment (1 question);

- FS: Failure Statistics (3 questions);
- CC: Causes of Collapses (2 questions);
- FU: Follow-up on collapses (1 question);
- IM: Improvements to professional practice (4 questions);
- AC: Additional Comments (1 question).

All questions except for the last one (i.e. AC) include multiple-choice answers but only for 5 of them the respondent can choose more than one answer among those indicated. Moreover, each question includes an 'additional comment' section where the respondent is free to add further information useful to either clarify his/her response or to provide further details, if needed. This option provided relevant additional information.

TG 5.1 was able to identify and select national experts representative of 36 out of 68 IABSE Member countries but only 22 accepted the invitation and completed the questionnaire.

In the article the major issues arisen from the preliminary analysis of sections PP, HA, CC, FU, IM are highlighted and discussed.

It appeared that forensic engineering is known in various countries, but it is not well established in the majority of countries. Professional organizations are lacking, and limited examples of university courses or lifelong learning initiatives are known. Often no formal requirements related to the expertise of experts and no protocols regarding the investigation process are issued.

As still there are several structural failures, ranging from minor cracks to full collapses, it is of importance that lessons can be learnt from earlier collapses to prevent future failures. Furthermore, many failures are causes by natural hazards, where forensic analyses can provide information regarding vulnerability of specific structures. Finally, large failures come with large costs. Therefore, investigations are needed that lead to reliable outcomes regarding causes of failure and parties responsible. Therefore, knowledgeable experts and a trustworthy investigation process is of utmost importance.

IABSE's TG5.1 will continue its efforts to learn from past failures and to improve forensic investigation processes.

Keywords: forensic structural engineering; survey; structural failure; structural collapse.

ID-401

Lessons in Remote Infrastructure: Connecting People and Landscape to Promote Economic Vitality & Create Social Value

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Abstract

Transportation systems offer opportunities to connect rural communities with economic possibility. Intentional infrastructure interventions connect citizens with resources and reduce travel time between remote and urban areas – creating sustainable value for entire economic regions. Remote infrastructure presents a tension between creating social value without destroying environmental value.

Presenting two multi-bridge infrastructure projects in Norway and South Africa, Dissing+Weitling explores the opportunity for a design team to partner with local authorities to provide aesthetic interventions that align with environmental protection goals, increase connectivity for rural communities, and balance social value creation with the preservation of landscapes with high natural value.

Keywords: rural; remote; logistics; biodiversity preservation; landscape; large-scale; environmental impact; social value creation; national authorities; integrated planning

1 Design Intent Within Remote Infrastructure

For rural communities, new road systems create gateways to access and economic vitality – while simultaneously challenging long-standing ways of living, working, and being in community with each other and nature. A key challenge for the development of remote infrastructure is to respond to these trade-offs and tensions – and to use the architectural design process as a gateway to maximize sustainable value creation across the triple bottom line.

Dissing+Weitling offers two multi-bridge remote infrastructure projects in South Africa and Norway to demonstrate how design team partnership and stakeholder engagement can strengthen project outcomes.

To frame for this investigation, it is important to note that all projects presented are incomplete. The value in their presentation lies in understanding how mobility architects approach a design within remote locations – how the relationship between client expectations, engineering parameters, and aesthetic considerations can together define user experiences with nature during the act of crossing.

2 Eastern Cape South Africa

As key parts of N2 Wild Coast Road Project, the Msikaba and Mtentu bridges provide safe crossing for road traffic over their respective rivers – and bring the promise of greater connectivity between rural populations with urban economic centres in the Eastern Cape. Although both infrastructure projects have not been without controversy, the design intention has been to propose holistically sustainable solutions: visually impactful yet minimalist crossings that ensure public safety, reduce transit time, and both respect and connect to the natural landscape.

Both the Msikaba and Mtentu bridges offer a unique aesthetic opportunity: how can a bridge respond to the remoteness of the landscape in situ – in a way that is holistically sustainable? Could the act of crossing the bridge allow drivers to develop a deeper connection to the landscape? Dissing+Weitling's approach to both the Msikaba and Mtentu was driven by the belief that the bridges must balance minimalism with a dramatic profile that speaks to the magnitude of their size, scale, and location. The experience of crossing the gorge must reinforce the user's understanding of place – rather than separating the driver from nature, driving over the bridge provides direct views into the river valley.

3 Sula and Halsa Fjord, Western Norway

The Norwegian Public Roads Administration manages the E39 and is responsible for the implementation of a long-term national policy goal: a ferry-free coastal highway supporting efficient movement across Norway's Western Coast. An examination of the pre-project phase investigation of potential crossings in the Sula and Halsa Fjords – including four proposed bridges at different alignments - provides insights into how proposed mobility solutions can deliver across two dimensions: ensure efficiency within the context of a larger road system – while using aesthetic expression to create a conversation between user and landscape during a specific crossing.

The structure of the competitive investigation allows the design team to engage in robust scenario analysis. There are several direct benefits of this workflow to the project outcome: across the concept value chain all parties understand the impacts a wide variety of variables and design parameters will have on the aesthetic recommendations of each potential bridge. Regular engagement across stakeholder groups also allows for different systems thinking lenses to be applied to the same project. There are several direct benefits of this workflow to the project outcome: across the concept value chain all parties understand the impacts a wide variety of variables and design parameters will have on the aesthetic recommendations of each potential bridge. Regular engagement across stakeholder groups also allows for different systems thinking lenses to be applied to the same project.

In the case of all four proposals, aesthetic opportunity stems from designing for user perception across different modalities. Understanding the needs for - and difference of - spatial feeling between car, bicycle, and foot traffic can widen the impact of a bridge. The total amount of time spent on a bridge varies greatly by modality – but mobility architecture must provide all users with a fundamental understanding of where you are and where you are going.

4 Connecting People and Landscape

At the heart of mobility architecture is the desire to ensure bridges and crossing infrastructure create the best possible user experiences. This requires an understanding of user profiles and an ability for the design team to be responsive to geographic considerations. In comparing the South African and Norwegian multi-bridge projects, we can see how designers' partner across the infrastructure value chain to align economic priorities with environmental protection and social impact.

Despite their differences in regional geography, both the N2 Wild Coast Road Project and the E39 Coastal Highway Route Project share a starting point: remote infrastructure is a change catalyst.

How then can mobility architects support holistic sustainable value creation within remote infrastructure projects? The answer lies in using aesthetics to reinforce user perception and the design itself supporting not only human movement but human experience. Within complex infrastructure value chains, mobility architects are responsible for centring user perception – and this can be supported by multi-stakeholder collaboration processes that ensure all parties can robustly compare options, alternatives, and trade-offs.

ID-466

Towards Attaining Sustainable Development Goals in Design and Construction of Highway Bridges – A Critical Review

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ABSTRACT

Bridges are an integral part of highways. India became independent in 1947. However, development works in the highway sector have been undertaken continuously since pre-independence days. The paper describes details of some of the policies and guidelines, progressively implemented for the development of highways including bridges, which support activities towards attaining Sustainable Development Goals (SDGs) adopted by the United Nations in 2015, These are with regard to rationalisation of procedure of land acquisition, rehabilitation and resettlement, environment protection framework, bridge construction/reconstruction programme adoption of new technologies and innovations in design and construction, use of non-conventional energy, impact of climate change on hydrology, and road safety. Besides, the Government has been receiving enhanced international support and co-operation continuously, leading to a faster pace of development.

Keywords: SDGs, environment, land acquisition, IRC, Environment Management Plan, GHG emissions, wildlife, design and construction of bridges, international support and co-operation,

1.There are 17 Sustainable Development Goals (SDGs) which were formulated by United Nations to create a framework for global development from 2015 to 2030. Development of roads and highways has continuously aimed at sustainability emphasizing on proper design and construction practices in accordance with IRC codes, guidelines and manuals, keeping in view the latest world-class knowledge and technology in respective fields, along with environmental and social protection.

2. Land acquisition is vitally important for any road / or bridge project. A comprehensive Land Acquisition, Rehabilitation and Resettlement Act (LARR) was enacted in 2013 which provides transparent procedure and fair compensation for rehabilitation and resettlement of the affected parties, without any discrimination. The process of transfer of forest land for roads is very stringent. The LARR impacts SDG no. 1,5 and 8.

3. The legal framework for the environment consists of several acts, notifications, rules and regulations to protect the environment and wildlife. Accordingly, the Initial Environmental Examination (IEE) of all road and bridge projects is carried out at the project preparation stage. Based on its outcome Environment Management Plan is prepared for incorporating mitigation measures for any adverse environmental impacts. for large projects or for projects having very significant negative impacts, stringent procedures for obtaining environmental clearance from designated authority.

Some of the important activities for environmental protection/enhancement are as follows : (i) plantation of 5 to 10 times the number of felled trees (ii) rainwater harvesting and replacement of water bodies; (iii) Protection of aquatic life by minimising the number of foundations in the river (iv) recycling of dismantled materials as aggregates (v) use of fly ash as blending agent in cement (vi) Use of fly ash or other industrial wastes in embankment(vii) use of plastic wastes in bituminous wearing coat (viii) providing noise barrier, road safety features, protection gears to workers (ix) animal overpass with large vertical and horizontal clearances (x) reduction of Green House Gas (GHG) emission or carbon footprint through choice of construction technology (xi). The impact of Environment and Social framework relates to SDG No. 9, 12,13 &15.

4. IRC publishes codes of practice, specifications, guidelines and manuals for design, construction and maintenance of roads and bridges. During the first three Five Year Plans 1951 to 1966, emphasis was made on construction of missing bridges, and widening and strengthening of narrow and weak bridges Many innovative and new technologies have been brought in the design and construction of bridges, like cantilever construction, cable-stayed bridge, extradosed bridge etc. IRC has published several codes, such as limit state design, increase in the design life of bridges to 100 years, use of new materials like FRP and GFRP, road safety etc. Based on the whole life cycle cost of a bridge with guide bunds, a policy decision has been taken to provide a bridge across the full Khadir width of meandering rivers, thus increasing the initial cost. Ministry has also issued directions for the use of solar energy and alternative fuels in vehicles including electric vehicles. Actions as per UN Decade of Action for Road Safety are being taken. Important developments are designing forgiving roads and enacting Good Samaritan Law. Design, construction, maintenance and operation of bridges impact on SDG no. 3, 7,9,11,12,13 &15

5. . Indian National Group of IABSE was set up by the Ministry of Surface Transport in 1957. Similarly, India became a member of PIARC. Fib and ASCE also provide technical forums. Besides World Bank started providing loans for the development of roads in the 1960's Similarly ADB, OECF and JICA also provided loans/grants in the sector. These organisations and other multilateral and bilateral agencies provided training to Indian road and bridge engineers. All these resulted in a faster pace of development. Besides Indian companies could participate in tenders in other countries.

6. . In conclusion, the road and bridge sector has been promoting 11 out of the total 17 SDGs progressively.

ID-475

Designing on Existing Bridges: A Paradigm of Sustainability Applied to Civil Engineering

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Abstract

One of the areas where the bridge designer has a real influence on the sustainability of the performance is in the widening of existing bridges. The use of the structure is always beneficial from an environmental point of view as the life span of the bridge is increased by using the existing structure. A good example of this is the widening of bridges. The article includes examples of the widening of three different structural types: a stone arch bridge, a prestressed concrete bridge with box section and a cable-stayed bridge. In all three cases, the existing structural systems have been used thanks to the team's willingness and knowledge of the techniques associated with bridge maintenance and preservation.

Keywords: Sustainability; widening; vaulted bridge; concrete box deck; external prestress; cable-stated bride.

1 Introduction

The concept of sustainability is closely related to the optimisation of resources. In engineering, once it has been decided to build a project (the what), it is necessary to move on to the how. This how will always involve CO_2 emissions over which the engineer has minimal control. Saving materials is always a condition for any project that can be called an engineering design. Engineers understand nature's resources are scarce and that it is our duty to optimise their use. The bridge designer has a minimum palette of materials to use: concrete, steel or a combination of both. Sustainability will be determined by the logical use of these materials according to the span of the bridge and its type. Therefore, the mere accounting and comparison of CO_2 emissions will not help us to analyse sustainability, which includes the long-term use of the structure.

The control of CO_2 emissions is in any case one of the basic premises of any current design, however, the control or reduction possibilities, in bridge engineering is minimal because only two basic materials are available. It is the manufacturing processes of these materials that are the fundamental aspect that can be influenced. The designer's task will be to choose from the range of concretes, for example, those with the lowest CO_2 emissions.

However, there are other factors that are often not included in the analysis of the sustainability of a project, and which are much more important, as they can condition the future of an area and therefore of part of the local population. For example, the position of the piers of a bridge over a river or a vertical clearance that limits navigation in the medium and long term can have a negative influence on local development and can therefore make the project unsustainable in the not too distant future. In the same way, making the best use of the built environment is something that is in the hands of the bridge designers. For this, it is essential to have a thorough technical knowledge

of the resistance systems and materials used in each period, as well as respect for those works that have a heritage value.

2 Functional obsolescence and sustainability

A paradigmatic case of the use of sustainability in the design of bridges is the intervention on existing structures. A very frequent design situation in practice occurs when the road which the bridge serves has to be widened in order to maintain the level of functionality of the road or railway which it serves. This is a clear case of functional obsolescence which admits several solutions: widening of the deck, duplication of the deck, construction of a new bridge, etc. The least radical case is usually the extension of the deck, since a priori, it is the optimal solution as it will consume fewer resources and will also increase the useful life of the bridge.

The re-use of the existing structure has the added advantage that the waste generated is minimal since it will not be necessary to carry out major demolitions, as it is a question of making the most of the existing structure.

3 Towards sustainability through conservation: bridge widening

Bridge widening is always a work that requires knowledge and creativity to make the best use of the existing structure. As mentioned above, respect for what has been built, if it is of high quality, is one of the basic premises of any extension. Obviously, the widening solution will depend on the condition and possibilities of the structural solution of the existing bridge. In general, the widening will generate additional loads because of the increased width of the road or railway; it is also likely that there will be an increase in loads because of more than the frequent change of regulations. In addition, the materials may have deteriorated because of aging and the continued action of loads and weathering.

The following includes three widening designed by FHECOR on structures with different types, all of them in Spain.



Figure 3. View of the Ponteceso widened bridge.



Figure 4. View of the widened Los Santos bridge



Figure 5. Section with lateral widening (phase 2)

4 Conclusions

As we have seen from the previous examples, the widening of existing bridges is always a design challenge, as it is necessary to reconcile functional, constructive, resistant, and cultural issues.

The designer must have strong desire to make the most of the available resources, since there is nothing more sustainable than making the most of what already exists.

ID-645

Long-Term Sustenance Issue of Cables for Cable-Supported Bridges

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1 Introduction

Across the world, the use of Cable Supported Bridges has been on the rise for the last fifty years. Cables, with higher strength than the structural sections and innate flexibility, offer economic solutions for medium and long-span bridges. The use of cable allows the depth of deck structures to be reduced and adds to the aesthetic beauty of the completed structure. The reduced weight of the structural material helps in contributing to the demands of Sustainability, a key factor in today's world and its long-term survival.

The use of cables in bridge structures has been an ancient practice, perhaps inspired by the crossings created by naturally grown creepers across gorges in hilly areas. There are many green bridges still in use by the local population in the sub-Himalayan areas in North-east India. Lower Himalayan areas are credited with the introduction of the easily manoeuvrable deck structure with the use of two parallel cables and the use of hangers with variable lengths.

Cable-supported bridges come in three different arrangements - (a) the Suspension bridges that have the cable in the central span in parabolic form as a catenary, and crossing over tall towers at either end to be anchored at the ends, with rigid supports; (b) the Cable Stayed bridges (CSB) where the deck is supported with inclined straight cables, hung from tall towers; and (c) the Extra dosed bridges (EDB), where cables are hung from shorter towers, to provide support to the deck girders, thereby allowing longer spans to be built without strengthening the deck System.

It is the CSB and the EDB variety that have become the favourites of bridge engineers across the world, particularly in developing countries like India, where such structures are in high demand by even local municipalities. The proliferation of such bridges has often resulted in the involvement of designers and constructors with inadequate skills for creating safe structures with long life as is essential for such bridges that have many critical areas that require attention from the design stage itself. The vulnerabilities of these bridges are getting evident with reports of deterioration of many bridges after use of fewer than twenty years, a rather daunting situation, after heavy investment done for creating such elegant structures.

This paper reviews the present situation, with emphasis on CSB and EDB, and the challenges for the engineering community in ensuring safe sustainable structures with cables in the future and actions needed for avoiding sudden failures of structures, already built without proper care and precautions.

1 Vulnerable Areas of Cable-Stayed Bridges

Cable-stayed bridges have four defined elements, - (a) the foundation of the towers for transferring the loads onto subsoil and the anchor blocks for resisting the uplift; (b) the towers (pylons) that support the cables and are the main compression elements; (c) the cables in tension that support the deck and in turn transfer loads on to the towers; and (d) the deck structure that carries the traffic

and are in compression to balance the horizontal component of the tension cables.
It is the cables that are in tension, the quantum varying with the movement of traffic on the deck, and are subject to vibration due to moving loads and the effect of wind. The distress of the cables makes the structure prone to sudden failure in absence of any redundancy. Exposed to the elements, the cables, that have voids due to the formation of multiple wires, can be affected by corrosion easily. The cables are not accessible for inspection visually or otherwise unless special facilities are created during their planning and installation. The intrusion of water in the interstices promotes corrosion that cannot be detected readily.

Protection against corrosion is attempted by the use of galvanized wires, wrapping the cables, and introducing grouting materials protected by impermeable sheaths. However, all such protection starts deteriorating with time and exposure to changing weather conditions.

The unbalanced vertical uplift from the stay cables, in the case of river bridges in soft soil, is resisted by the Anchor cables (vertically placed holding down cables) which are permanently in tension and are held by fixing them to the concrete anchor block that provides resistance due to its self-weight and the friction with surrounding soil mass. These holding-down cables are affected by snow and rainfall, and the consequent accumulation of water inside the anchor blocks, making the bridge extremely vulnerable to sudden distress that can lead to the collapse of the bridge. The use of a limited number of Anchor cables makes their replacement, one at a time difficult, as the forces in the individual cable cross safe limits. Planning of the replacement, therefore, needs to be done at the design stage.

2 Occurrences of Failures

Over the last fifty years, when CSB and EDB have gained popularity, there have been many failures reported across the world. Most of them have occurred due to undetected corrosion in cables and in their anchorages. The need for regular inspection and health monitoring has been emphasized by many authors and institutions.
In recent times codes and guidelines have come out, that highlight the need for regular review.
The problem is heightened due to the absence yet of guaranteed methods of evaluation of the health condition of the cables. Measurement of tension in the cables for the bridges under use needs to be appropriately compared with the theoretical estimates for known loading conditions.

3 Conclusion

While many different modes of health assessment have been identified, none of them offer guaranteed results on the condition of the cables. It has become imperative to follow systematic monitoring of all such bridges at regular intervals. For all new bridges, the facilities for systematic health monitoring have to be introduced by the designers, ensuring accessibility for carrying out the health tests as also the facility for periodic replacement of the cables, when the situation warrants the same. The use of inbuilt sensors for systematic health monitoring is being considered for new bridges as also for bridges under use.

4 References

1 C. DESIMONE, P. KATCHADJIAN, M. TACCHIA, R. GIACCHETTA – CNEA, Ultrasonic Inspection of Parallel Wires Type Ropes for Suspension Bridge, Roma 15th WCNDT, 2000
2 SEUNGHEE PARK, JU-WON KIM, CHANGGIL LEE, AND JONG-JAE LEE, Magnetic Flux Leakage Sensing-Based Steel Cable NDE Technique, Hindwai Publishing Corporation, Shock & Vibration, Vol-2014, Article ID 929341, 8 pages, 2014
3 HABIB TABATABAI, University of Wisconsin–Milwaukee NCHRP SYNTHESIS 353- Inspection and Maintenance of Bridge Stay Cable Systems (2005)
4 AMITABHA GHOSHAL, Sustainability Of Cable-Supported Bridges, Journal Of The Indian National Group Of The International Association For Bridge & Structural Engineering, IABSE, Volume 52, December 2022

Session-2

Case Studies in Sustainable Materials,

Technology and Practices

ID-76

Innovative Bridge Structures Recently Built in Poland

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Abstract

Intensive modernization of the transport network is underway in Poland. New highways and expressways are built, and railway lines are modernized. Therefore, many new bridge structures have been built in recent years, and even more, are being built. The new facilities include design innovations such as large extradosed bridges and new generation composite (hybrid) bridges, using new type connectors.

Keywords: Bridges, hybrid structures, composite dowels, network arch, extradosed bridges, stress-ribbon structures, prestressed concrete

1 Introduction

In Poland, intensive work has been carried out over the last 20 years on the modernization of transport infrastructure. During this period, the following were built or modernized:

- A basic network of motorways and expressways totalling 3,804 km (data from 2022).
- A series of bypasses of large cities.
- Over 2,000 km of railway lines, replacing many depleted old bridges with new ones.
- Over 17,000 km of bicycle paths, along which interesting bridge structures were built.

In connection with the works carried out, over 3,000 new bridges were built, and several innovative solutions in this area were implemented.

2 Concrete-steel hybrid bridges of short and medium spans

In Poland, in cooperation with centers from Germany, Romania, Luxembourg and other countries, research and development work on new possibilities of shaping hybrid structures has been carried out for several years, ending with implementations. Figure 1 shows various possibilities of shaping the cross-sections of such girders. Strip steel dowel connectors connect the steel elements and the concrete. Details on the design and application of such connectors and the technology of their production are given in the paper.

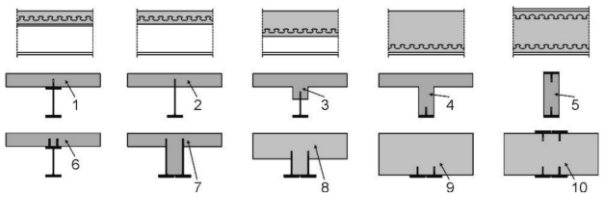


Figure 6. Hybrid steel-concrete girders used in Poland; 1,6 - a classically shaped composite girder, 2-5, 7-10 - various other solutions

3 Network-arch bridges with cold bent steel elements

In Krakow, a group of bridges was built over the Vistula River along the E-30 railway. The crossing consists of three bridges with four tracks and a path for pedestrians and cyclists. The arch consists of horizontally rotated HD 400 sections whose arc geometry is obtained by cold bending [10]. Spans are 49,5 + 116,0 + 63,5 m long.



Figure 2. The finished bridge (ot.: Piotr Hamarnik, PKP Polskie Linie Kolejowe S.A)

4 Beam bridges

The viaduct over the valley along the S7 expressway in Skomielna Biała (Fig. 3). The presented viaduct consists of two parallel structures for each carriageway. The total length is 992 m. The main part of the viaduct is a frame structure with spans of 90 + 2x 140 + 90 m constructed using the cantilever concreting method.



Figure 3. Viaduct along the S7 expressway in Skomielna Biała (2019). Project Vössing and Mosty Gdańsk Ltd, constructed by PORR SA and Salini Imperegilo S. p. A. (fot. A. Kasprzak)

5 Extradosed bridges

In recent years, several extradosed bridges have been built in Poland. These are objects of various construction and span lengths. The earlier built bridges in Kwidzyn and Ostróda have already been presented in reports and papers, which is why the recently completed bridge in Kurów over the Dunajec River is shown here (Fig. 4).



Figure 4. Kurów Bridge over Dunajec River (fot. Grzegorz Momot / PAP)

6 Stress-ribbon footbridge

In 2019 a stress-ribbon footbridge was built in Zagórze Śląskie in Poland. It is a two-span stress ribbon structure with spans of 22 and 80 m (Fig. 5), and the total length of 125.6 m (measured with the abutments).



Figure 5. View from the north embankment (photo submitted to the "MODERNIZACJA ROKU & BUDOWA XXI W" competition). Design: Mosty-Wrocław Research and Design Office; Constrution: Strabag.

7 Summary

Further infrastructural investments in Poland are expected in the coming years. The design of the Central Communication Port is in progress, including a central airport integrated with railway and road junctions. This will make it possible to get there from the most important Polish cities by train or car within 2.5 hours. This investment will force he construction of new railway lines and motorway connectors.

ID-137

Design of Multi-span Cable Stayed Bridge at Ambhora, near Nagpur, Maharashtra

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Abstract

A multi-span cable stayed bridge is proposed over river Wainganga to re-establish the state highway link from Bhandara to Butibori. The location of the bridge is an important tourist and pilgrimage destination with lush green surroundings and backwaters of Gosekhurd Dam. The bridge has an overall length of 705m and deck width of 15.25m to accommodate 2 lanes of vehicular traffic and 3m+3m footpath for pedestrians. The structural arrangement of the bridge comprises 2 modules, with Module 1 of 420m and Module 2 of 280m length with span arrangements of 70m+140m+140m+70m and 70m+140m+70m respectively. The superstructure is cable stayed with RCC deck with an RCC pylon height of 30m above deck level. The pylon P3 at the center of the bridge is also proposed with Viewing Gallery 40m above deck level which is structurally independent from the main bridge. The Module 1 of the bridge is constructed by cantilever method for pylon P2 and anchored span method for pylon P1 and P3. The Module 2 of the bridge is constructed on staging. This presentation discusses the design and construction aspects of the bridge along with staged construction analysis. This is one of the very few cable stayed bridges in India where all 3 methods of construction of a cable stayed superstructure are adopted in the same bridge.

Keywords: Cable stayed bridge, Multi-span, Cantilever construction

1 Introduction

A high-level multispan cable stayed bridge across the river Wainganga is constructed. A five-span bridge with pylons spaced at 140m was proposed at the location.

A sky gallery was proposed to be built above the central pylon with staircase and elevator access. For that purpose, wide footpaths of 3m on either side of the carriageway were proposed thus taking the total carriage way width to 15.25m.

At the location of the bridge, the lowest bed level is 18m deep from the FRL, posing major challenges in the engineering of the permanent structure as well as the construction stage design. This paper provides an insight into the service stage and construction stage engineering of the bridge.

2 General arrangement and Geometry

The cable stayed portion of the bridge is 700m long which is divided into 5 equal spans of 140m each (see Figure 1). The bed profile varies in such a way that the waters are shallow between the Nagpur side abutment (A1) and the first pylon (P1), and for a portion of about 300m towards the Bhandara side abutment (A2). This meant that the fourth and fifth spans of the bridge could be entirely constructed on staging arrangement erected from the bed level, while a portion of the first and third spans could also be constructed on staging erected on filled up bed.

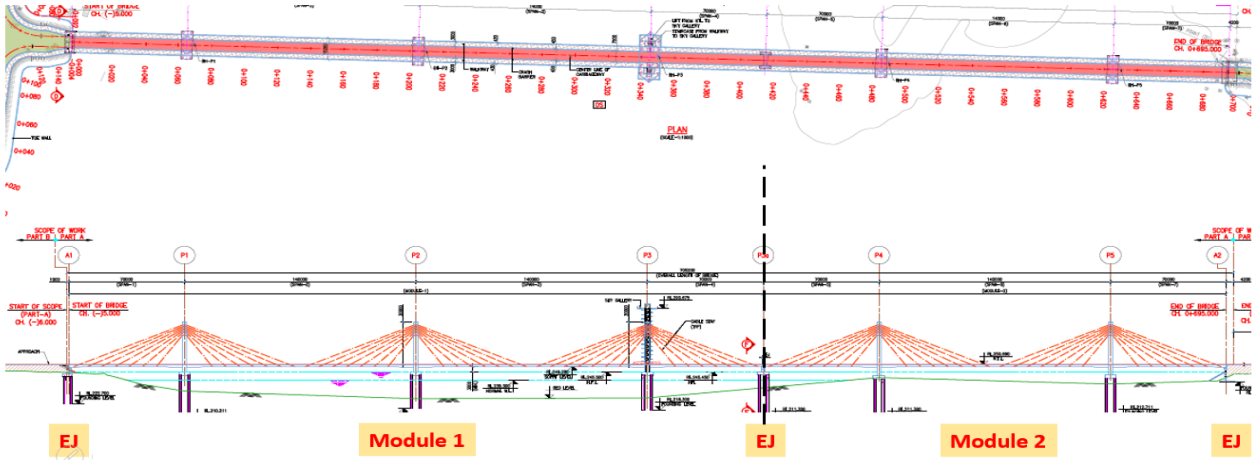


Figure 7: General Arrangement of Ambhora Cable Stayed Bridge

The superstructure consists of a 7.5m wide 2 lane carriage way with 3m wide footpaths on either side. The deck spans between RCC cross girders spaced at 4m in longitudinal direction. The load is then transferred to the two main longitudinal girders, thus creating a Pi-shaped cross-section. The superstructure is supported by 7 numbers of stay cables placed at 8m spacing on the deck level. The cables are connected to the pylon from either side through a composite steel anchorage (links) and form a semi fan-harp arrangement.

The twin RCC pylons are 30m high above the deck level and are connected at two levels by RCC tie beams. The twin pylons rest on common pile foundation whose piles are socketed into the hard rocky strata.

3 Design of superstructure

The cable-stayed bridge is analysed and designed for 2-lane vehicular live load with a design speed of 80 kmph and pedestrian live load on the 3m wide footpath. Loading on the bridge is considered as per IRC:6-2017 and the design of RCC elements is carried out in limit state method as per IRC:112-2011. The adequacy of stay cables is ensured as per requirements of fib 89 - Acceptance of Cable Systems using Prestressing Steels.

Construction stage analysis is carried out in SOFiSTiK by modelling the various stages of construction, activation and deactivation of loads and elements as per the designed sequence of construction. Creep effect is considered between the construction stages by defining the duration between the stages and the parameters relative humidity and temperature of the concrete. As the anchor span of Module 1 rests on staging support during the construction stages, this staging is represented by spring elements defined at regular intervals of the anchor span girder i.e., between abutment A1 and pylon P1, and between pylon P3 and pier P3a. The internal forces of girders, normal forces in cables, and the support forces (minimum compression in bearings) are checked at each construction stage for adequacy.

The bridge components are analysed and designed for fatigue, cable replacement, and cable breakage conditions as per PTI recommendations.

4 CONSTRUCTION METHODOLOGY

Construction methodology of cable-stayed bridge depends on the profile and accessibility of the ground underneath. Different methods of construction are adopted for modules 1 and 2. Module 2 of the bridge is cast in-situ on staging erected from filled up murum on the riverbed in shallow waters.

For Module 1, the superstructure on either side of Pylon P2 is constructed by cantilever method due to deep waters. However, for pylons P1 and P3, the superstructure of one span is cast on the staging which then acts as an anchored span for the other span to be constructed by cantilever method on a form traveller.

5 Form traveller

The form traveller is designed to be lowered during movement to steer clear of stay cable anchorages in the girders. Raising and lowering is carried out by synchronized hydraulic jacks placed under the C-frame above deck and at rear roller support of the truss. After each construction cycle, the form traveller is pushed by a different set of hydraulic jacks that are abutted to the rail beam.

6 Bridge profile monitoring and correction during construction

For cantilever construction of the Module 1, precamber is provided during construction of each segment to achieve the desired deck profile after the final stage stressing. The precamber is achieved by modifying the deformations of the system without affecting the internal forces. For Module 2 the precamber of the deck is considered in Staging and Shuttering of deck.

ID-142

Seismic demand assessment for 20km long Elevated Expressway in Chattogram, Bangladesh

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Abstract

Bangladesh is surrounded by 2500km long Himalayan Frontal Thrust at North and by Indo-Myanmar Subduction zone at the East. These two fault zones are primary source of many large historic earthquakes that had occurred along the border of Bangladesh extended from North and wrapping East. The Chattogram region of Bangladesh is hilly and experiences frequent smaller earthquake shaking compare to other area of the country.

The Elevated Expressway (EEW) project being constructed from Airport to Lalkhan Bazar in Chattogram city by Chattogram Development Authority (CDA) is almost 20km long elevated bridge structure made of Concrete and partly of Steel that runs through a much-crowed habitat. Due to scarcity of land at grade, the EEW is supported on single pier thus with no redundancy in Earthquake Resistance System (ERS).

Bangladesh National Building Code (BNBC) provides only Peak Ground Acceleration (PGA) for 2475 years return period. The Country is divided into four seismic zones with PGA varies from 0.12g to 0.36g. Data required for seismic analysis of a bridge using AASHTO Code requires PGA associated with 1000 years return period, horizontal response spectral acceleration coefficients for different structural periods are not readily available in BNBC. Interpolation of data from only two available data [225yrs. from BNBC/93 and 2475 yrs. from BNBC/2020] may not reflect the correct risk scenario.

To calculate the seismic risk for EEW Project, Probabilistic Seismic Hazard Analysis [PSHA] was done and compared with the data available in the Code to finalize seismic risk parameters for the EEW Project.

Keywords: Seismic risk, Himalayan Frontal Thrust, Indo-Myanmar Subduction Zone, PSHA, Peak Ground Acceleration

1 Introduction

In accordance with standard practice in Bangladesh, the design of Bridge/Flyover and related structures follows the AASHTO LRFD Bridge Design Specification [1]. The earthquake risk parameters for a 1000-year hazard as per AASHTO LRFD provision are not available in the Bangladesh National Building Code (BNBC) [2]. As a result, alternate approaches, such as interpolating existing data of BNBC using a power curve function is commonly used to calculate the 1000-year hazard.

The objective of this study is to determine the seismic risk parameter for a 1000-year hazard, namely, the peak ground acceleration, horizontal spectral acceleration for 0.2 seconds period, 1.0

second period through Probabilistic Seismic Hazard Analysis (PSHA) for the Chattogram area where the project is located. By determining these seismic risk parameters, the study aims to provide valuable information for the safe and efficient design of the EEW and related structures

2 Existing Hazard Data

As per BNBC/2020, Chattogram is situated in the Zone – II with PGA = 0.28g. If we summarize the data of PGA calculation from 1972, say for Chattogram zone, we can get a list like Table 1. Summary of zoning coefficient for Chottogram zone

Table 1. Summary of zoning coefficient for Chottogram zone

Year	Earthquake coefficient	Probability of exceedance	Return period
1972	0.067g ~0.08g	-	-
1978	0.05g	-	-
1993	0.15g	20% in 50 years	224
2020	0.28g	2% in 50 years	2475

3 Study Parameter

3.1 Study Area

The study area is far from the maximum earthquake demand of Chattogram city. The Elevated Expressway (EEW) project being constructed from Airport to Lalkhan Bazar in Chattogram city by Chattogram Development Authority (CDA) is almost 20km long elevated bridge structure made of Concrete and partly of Steel that runs through a much-crowed habitat. Due to scarcity of land at grade, the EEW is supported on single pier thus with no redundancy in Earthquake Resistance System (ERS).

3.2 Seismic sources and seismicity

Major seismic sources [3] around Bangladesh are i. Himalayan Frontal Thrust; ii. Indo-Myanmar Fault; iii. Dauki fault; and iv. Kabau fault. Any active plate boundary and/or fault line within Bangladesh is very unlikely. These major faults are considered as 'line source' and the whole Bangladesh region is considered as an 'area source' is this study. Seismic activity [3] Chattogram zone from 1900 to 2022 is used to understand the seismicity of the area.

Seismicity of the sources are tabulated in Table 2.

Table 2. Seismicity sources

Name	Expected value of *b*	Expected earthquake magnitude	Remarks
Himalayan Frontal Thrust	0.8	8.5	See Ref. 4
Dauki Fault	0.8	8.0	See Ref. 4
Kabau Fault	0.8	8.0	See Ref. 5
Indo-Myanmar Fault	0.65	8.5	See Ref. 5
Area Fault	1	6.0 ± 0.5	Standard value

3.3 PSHA Procedure

Modified Gutenberg-Richter model (Cornell and Vanmarke, 1969) was employed for Probabilistic Seismic Hazard Analysis (PSHA) for the study area. Attenuation law used that proposed by Abrahamson, Silva and Kamai (2014) NGA West 2.

Software used R-Crisis (http://www.r-crisis.com/)

4 Output of the Study

PGA maps for 1000 year return period and Horizontal Spectral acceleration for 0.2sec and 1.0sec are produced.

Table 3 Horizontal Response Spectral Acceleration coefficient at the study area

Hazard data for 1000-year return period Earthquake		
Peak Ground Acceleration (PGA)	**0.2 sec Spectral Acceleration (S_S)**	**1 sec Spectral acceleration (S_1)**
0.135g	0.261g	0.077g

To compare the data with BNBC/2020, PGA for 2475 years return period is also prepared

5 Calculated Earthquake Demand

As per BNBC, PGA for 2475yrs. return period for the project site shall be nearer to 0.20g as the site is at the lowest boundary of the 'band' with value between 0.20g to 0.28g. For the Chattogram zone, PGA data controls by the PGA of the Hill Tracks zone [85 km away from the project site] which is nearer to the Indo-Myanmar fault.

Table 4 Comparison of output

Hazard data for 1000-year return period Earthquake

Peak Ground Acceleration (PGA)		**0.2 sec Spectral Acceleration (S_S)**		**1 sec Spectral acceleration (S_1)**	
Power Law	**This study**	**Power Law**	**This study**	**Power Law**	**This study**
0.221g	0.188g	0.552g	0.367g	0.221g	0.138g

The calculated values as shown in Table 4 are maximum in the Chattogram zone and were used in the analysis and design of the EEW. However, actual seismic parameter at site location is much less as can be seen in Table 3.

6 Conclusion

In Bangladesh, earthquake analysts often view the country as a high-risk seismic zone, which is not really supported by experience and available data. This results in using higher loads in structural designs which gives a false safety assertion. However, the belief that higher loads equate to increased safety can be misguided. In reality, the most significant factor in preventing structural collapse is quality construction. Therefore, it is essential to prioritize construction quality control and structural detailing to ensure the safety of all structures. By emphasizing these factors, design engineers can create resilient structures that can withstand the potential seismic activity in the region.

Further, it is important for engineers to have a solid grasp of the underlying principles and assumptions that estimate the seismic hazard. By taking a more proactive approach structural engineers can make efficient decisions and create safer, more resilient and above all efficient structures that can withstand potential seismic activity with optimum use of the material resources.

7 References

[1] AASHTO LRFD Bridge Design Specifications 2020, American Association of State Highway and Transportation Officials. 555 12th Street NW, Suite 1000; Washington, D.C. 20004

[2] Bangladesh National Building Code (BNBC), 2020, House Building and Research Institute (HBRI), 120/3, Darussalam, Mirpur Rd, Dhaka 1216

[3] United State Geological Society (USGS). 12201 Sunrise Valley Drive Reston, VA 20192, USA

[4] Berryman K., Ries W, Litchfield N. The Himalayan Frontal Thrust: Attributes for seismic hazard. Report produced in the context of the GEM Faulted Earth Project. December 2014, Version 1.0.

[5] J. L. Gautam, Prasanta C., Baruah S., R.P. Tiwari. Spatial and Temporal Distribution of Seismicity Parameters in Northeast India Constrained to Indo-Myanmar Region. Journal of Indian Society of Earthquake Science December 2018, Bhookampan Vol. 5, pp. 32-45.

ID-162

Independent Design Checking of Brahmaputra Bridge, Guwahati – Sharing Experience & Lessons Learnt

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Abstract

The new bridge over river Brahmaputra connecting Guwahati and North Guwahati is currently in the advanced stages of construction. Designed to be an iconic bridge with state-of-the-art aesthetic features, it is being built at a cost of INR 26 billion (USD 316 million). This mega project includes not only the river bridge over the mighty river Brahmaputra but also long elevated viaducts and approaches on both sides. The project is being executed in EPC mode. The paper brings to the fore the culture of proof checking generally performed in infrastructure projects in the country and describes the unique feature of IDC performed in this specific project. The author draws on his own experience as well as published information to illustrate the importance of establishing a culture of independent checking everywhere to add confidence and mitigate the risk of failures.

Keywords: Extradosed Bridge, Stay Cables, Well Foundation, Pile Foundation, Segmental Box Girder, Proof Checking.

1 Introduction

For the mega project of bridge across the river Brahmaputra at Guwahati, the Client has included the services of an independent design checker (IDC) for which the author was associated. The scope of IDC included structural and geotechnical verification of the entire project. IDC certification includes the commitment that the work has been independently checked and verified and complies with the Employer's Requirements.

2 Project Highlights

2.1 Location & Background

The alignment connects the North Bank and South Bank of the city through a six-lane road. The project commenced in August 2019 and the anticipated completion date is December 2024.

2.2 Project Details

The project involves the construction of an Extradosed Bridge over the River Brahmaputra connecting Guwahati and North Guwahati including structures on approaches such as a flyover, viaduct, ROB, VUP, and Minor Bridge on EPC mode. The six-lane 1240m long main Extradosed Bridge over the river Brahmaputra has five main spans of 200m length and two end spans of 120m.

2.3 Agencies Involved

- Owner Client : Public Works Road Department, Assam

- Contractor : M/s S.P. Singla Constructions Pvt. Ltd, Panchkula, Haryana
- Authority's Engineer : M/s Systra Engenharia e Consultoria Ltda
- Design Consultants : M/s Wiecon Co. Ltd. & M/S ASC Infratech Pvt. Ltd
- Independent Design Checker : M/s B&S Engineering Consultants Pvt. Ltd.

3 Need & Importance of carrying out Proof Checking

Independent checking is performed with the following objective to reduce the risk of errors and add confidence to all stakeholders about the correctness of the design.

4 Traditional practice of Proof Checking of structures

When the concept of proof checking was initiated in India in the mid-80s, the practice of proof checking used to be carried out with due diligence, with all sincerity. The client used to get experienced and learned practicing Consultants to perform the task of proof checking and used to derive maximum benefit of proof checking in those days. At a very small extra fee, the risk of design errors used to be significantly minimized in the process. However, with time, the process of proof-checking has been significantly diluted. Since most of the major bridge contracts are now-a-days in Engineering, Procurement, and Construction (EPC) model or Hybrid Annuity Model (HAM), the owner client entrusts the responsibility of proof checking entirely to the Contractor. This is a flawed concept in the author's view since the proof checker will not be able to perform with freedom if the proof checker is commercially dependent on the Contractor.

5 How this project departs from traditional practice in terms of proof checking?

One of the major differences in this project is defining clearly the role and responsibility of the independent design checker. The contract agreement of the Owner Client with the EPC Contractor clearly puts greater responsibility on IDC than a conventional proof checker. IDC has to carry out independent checks in this case before certifying the construction designs, which is not required in other projects.

The project got immensely benefited due to the greater involvement and participation of IDC in this project. Besides checking and certifying the construction drawings, IDC suggested and recommended many improvements in the structural schemes to achieve the overall economy and safety of the structures.

6 BIS Guideline on requirements for Proof Checking Services

The need for a well-documented standard procedure for proof checking of structural designs has been long recognized by the Bureau of Indian Standards. The Bureau of Indian Standards (BIS) has formed a special committee to bring out a national publication which defines the role and responsibilities of various stakeholders, and different models of appointment of IDC / Proof Consultant depending upon different categories of proof checking, as demanded, based on their level of independence.

7 Concluding Remarks

a) The bridge across the river Brahmaputra at Guwahati was subjected to systematic, competent, thorough, and independent design checking, which has proved very useful and helped in reducing the risk of design errors.

b) Though the process of IDC was appreciable, there is always scope for further improvements. The services of IDC should be procured directly by the Owner Client rather than through the Contractor. This will help IDC to function with technical and commercial freedom.

c) The cost of an independent design check is insignificant as compared to the value and added confidence it provides. Therefore, Owner Clients should actively consider this approach and re-establish the culture of independent and thorough checking.

ID-171

Structure of the New Movable Railway Bridge on Pamban Island

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Abstract

A new Tower Vertical Lift bridge on Pamban Island (India) replaces the existing "Scherzer" Rolling Bascule bridge within the railway line that connects the island to the Indian subcontinent across the Palk Strait. The lift span of the new bridge consists of a 77.5 m simply supported structure composed of two lateral steel Warren trusses of variable depth and a platform 10.3 m wide, holding two railway lines. The lift movement of the bridge is carried out through two sets of electromechanical systems placed in two towers 40 m high, located at the ends of the lift span, which hold the machinery in their upper part. The choice of this system responds to the criteria of reliability and robustness. Also, the high incidence of marine corrosion in the bridge location has been decisive in the design. The existing bridge is a national icon in South India; therefore, the aesthetic has been a fundamental condition.

Keywords: movable bridge, vertical lift, tower drive, steel structure, Warren truss, railway, deep foundation

1 General concepts and criteria

The new vertical lift bridge on Pamban Island (India) replaces the existing "Scherzer Rolling Bascule" bridge, which is part of the railway line that connects the island to the Indian subcontinent across the Palk Strait. The project has been promoted and financed by the Indian public company RVNL.

The existing hundred-year-old bridge is a national icon for its typological uniqueness and for being the first sea bridge built in India. For this reason, it is nicknamed "The Queen of Indian bridges" and has become a tourist attraction. The significant pathologies detected due to intense corrosion in the steel elements, make it necessary to completely dismantle and replace it with a new vertical lift bridge in parallel with the existing one.

The main operational criteria of the bridge design are the following: a double track railway with a 5.3 m track axis distance, a minimum vertical clearance of 5.87 m, a 72-width navigation channel, a 22-m vertical navigation gauge, and a provision of the future electrification of the track. The structural design has followed the fundamental criteria of simplicity, reliability, and robustness. These criteria have also been considered for the bridge design movement system. Additionally, the bridge is in one of the most corrosive marine environments in the world; therefore, the conceptual approach of the design decisively considers this aspect from the beginning of the project.

2 Structural design

As a result of a study of alternatives, a Tower Drive Vertical Lift typology is determined according to the criteria of simplicity and robustness and the mentioned requirements. In general terms, the vertical lift type consists of a simple span raised straight up to provide clearance under the bottom of the span in the navigation channel, being supported by two towers at each end of the span. The towers have rotating sheaves mounted at their top, with ropes connected at each end to the lift span. The other rope ends are connected to counterweights, so the lift span weight is balanced. The principle of the Tower Drive Vertical Lift type is that the span drive machinery, which rotates the sheaves, is mounted atop each tower in the most favourable location to minimize maritime corrosion.

A steel structure bridge has been proposed for the lift span and towers, with a deep foundation of in situ reinforced concrete. The lift span of the new bridge is formed by a 77.5 m single-supported span composed of two lateral steel Warren trusses of variable depth and a platform 10.3 m wide, holding two railway lines. The structure of each tower consists of two vertical shafts, which transmit essentially vertical forces to the foundation, two back inclined struts (figure 3) that collaborate with the shafts to receive horizontal forces, mainly wind and earthquake actions, and an upper lintel that generates a frame system in the transversal direction, which also has the essential function of housing most of the mechanical movement systems of the bridge and the control cabin. The lintel structure consists of an open space truss, which must be compatible with the bridge functionality for what is necessary: providing space for the location and support of machinery: pulleys and electromechanical systems, allowing the removal and replacement of the sheaves and electromechanical systems from the outside using cranes, locating the control cabin and allow general access to the lintel and circulation inside it for system maintenance, and allowing maximum visibility from the control cabin necessary for adequate visual monitoring of maritime and rail traffic.

The counterweights located in each of the towers have the function of balancing the weight of the lift span so that the power of the motors is the minimum corresponding to the forces of inertia and the friction of the mechanisms. In practice, a slight imbalance is common to provide a minimum load in the span bearings. In this case, it has been established prismatic geometry counterweights with dimensions 14.6 x 3.0 x 1.5 m, which is significantly lighter than the theoretical weight of the span.

Vertical lift bridges include two essential specific structural elements: the ropes and the sheaves. The raised lifting system consists of 4 groups of four 46 mm diameter ropes located in correspondence within the four corners of the lift span. The sheaves support the cables and provide lift span movement through the friction between the rope and the sheave groove. The material of the shaves is cast steel which is a suitable choice for a component of irregular shape subjected to loading that varies in direction and magnitude. Other specific structural elements of interest are the following: spherical bearings of the lift span, lift span centring devices, lower lift span lock devices, upper counterweight lock devices, and guides of the lift span and counterweight.

3 Conclusions

The bridge design has been carried out based on maximum simplicity, reliability, and robustness criteria. Also, protection against maritime corrosion has been a fundamental factor in the design. The choice of the fundamental typology: Tower Drive Vertical Lift, in which the actuation machinery is housed at the top of the towers, responds to those criteria and concepts. The bridge structure has been also designed following fundamental criteria of optimization of materials, reduction of self-weight and maximum protection against marine corrosion.

ID-567

Case study using Non-Linear Finite Element Analysis for Assessment of Slutchers Lane bridge

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Abstract

200 years of British railway infrastructure is now owned, managed, and developed by Network Rail. Safe and effective management of the rail network needs to have up-to-date information regarding the capacities of these ageing assets. Slutchers Lane bridge (Warrington, UK) is a structure designed to carry rail loads over a public road. According to the 2010 NBSI assessment and the archive drawings, bridge widening took place circa 1907.

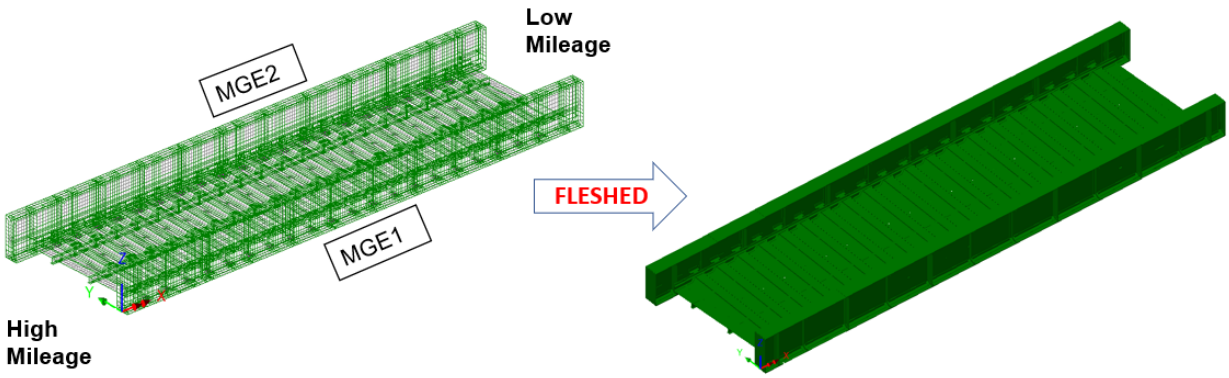
The previous assessment of this bridge was carried out using simple statics with an idealised line beam approach, the results obtained were inadequate to serve the current load requirements of Network Rail. To get a more accurate theoretical capacity, a more refined analysis was required, incorporating recent site inspection data representing the current condition of the bridge. Performing a nonlinear finite element analysis was found to be suitable for this requirement.

For the study, the entire structure was modelled in LUSAS software using shell elements and analysed for various potential failure mechanisms. The finite element model was able to capture all the deteriorations identified during the recent site investigation. A mesh sensitivity study was carried out for the selection of an appropriate mesh size. In the analysis, material nonlinearity is considered along with geometric nonlinearity. The initial geometric imperfection is assigned based on the critical buckling mode identified in the linear Eigenvalue buckling analysis with appropriate scale factor. To determine the results at both ultimate limit state and service limit state, the following outputs were captured, Von Mises stresses, the extent of material yielding, and the propensity for buckling. Recommendations were made based on standard guidance and engineering judgement.

From the nonlinear finite element study, it was established that the structure in its current condition is adequate for the current Network rail requirement, which is an improvement on the results of the previous assessment.



Slutchers Lane bridge detail



Slutchers Lane bridge finite element model

Keywords: Finite element analysis; Eigen value Analysis; Non-Linear Analysis; Geometric nonlinearity; Material nonlinearity.

Session-3

Analysis, Research and Standardisation

ID-5

Experimental Study on Dynamic Characteristics of Rubber Sand Mixtures

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1 Introduction

Although most scholars have studied the dynamic characteristics of rubber sand mixed soil by using resonance column test. However, the American test standard compares the resonant column test and the dynamic triaxial test used to test the dynamic characteristics of the soil, and points out that the modulus attenuation curve measured by the resonant column test is significantly different from the dynamic triaxial test. The reason is that the research on the dynamic characteristics of the soil in the resonant column test is mainly concentrated in the small strain range, and it is difficult to accurately test the dynamic parameters of the soil in the large strain range. Therefore, this paper uses dynamic triaxial tests that can be tested in a large strain range to study the effects of rubber content and confining pressure on the stress-strain characteristics, shear modulus and damping ratio of rubber sand mixture.

2 Experimental Test

2.1 Materials

The photos of rubber particles and standard sand were shown in Fig 1 (a) and (b), respectively.



(a). Rubber particle (b). Sand

Fig.1 Photos of materials

2.2 Sample Preparation

Seven samples with different rubber contents (R) were shown in Figure 2. The grading curve of rubber and standard sand was shown in Fig 3.

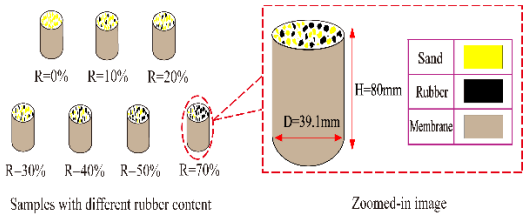


Fig.2 Testing Specimens

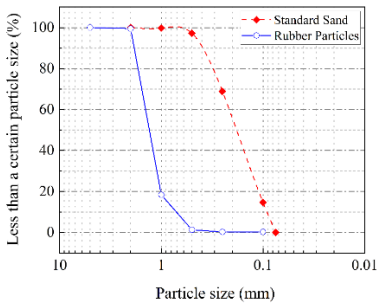


Fig.3 Grading curves of the rubber particles and standard sand

2.3 Test Procedures

Dynamic triaxial test procedures are shown in Fig 4.

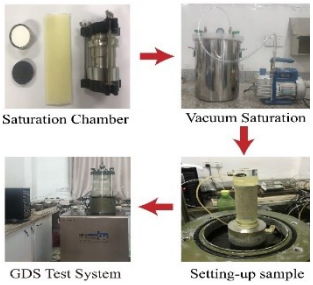
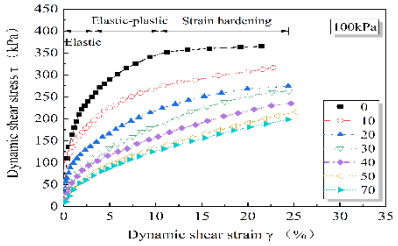


Fig.4 Testing procedures

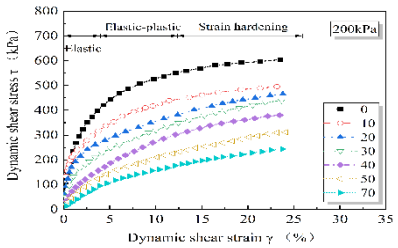
3 Experiment Result Analyses

3.1 Dynamic shear stress-shear strain curves

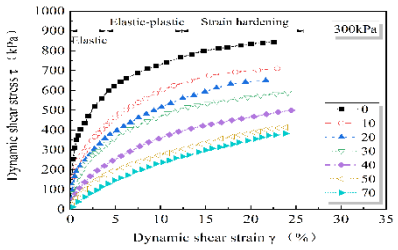
The dynamic shear stress (τ) - dynamic shear strain (γ) curves of rubber sand mixture samples under different rubber contents and confining pressures were illustrated in Fig 5. According to the test results, the stress-strain curve of the rubber sand mixture can be roughly divided into three stages.



(a). Confining pressure 100 kPa



(b). Confining pressure 200 kPa

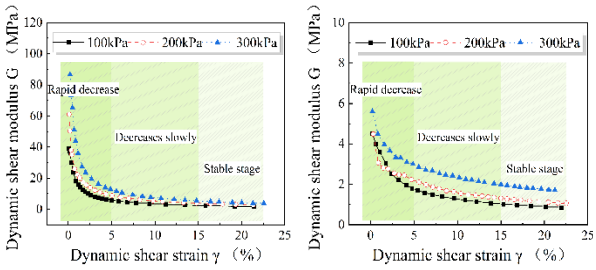


(c). Confining pressure 300 kPa

Figure 5. τ - γ curves of rubber sand samples with different rubber contents

3.2 Dynamic Shear Modulus

Due to the limited space, this paper only gives the dynamic shear modulus (G) - dynamic shear strain (γ) of the samples with rubber content of R=0 % and R=70 %. Fig 6 shows that with the increase of dynamic shear strain, the dynamic shear modulus curves of samples with different rubber contents all change in three stages.



(a). R = 0% *(g). R = 70%*

Figure 6. G – γ curve of rubber sand with different rubber contents

3.3 Damping ratio

Based on the experimental results, as shown in Fig.7, we divided the rubber content affecting the damping ratio of the specimens into three categories: Low damping ratio; Medium damping ratio; and High damping ratio.

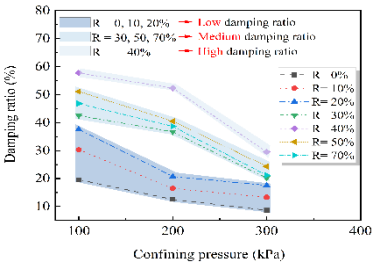


Figure 7. Damping ratio variation of rubber sand mixture under different rubber content and confining pressure conditions

4 Reference

[1] Xue J, Aloisio A, Lin Y, et al. Optimum design of piles with pre-hole filled with high-damping material: Experimental tests and analytical modeling. *Soil Dynamics and Earthquake Engineering*, 2021, 151: 106995.

[2] Fu R H, Briseghella B, Xue J Q, et al. Experimental and finite element analyses of laterally loaded RC piles with pre-hole filled by various filling materials in IABs. *Engineering Structures*, 2022, 272: 114991.

[3] Aloisio A, Pelliciari M, Xue J, et al. Effect of Pre-Hole Filled with High-Damping Material on the Inelastic Response Spectrum of Integral Abutment Bridges. *Journal of Earthquake Engineering*, 2022: 1-22.

ID-44

Gap Filler to Eliminate the Hole Play Between Base Plate and Channel Bolts Installed in Anchor Channels to Sustain Higher Seismic Loads

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Abstract

Anchor channels are a common fastening system for attaching highly loaded base plates of non-structural and structural components to reinforced concrete structures using channel bolts. The reliability and robustness makes this fastening system also popular for seismic applications. An innovative gap filler set was developed to eliminate the gap between the base plate and the channel bolt as well as between the channel bolt and anchor channel, and thus to further improve the seismic performance. Following the introduction of anchor channels and channel bolts in the context of seismic loading, some background information is provided, and qualification as well as design is addressed. Finally, monotonic (static) and cyclic (seismic) tests on channel bolts installed without and with gap filler are presented and discussed to demonstrate the benefits of gap filling.

Keywords: Anchor channels; channel bolts; static and seismic performance; concrete fastener.

1 Introduction

Channel bolts installed in cast-in anchor channels enable the sound connection of non-structural and structural components to reinforced concrete structures. Anchor channel-channel bolt-systems, also simply known as anchor channels, reliably take up monotonic and cyclic loads even under extreme conditions to be anticipated in seismic regions. This is particularly relevant for critical infrastructure such as high speed railway bridges (

Figure 8).



Figure 8. Taiwan Highspeed Railway viaduct in a seismically active country

2 Background

The invention of anchor channels with channel bolts more than 100 years ago was driven by the need to connect components to the then upcoming reinforced concrete structures (Figure 9).

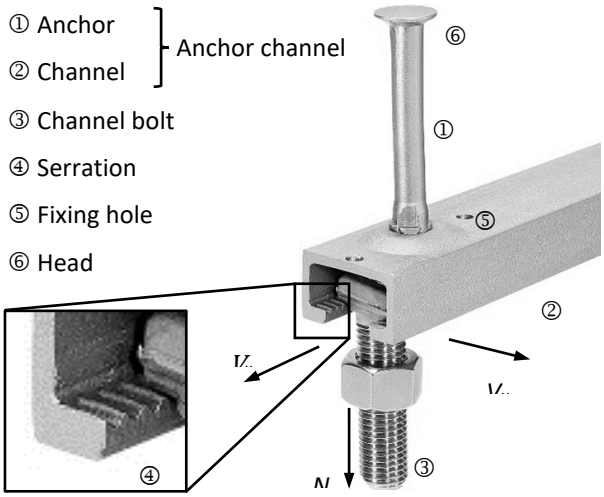


Figure 9. Serrated anchor channel components and matching serrated channel bolt

3 Hammer effect

Transient seismic excitations cause cyclic displacements of the base plate which then generate cyclic impulses if the displacement is larger than the gap width Δ (Figure 10).

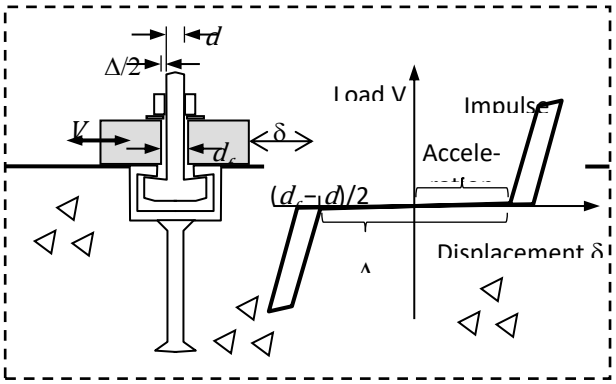


Figure 10. Illustration of hammer effect acting on a channel bolt installed in an anchor channel

To fill both, the gap between the base plate and channel bolt as well as between the channel bolt and anchor channel, a gap filler set was developed (Figure 11).



Figure 11. Filling of gap between base plate, channel bolt, and anchor channel

4 Tests w/ and w/o gap filler set

The load bearing behaviour of the serrated system with and without gap filler was tested (*Figure 12*).

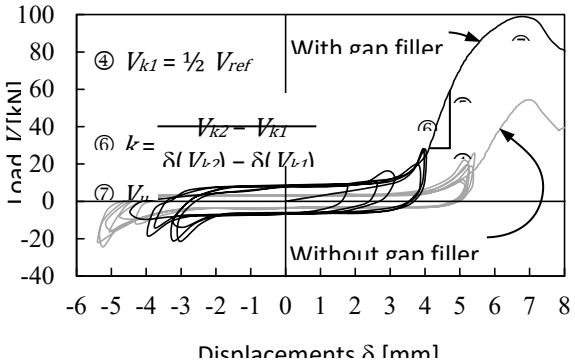


Figure 12. Example load displacement curves, first and last cycle of each load step shown only (cyc_x_ref and cyc_x_fil, right)

5 Conclusions

Gap filling efficiently prevents the hammer effect from happening and provides some extra safety margin readily available when it is needed most – during earthquakes.

The views expressed in the paper are the views of the authors only and do not necessarily reflect the views of Jordahl (PohlCon), Purdue University, and Profab Engineers.

ID-91

Sandwich panels with bio-based core of wood fibre insulation

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Abstract

In light of the climate crisis, the building sector faces the increasing challenge and urgency to improve its sustainability and significantly reduce its consumption of non-renewable resources. Therefore, the EU-funded research project InCSEB is developing ultra-low carbon footprint building steel envelope systems through the innovative use of wood fibre as a core material of sandwich panels. By using the new bio-based core material, the carbon footprint and the environmental impact of buildings with this type of envelope system can be reduced. Within the InCSEB project, various studies are being carried out on sandwich panels with a bio-based core. In addition, studies are being carried out on full-scale building prototypes with these new solutions. In this paper, the results of the static-mechanical tests and the assembly of the sandwich panels with a wood fibre core are presented to indicate the future scope of potential roof and cladding applications.

Keywords: lightweight structure, sandwich panels, wood fibre insulation, bio-based core material, mechanical tests, building prototypes, experimental studies

1 Introduction

For building constructions, sandwich panels usually consist of two metal face sheets and a core of polyurethane (PU) or mineral wool (MW). They are characterized by combination of lightweight construction, thermal insulation, sealing function in one component. Hence, sandwich panels are already established as an economical solution for building envelopes in industrial constructions in Europe.

The urgency to rethink established construction methods and building materials has been made aware through the European Green Deal which aims to reduce the net greenhouse gas emissions in the European Union to zero by 2050. For the construction sector, it therefore requires material-saving, lightweight and environmentally friendly solutions. One of them can be sandwich panels with a bio-based core of wood fibre (WF) insulation, which shows a reduced global warming potential (GWP).

The Europe-wide research project InCSEB develops five steel envelope systems with wood fibre insulation. Three of these are sandwich panels with a WF core which were studied at TU Darmstadt regarding their static-mechanical behaviour. Furthermore, two full-scale building prototypes incorporated all five envelope solutions have been built at TU Darmstadt to analyse their performance under real environmental conditions.

2 Experimental studies

Mechanical tests according to EN 14509:2013 [1] were conducted for the sandwich panels LR_150, LW_150 and BR_200 with thicknesses of 150 mm and 200 mm. In small-scale tests the mean values of the strengths and stiffnesses of the WF core were determined, see Table 5. Whereas from the full-scale six-point bending tests the load-bearing capacity of the WF sandwich panels with a span of 6 m was obtained, see Table 5 and Figure 13.

Table 5. Test results of WF sandwich panels

	LR_150	LW_150	BR_200
E_{cc} [MPa]	12.55	10.34	0.92
E_{ct} [MPa]	11.19	9.56	0.51
G_c [MPa]	11.87	10.25	1.52
f_{cc} [MPa]	0.1286	0.1083	0.0637
f_{ct} [MPa]	0.0668	0.0540	0.0048
f_{cv} [MPa]	0.0807	0.0765	0.0086
ρ_c [kg/m³]	123.73	118.93	116.51
F_{pos} [kN]	19.29	14.97	4.79

For evaluating the test results, they are compared with each other and with conventional sandwich panels. Since the density and texture of the wood fibre insulation is comparable to mineral wool, it was chosen as a reference. While the results of the L series fall, except for the tensile properties, within the range of mineral wool, large deviations can be observed for the B series. Here, the magnitudes, excluding the compressive strength, are significantly lower than for the L series or MW due to the different orientation of the wood fibres in the series L compared to B. This clearly indicates a highly anisotropic material behaviour of the WF core. Regardless of this, it is evident that the tensile stiffness and strength of the WF core are noticeably below the values of mineral wool. Nevertheless, the WF sandwich panels have the potential of being in the range of conventional solutions in terms of load-bearing capacity.

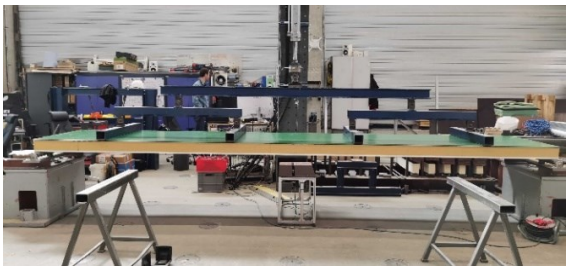


Figure 13. Six-point bending test, LR_150, L = 6 m

3 Conclusion

Sandwich panels with wood fibre core could be a promising ecological alternative to established solutions. The test results show that sandwich panels with wood fibre core can principally compete with sandwich panels with conventional core materials from a static-mechanical point of view. Regarding their assembly, the WF sandwich panels were also comparable with the MW reference panels. A more comprehensive assessment can be made when further research results on the performance under all aspects such as durability, fire protection, building physics, economic efficiency and sustainability are available.

4 Funding and Acknowledgement

The InCSEB project has received financial support from the European Community's Research Fund for Coal and Steel (RCFS) under grant agreement No. 101033984.

5 References

[1] EN 14509:2013-12. *Self-supporting double skin metal faced insulating panels - Factory made products – Specifications. Berlin: Beuth; 2013.*

ID-124

Experimental and analytical investigations on the shear capacity of prestressed concrete bridges

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Abstract

A recalculation according to Eurocode 2 (EC2) of bridges, which have been built in Europe before the introduction of EC2, shows a deficit of the existing shear reinforcement. However, prestressed concrete bridges have additional load-bearing reserves. Even refined analytical approaches do not sufficiently capture the simultaneous effect of the concrete and reinforcement contribution on the shear capacity. Hence, it is important to verify the shear capacity of existing concrete bridges with a new improved design approach. In this work, sixteen large-scaled shear tests (16,5 m continuous post-tensioned girders with uniformly distributed loads) have been conducted. To examine the interaction of the concrete contribution and the strut-and-tie model, the specimens were built with low shear reinforcement and varying cross-sectional shapes. Finally, it will be shown that the service time of existing structures can be extended significantly by using the new analytical design approach.

Keywords: shear capacity, prestressed concrete girders, large scale, recalculation, bridge, Eurocode

1 Introduction

The shear design according to EC2/NA(D) is not suitable for determining the shear reserves of existing prestressed concrete bridges, because the application of the truss model requires a minimum shear reinforcement. At the time of construction of most bridges in Germany, the design was based on the main stress criterion, which differs from the design according to today's standards, resulting in a significantly lower amount of shear reinforcement. Therefore, there is an urgent need for more detailed design models with an accurate determination of the shear resistance. Extended design approaches have already been formulated in the German recalculation guideline, but they do not answer all remaining questions regarding the various influences on the shear resistance.

2 Experimental investigations

The purpose of the experimental studies conducted at the Institute for Structural Concrete (IMB) of RWTH Aachen University is to refine the assessment of the shear capacity of older prestressed concrete bridges by means of more accurate verification methods that allow a more precise quantification of computationally unused shear reserves. A total of sixteen partial tests were carried out on eight post-tensioned girders. The cross-section, the load type, the shear slenderness, the stirrup reinforcement ratio, and level of prestressing were varied. Two partial tests were conducted on each specimen. While partial test ① was conducted at the intermediate support, partial test ② was caried out at the simple support. The comparison of the ultimate loads provides several insights:

- An increased shear load can be transferred in complex cross-sections than in simple cross-sections,
- an increased shear load can be transferred because of a continuous load in contrast to simple loads,
- an increased shear load can be transferred because of a higher prestressing,
- the shear resistance increases with higher amounts of shear reinforcement.

3 Discussion of Design Approaches

Overall, the evaluation shows that the shear capacities according to EC2-2/NA(D) are significantly more conservative than those according to the NRR. In addition, with the 2nd amendment of the NRR, significantly better agreement between analytical and experimental load-bearing capacity is determined. In summary, the 2nd amendment of the NRR provides good agreement between experimental and analytical shear capacity.

The investigation shows that the positive influences of the complex cross-section compared to the solid cross-section are not represented by all design approaches, since all data points of complex cross-sections are above the rectangular ones. In addition, an increase in the shear capacity when loaded by continuous loads is also not considered by the design approaches. Analogously to partial test ①**Error! Reference source not found.**, the e valuation of partial tests ② confirms that complex cross-sections are clearly more underestimated by the design approaches than the girders with solid cross-sections. It is also approved that the higher shear capacity due to loading by continuous loads compared to loading by single loads is not sufficiently represented by the design approaches. As the degree of shear reinforcement $\rho_{w,prov}/\rho_{w,min}$ increases, more accurate load capacities are determined according to EC2-2/NA(D) and both the 1st and 2nd amendment of the NRR.

4 Conclusions and outlook

The paper presents shear tests on 16,5 m prestressed concrete girders conducted at the Institute for Structural Concrete (IMB) of RWTH Aachen University. The influences of the loading type, the cross-sectional shape, the degree of restraint d_r, the stirrup reinforcement ratio and the prestressing were elaborated. Subsequently, the experimental shear capacities were compared with the analytical capacities according to EC2-2/NA(D) and NRR including the 1st amendment as well as the 2nd amendment. It was revealed for which conditions the analytical shear capacity according to NRR is particularly conservative:

- For complex cross-sectional shapes compared to solid cross-sectional shapes,
- For components with loads due to continuous loads compared to components with loads due to single loads.

Since these experimentally confirmed positive effects on the shear capacity of prestressed concrete girders are not considered even in recent design approaches, they are to be investigated in more detail in further studies in order to enable an economic recalculation of concrete bridges.


a) View on simple support


b) View on F_{cant} and intermediate support

ID-129

The Evolution of the Indian Standard IS 1893 Focusing on Base Shear Values of Seismic Forces for a Forty-Three-Storey Reinforced Concrete High-Rise Building Using the Response Spectrum Method

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Abstract

Comparative studies of the old Indian standard IS 1893:2002 and the existing IS 1893:2016 have been presented for high-rise buildings in India; however, they have not been presented for high-rise buildings in Sri Lanka. This case study compares the old and existing IS standards, as well as Australian standard AS 1170:2007, and EURO code EU 8:2004, in terms of lateral effect focusing on the base shear values of seismic forces on a 43-storey high-rise building with three basement levels located in Colombo, Sri Lanka. This project was analyzed and designed in 2006; however, only bored pile load testing and tangent pile walls were completed before the project was suspended. This comparative study of the building uses the response spectrum method, which was performed by ETABS 18,1,1. The purpose of this paper is to identify the major changes in the evolution of IS 1893, and how the revisions have made IS 1893:2016 a more reliable earthquake code than IS 1893:2002.

Keywords: IS 1893:2002; IS 1893:2016; base shear values; response spectrum method; high-rise building.

1 Introduction

The evolution of seismic design procedures is based on performance analyses of structures during past seismic events, considerable advancements have been made over the years in earthquake resistant design of structures, and seismic design requirements in building codes have steadily improved. Therefore, seismic codes need revision from time to time. Buildings designed in accordance with earlier versions of codes may be checked to establish whether existing buildings are safe for carrying out recommendations made by the revised codes. This paper focuses on the evolution of the Indian standard IS 1893 using the response spectrum method. It compares the seismic analyses for different provisions of the old IS 1893:2002, the existing IS 1893:2016, the EURO code EU 8:2004 and the Australian standard AS 1170:2007 in terms of base shear values of seismic forces. The structural model was an ordinary reinforced concrete (RC) building with shear walls (SW). This study was performed on a 43-storey high-rise residential RC building with three basement levels located in Colombo, Sri Lanka. This project was analyzed and designed in 2006; however, only bored pile load testing and tangent pile and tangent walls were completed before the project was suspended.

2 The Comparison of codes i.e., IS 1893 (part 1) 2002 and IS 1893 (part1) 2016

The revisions to major clauses are presented in Table 1 with key comments.

Table 6. The Revisions in Major Clauses

Item	IS 1893 (PART 1) 2002	IS 1893 (PART 1) 2016
1	Importance Factor (I): Importance factor 1,5 was for important structures and 1,0 was for all other buildings, Table 6.	Importance Factor (I): For residential or commercial buildings with occupancy of more than 200 people, importance factor 1,2 has been assigned in the existing code, Table 8.
2	Moment of Inertia (I): Clause regarding moment of inertia is not mentioned in old code. Thus, analysis is made considering full moment of inertia, i.e., uncracked sections are considered.	Moment of Inertia (I): The moment of inertia for structural analysis shall be taken as follows: for RC and masonry structures: I_{eq} = 70% for columns I_{eq} = 35% for beams

3 Objective of the Study

The purpose of this paper is to identify the significant changes in the development of IS 1893, and how these revisions have made IS 1893:2016 a more reliable earthquake standard than IS 1893:2002. This analysis focuses on comparing the standards in terms of the base shear values.

4 Details of the Building

The building has a length of 76,5 m, width of 33,5 m, superstructure height of 133,0 m and substructure depth of 8,5 m.

5 Analysis and Results

This paper conducts a comparison of the seismic analyses for different provisions between the IS 1893:2002, the IS 1893:2016, the EURO code EU 8:2004, and the Australian standard AS 1170:2007, that refer to the relevant codes or standards, and compares them in terms of the base shear values of seismic forces (Table 2). This comparative study of the building uses the response spectrum method, which was performed by ETABS 18,1,1. No effect of soil-structure interaction was considered and the base of all columns and SWs were assigned with idealized fixed support conditions.

Table 7. The Comparison of the Base Shears of the AS 1170:2007, IS 1893:2002, IS 1893:2016, and EU 8: 2004 Standards

Axis	Base Shears of AS 1170: 2007 (kN)	Base Shears of IS 1893: 2002 (kN)	Base Shears of IS 1893: 2016 (kN)	Base Shears of EU 8: 2004 (kN)
X	1191	1068	1543	1882
Y	893	944	1340	1702

Table 3. The Increase in Base Shears from the IS 1893:2002 to IS 1893:2016 Codes

Axis	Base Shears of IS 1893:2002 (kN)	Base Shears of IS 1893:2016 (kN)	Increase in Base Shears (%)
X	1068	1543	44
Y	944	1340	42

6 Conclusions

The base shear values of the IS 1893:2002 code and the AS 1170:2007 code had very similar results in both X and Y directions while the IS 1893:2016 and EU 8:2004 codes showed highly different results, as shown in Table 2. The codes differ from each other

in many provisions, which makes the comparison field huge. In accordance with the significant changes in the development of IS 1893 as shown in Table 1, the comparison data of the IS 1893:2002 and IS 1893:2016 codes on the X-and Y-axis found that the base shears of IS 1893:2016 increased by 44% and 42%, respectively, over those of IS 1893:2002 as shown in Table 3. From the above result, it can also be concluded that the existing code IS 1893:2016 is safer for seismic design than the old code IS 1893:2002.

ID-138

Influence of Train Composition on Crack Propagation at Structural Components of Welded Railway Bridges

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Abstract

The application of fracture mechanics allows a detailed assessment of structural details of existing railway bridges. By using crack propagation calculations, the residual service life and respective safe inspection intervals can be determined. For this purpose, cyclic loading due to train passings is needed as an input parameter. Furthermore, an initial crack length and material parameters need to be assumed. In this paper, the focus lies on the loadings generated by each passing train. The influence of single trains as well as the composition of trains and their order on crack propagation is investigated. Train models in the Eurocode [1] are considered and the effects are analysed in the frame of linear elastic fracture mechanics. Combined with the span length, the in-fluence of service trains is varying and an impact of train composition is present. Sequence effects are if at all only slightly visible and therefore may be neglected within the considered calculations.

Keywords: welded railway bridges; linear elastic fracture mechanics (LEFM); crack propagation calculations; train composition; load sequence effects; assessment of existing bridges; Paris' law.

1 Introduction

A variety of concepts is available for determining the residual service life of existing railway bridges. Applying fracture mechanical methods allows a more detailed analysis compared to the nominal stress concept. It results in more realistic lifetimes and therefore more sustainable assessment. This includes the derivation of inspection intervals ensuring a controlled crack growth and thus a safe operation between two intervals. For this purpose, crack propagation calculations are conducted, starting from an assumed defect size. Based on the stress intensity factor at the crack tip, the stepwise growth of the crack due to cyclic loading can be described by the Paris' law. The risk of brittle fracture is covered by means of the failure assessment diagram. As input parameters, the acting stress ranges as well as an initial defect size and material parameters are needed.

This paper focuses on cyclic loading due to train passings and resulting crack propagation. Each train generates several applied forces, depending amongst others on the distance between the axles and the axle loading. From the resulting time series of stresses, the corresponding stress ranges can be obtained by rainflow counting. Obviously, assumptions of the characteristics of passing trains need to be made, unless detailed measurements of train crossings are available. For this purpose, train models according to EN 1991-2 [1] can be used. Train composition and number of crossings per day are distinguished depending on the type of traffic (standard, light, heavy traffic).

Generally, load sequences may have an influence on the fatigue behaviour of structures, see e.g. [2].

For railway bridge applications, the question about the impact of load sequences on crack propagation arises. The consideration of the influence is investigated in the frame of linear elastic fracture mechanics (LEFM) in this work. This serves as background for the development of an assessment concept based on LEFM.

2 Results and Discussion

In this section of the full paper, results from crack propagation calculations are presented and discussed. In particular, the single train types in [1] are examined. These are analysed with and without consideration of the train compositions. Furthermore, the influence of the three different load compositions in [1] is investigated. Finally, sequence effects within the load compositions are treated and a conclusion concerning the consideration of sequence effects of trains within the frame of LEFM is drawn. Crack propagation calculations are conducted for a semi-elliptical surface crack in a plate under axial loading. Exemplarily, the results for the influence of train composition are shown in this extended abstract. Figure 14 shows the comparison of normalized crack propagation in thickness direction of the plate for standard traffic (ST), light traffic (LT) and heavy traffic (HT).

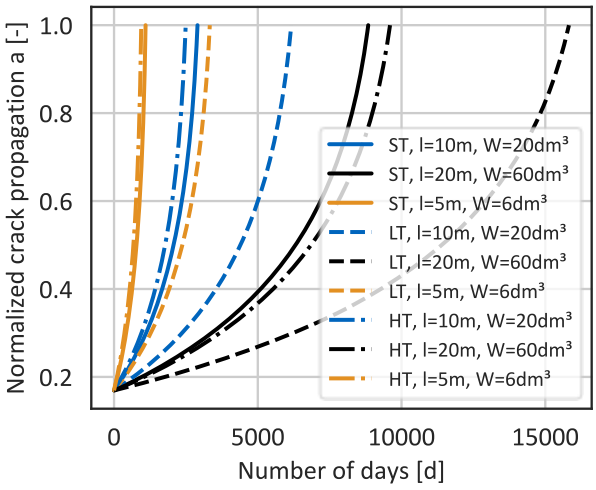


Figure 14. Comparison of the impact of train compositions in [1] on crack propagation dependent on length l and section modulus W

3 Conclusions

In this paper, the influence of train composition characteristics on crack propagation is investigated. To determine the possible influence of train composition and train sequence within these, the trains are examined separately at first. The largest impact within standard traffic results for train type 6 whereas train type 9 is dominant for light traffic. Crack propagation due to heavy traffic is dominated by train types 6 and 11 depending on the span length. Generally, the impact of each train is dependent on the span length and the impact can decline for very low maximum stress ranges. Based on the analysis of the specific train types, the influence of train composition and sequence effects is investigated. Light traffic can be assigned the slowest crack propagation whereas heavy traffic corresponds to the fastest one except for span lengths of about 20 m. Sequence effects are examined by sorting trains by increasing and decreasing impact respectively. For very high load levels, small impact is detected, which however is in a neglectable range.

Altogether, it can be concluded that the span length has a decisive influence on the impact of service trains and boundary conditions need always to be considered. Light traffic is more favourable compared to standard and heavy traffic. Sequence effects are not or only slightly visible within the conducted calculations in the frame of LEFM. Therefore, assuming the service trains passing randomly within the described procedure is a reasonable assumption and in addition close to reality.

4 Funding Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 506471463

5 References

[1] DIN German Institute for Standardization. DIN EN 1991-2: Actions on structures - Traffic loads on bridges; German version EN 1991-2:2003 + AC:2010. Berlin: Beuth Verlag GmbH.

[2] Richard HA, Sander M. Ermüdungsrisse: Erkennen, sicher beurteilen, vermeiden. 2nd ed. Wiesbaden: Vieweg + Teubner; 2012.

Session-4

Climate Change Adaptation and Disaster Resilience

ID-353

Addressing Climate Resiliency in Long Span Bridges Through Early Stage Aerodynamic and Climate Consulting

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Abstract

New long span bridges must be designed for climate resiliency based on historical records and long-term predictions. Existing bridges must be rehabilitated for climate resiliency to ensure safe operation and increased longevity. A multi-hazard assessment combined with bridge monitoring, wind tunnel studies and numerical analysis can provide an accurate picture of the current state of the bridge as a whole and specific components of the bridge including cables, deck, and hangers. Bridge microclimate past, present and future can be modelled, and climate scenarios can be applied to a digital model of the bridge to predict the response of the structure to the windstorms of tomorrow and to develop a framework of climate change adaption.

The authors will illustrate how aerodynamic and climate engineering consulting can inform decisions about the design and rehabilitation of long span bridges using case studies. Aerodynamic and climate consulting early in the design process contributes to both design, material, and carbon cost savings. Aerodynamic consulting and climate (weather) forecasting in construction stage planning ensures safe, efficient, and cost-effective construction of a bridge or a bridge rehabilitation plan.

A case study of the design of a new signature long span bridge, case studies of bridge cables and hangers and a case study of a bridge rehabilitation will be detailed to outline the benefits of early stage aerodynamic and climate consulting.

Keywords: Bridge Aerodynamics, Bridge Microclimate, Wind Effects, Bridge Rehabilitation, Carbon Footprint

1 Introduction

In recent years and even more in the last 3 years it has become apparent that aerodynamic studies targeting performance goals of long-span bridges are not limited to the detail design phase of new structures. There is a societal push globally to rehabilitate major bridges to adapt to their current and future use and to extend their design life.

In fact, aerodynamics studies are now carried out throughout the entire life cycle of a bridge, from the planning, conceptual design, detail design and construction phases to the in-service phase for safe operations and rehabilitation phase into a new configuration involving changes to the deck

cross-section or structural dynamic changes. The preferred approach developed over several decades is to carry out desktop knowledge-based studies, experimental studies in wind tunnels combined to analytical predictions.

The major steps of aerodynamic consultation for long-span bridges targeting optimum performance are generally as follows:

1. Site specific wind climate studies based on extreme value analysis of historical meteorological data. Such studies are carried out to define fact-based design wind speed as a function of return period and turbulence conditions on site;
2. wind tunnel tests to define a stable aerodynamic shape of the deck and its equipment to reach project specific performance stability criteria. The shape of the deck and barriers – fences are generally the focus of such studies;
3. wind tunnel tests to optimise the aerodynamic solution while targeting lower wind loading; and,
4. buffeting analysis, wind-induced response predictions and elaboration of equivalent static design wind loads.

Such steps are relevant for both new and existing bridges. Through case studies, the paper will elaborate on each of the steps and will illustrate if they differ for an existing bridge or a new bridge.

2 Meteorology and Climate Analysis

A rich body of work exist to predict the wind conditions, design wind speed and turbulence level expected for a particular site based on statistical analysis of meteorological data. This is established and is a must to have for long-span bridge projects, new and existing. In current days, such analysis considers climate changes since the challenge is to predict conditions for the next 50 to 100 years based on observations made for the last 50 years and the current conditions.

However, the climate has changed for most of the regions of the world. Arguably, the most important change is the accrued occurrence of severe thunderstorms bringing strong winds in the lower portion of the atmospheric boundary layer accompanied with intense rain fall, so intense that surface water drainage systems have been observed to be majorly ‘overwhelmed” even though their performance had been adequate for multiple decades.

In response to that, RWDI has developed short term weather forecasting tools that provide predictions of wind speed and direction, precipitations (rain or snow) and risks of lightening for bridge sites. The system can provide site specific weather forecasts every 3 to 6 hours and can be used for safe operation of a bridge (traffic management in cross-winds) or in support of the safety of critical construction operations. An example will be presented in the paper.

3 Focus on Performance

In this section, examples of aerodynamic modifications that lead to the definition of an aerodynamically stable deck cross-section will be provided. In most cases, reaching aerodynamic stability is also synonymous of reduction of wind loading. Other examples of optimisation of stability and reduction of aerodynamic forces will be provided in the paper.

The main take-away of this contribution is that through aerodynamic consultations, it is possible to reach prescribed performance criteria for long-span bridges in their environmental setting while reducing their carbon footprint, i.e. using less steel or concrete instead of adding material to increase stiffness or inertia.

ID- 371

Climate Change: Latest on the Wind Speed at the Coastal Regions of India

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Abstract

Indian sub-continent is subjected to many severe windstorms, especially the east coast is threatened by cyclones that have been known to cause damage to structures. However, the root cause of the damage cannot often be equated to high wind speeds only. In our recent studies, the design wind speeds corresponding to various risk levels were determined based on (i) the number of years of full-scale measurements from airports, (ii) numerically simulated data, as well as (iii) the fast-predictive cyclone wind hazard model. Based on all these studies, it is proven that the current recommended cyclonic factor (k4) in IS 875 (Part 3) will make the wind speed overly conservative.

Keywords: climate change; cyclone; India; wind-induced damages; wind speed.

1 Background

Climate change is a reality, and the impact of climate change is affecting us in multiple ways. Numerous studies have been carried out to understand the impact of climate change on wind speed. However, the results from these studies are not giving any proper guidance. The wind speed is increasing in some parts as well as decreasing in some other parts and there is no solid proof to substantiate the role of climate change in this wind speed variation. India is also subjected to many severe windstorms, primarily on the eastern coast. Suresh Kumar et al. [1] studied the extreme wind climate of India by analysing the wind speeds at non-cyclonic and cyclonic regions, using measured and simulated data. This study demonstrates that the existing wind speeds in IS code for regions such as Mumbai and Delhi are over-conservative, whereas for cyclonic regions such as Chennai and Kolkata, the current wind speeds are sufficient without the use of cyclonic factor (k4). Meanwhile some other studies indicated that the 50-year design wind speed on the east coast of India should be significantly higher than the speed provided in the IS code. This conclusion was made by investigating the maximum wind speeds of cyclones that made landfall on the east coast without any detailed investigation of the risk of exceedance. It is incorrect to use the maximum sustained cyclone wind speeds, which occur mostly over the ocean and far from the coastal line. Another major reason for getting high wind speeds was the usage of conditional probability to calculate the return period and the incorrect usage of significantly high threshold wind speed [2]. In summary, all the most recent studies revealed that the basic wind speed at the eastern coastline in the IS code is adequate as it is, without the cyclonic factor (k4). Hence, Suresh Kumar [3] discussed the removal of the cyclonic factor from the IS 875 (Part 3: BIS 2015).

2 Results from current study

Studies carried out on severe cyclones formed over the North Indian Ocean for the last 130 years, 1891 to 2021, shows that the frequency of

cyclones is quite high in the post-monsoon season compared to the pre-monsoon or monsoon seasons, as shown in Figure 1. Not all the cyclones formed over the ocean are making landfall and only about 50% of them make landfall in BOB, while only 20% are making landfall in Arabian Sea (AS), as shown in Figure 2. Considering 130 years of data, the chance of having on average a cyclone per year on the east coast is almost certain, while that chance is only about 15% on the west coast. Figure 3 shows the classification of various types of severe cyclones formed over the ocean, out of which only 45% made landfall. In short, there is no convincing evidence as to the argument for an increase in the frequency/intensity of cyclones in the North Indian Ocean.

3 Conclusions

The coastal region of India, especially the East coast, is threatened by multiple cyclones. In our recent studies, the design wind speed for various return periods at cyclonic and non-cyclonic regions was determined based on actual measurements, numerical simulations and based on a fast-predictive cyclone wind hazard model also. All these studies show that the current recommended cyclonic factor (k4) in IS 875 (Part 3) will make the wind speed overly conservative and as a result produce uneconomical structures. There is no clear indication of either increase in frequency or intensity in the last 5 decades. Proper cyclone wind speed measurement, especially during landfall, is required to determine the design wind speed at a specific return period.

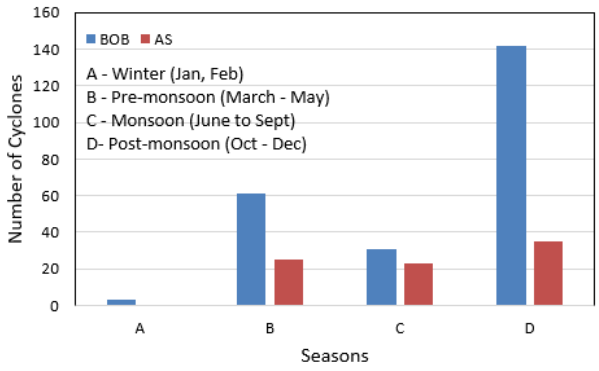


Figure 1. Seasonal frequency of severe cyclones formed over the north Indian ocean (1891- 2021)

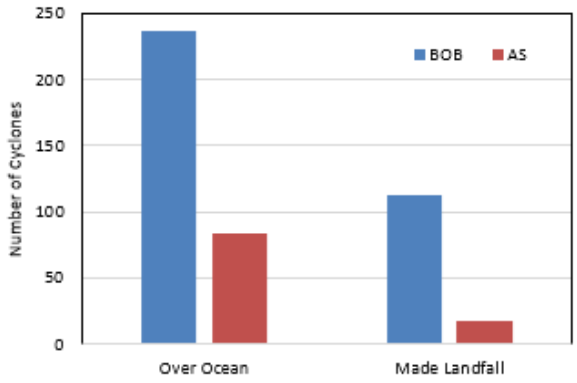


Figure 2. Cyclones formed over NIO and made landfall at Indian coasts (1891- 2021)

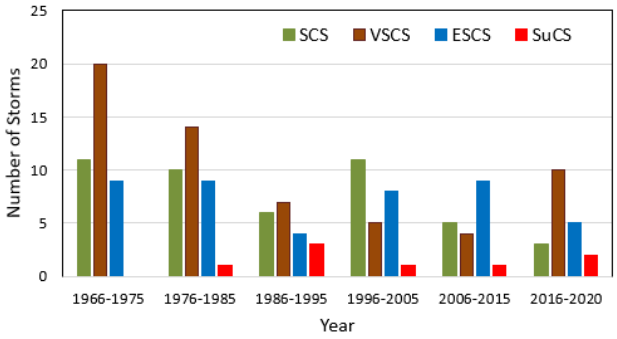


Figure 3. Frequency of severe cyclonic disturbances in the north Indian ocean (1966-2020)

4 References

[1] Suresh Kumar, K., Rahul, P.S., Li, S.H., Gibbons, M., (2021). Revisiting basic wind speed of metro cities of India. Nat. Hazards Rev. 22 (4).

[2] Li S.H., Suresh Kumar K. (2021). Cyclone wind hazard assessments for eastern coastal cities in India using a fast-predictive model. Journal of Wind Engineering and Industrial Aerodynamics, 218 , art. no. 104760

[3] Suresh Kumar, K., Rahul, P.S., Li, S.H., Gibbons, M., (2023). Closure to “Revisiting basic wind speed of metro cities of India”. Nat. Hazards Rev. 24 (2) -6996.0000494.

ID- 482

Functional Seismic Resilience of Reinforced Concrete Building Conforming to Indian Standards

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Abstract

Functionality and recovery are important resilience attributes but not considered in existing building design and assessment approaches. This study presents the probabilistic seismic resilience assessment of an archetypical IS code-conforming reinforced concrete building to gain insight in their repair cost, functionality, and recovery performance. Assessments are conducted for several intensities ranging from return periods of 50 to 9975 years. The results reveal that the IS code-conforming building meets collapse prevention and life-safety objectives. However, time for reoccupancy after a design-level event is about 13 days, while it takes 6 months for functional recovery which may not be acceptable for critical buildings. The study shows that including functionality and recovery-based objectives is essential for design of such buildings.

Keywords: Functionality assessment; Seismic resilience; Building reoccupancy; Functional recovery; Code-conforming building; Recovery curve; Performance-based earthquake engineering.

1 Introduction

Modern code-compliant buildings perform better in meeting life-safety objectives but often fail to be reoccupiable and functional for unacceptably long time [1]. Maintenance of functionality is a very important attribute of resilience which is not considered in existing conventional design and assessment approaches. The limited available literature shows that reoccupancy, functionality, and recovery performance of such buildings is unclear and there is a knowledge gap between current codes and user requirements. This study provides a deeper understanding of these performance attributes for a modern IS code-complaint reinforced concrete (RC) archetypical building for a series of intensities ranging from return periods of 50 and 9975 years. The study reveals need to incorporate functionality and recovery-based performance objectives in design and assessment approaches.

2 Methodology

Seismic resilience assessment of a building was conducted using performance-based earthquake engineering framework [2, 3] considering performance of structural and non-structural components and with due considerations to collapse potential and irreparability. Various uncertainties in response, damage states, repair cost, impeding time, and repair time were incorporated utilizing 5,000 Monte Carlo simulation realizations. Probabilistic seismic hazard analysis is used for development of conditional spectrum and corresponding ground motion selection. Nonlinear response history analyses of RC frames were performed employing concentrated plasticity approach in OpenSees to engineering responses. Component fragility and consequence functions were used for damage and loss assessments and further assess reoccupancy and functionality loss and corresponding recovery time and trajectories.

3 Results and Conclusions

Seismic performance is assessed in terms of collapse probability, red tag, excessive residual drift, repair cost ratio, reoccupancy, functional recovery, and full recovery over time after earthquakes. Figure 15 shows the performance in terms of probability of global consequences for different intensities. The building performs well against the collapse prevention objective of less than 10% at maximum considered earthquake (MCE). The building shows high potential for demolition due to excessive residual drifts (6% for design basis earthquake (DBE) and 20% for MCE). It has about 8% and 60% likelihood of getting red tag for DBE and MCE, respectively. The probability of a building to lose pre-earthquake occupancy capacity is 52% for DBE and 93% for MCE.

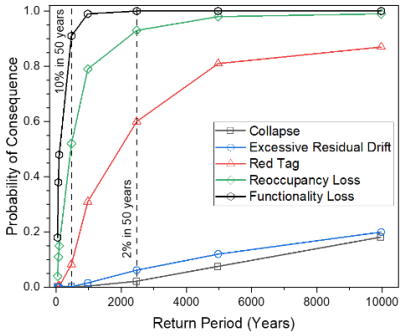


Figure 15. Performance assessment across different hazard levels

The mean repair cost, referred to as scenario expected loss (SEL), ranges from 1.2% to 71% and median values from 3.1% to 100% of the building replacement cost for intensities considered herein. The SEL values are about 11% and 37% for DBE and MCE, respectively, indicating expensive repair costs. The fitted 90th percentile repair cost values are 23% and 64% for DBE and MCE, respectively.

Figure 16 shows the variation of median repair, reoccupancy, functional recovery and full recovery time over different intensities. The building is expected to be immediately reoccupiable for lower levels (less than DBE) and take about 13 days and 270 days to regain pre-event reoccupancy level after DBE and MCE, respectively. The functional recovery is expected to take about 6 months after DBE and more than a year after MCE and higher intensities. Median full recovery time ranges from 111 to 630 days. The probability of reoccupancy or functionality of building evolves over time as the necessary repairs are carried out. One month, six months, and a year after DBE, the probability to regain pre-earthquake building occupancy is about 50%, 88% and 98%, respectively. For DBE and MCE, the probability of reoccupancy after a year is about 98% and 78% respectively. For DBE, the probability of achieving functional recovery jumps from 9% to 13% after a month, to 50% after 6 months, and to 88% after a year and a marginal improvement is observed for MCE.

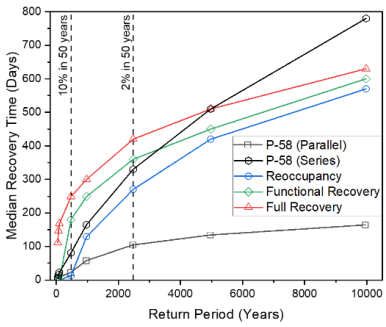


Figure 16. Median repair and recovery time across various intensities.

The major conclusions from the study are: The IS code-conforming building has satisfactory performance against collapse prevention objective. The probability of losing pre-earthquake occupancy and functionality even at design-level event is high. It experiences unacceptably long reoccupancy and functional recovery times. The mobilization time plays a very important influence on recovery time after high intensity earthquakes.

4 References

[1] Joo MR, Sinha R. Performance-based selection of pathways for enhancing built infrastructure resilience. Sustainable and Resilient Infrastructure 2023; 1–23. https://doi.org/10.1080/23789689.2023.2188347.

[2] FEMA P-58-1. Seismic Performance Assessment of Buildings Volume 1-Methodology. Washington DC: 2018.

[3] ATC 138-3. Methodology for Assessment of Functional Recovery Time. Redwood City, California: 2021.

ID-622

Influence of Design Practices and Climate Change Effects on the Seismic Fragility and Life-Cycle Cost of Highway Bridges

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Abstract

Refurbishment, maintenance, construction, repair, and replacement decisions for civil infrastructure systems may have an impact for up to 200 years. Therefore, it is imperative to consider future climatic circumstances while making decisions on building upkeep or during the design stage, as well as the related financial commitments. This may be primarily attributed to the long-term passive effects of climate change on the performance of reinforced concrete (RC) structures (Wang et al. 2010, Stewart et al. 2011). In light of the aforementioned findings, modern researchers, including TRB (2014), Dong & Frangopol (2016), Frangopol et al. (2017), and Li et al. (2020), among others, investigate frameworks to assess the economic loss costs of highway bridges under multiple hazards that take climate change effects into account. Recently, Mortagi & Ghosh (2020) explained how important it is to take climate change into account when developing ageing bridge fragility curves, specifically with regard to earthquake events. The main conclusions from the aforementioned study indicated that the combined effect of climate change and an increase in lifetime chloride concentration may further exacerbate the seismic performance and fragility of old highway bridges through a single point in time estimation. A lifetime performance indicator metric is essential for ongoing monitoring of the joint effects of corrosion deterioration (due to ageing) and climatic change on the seismic vulnerability of highway bridge structures. The economic loss cost estimate of ageing highway bridges has recently received significant study attention (Alipour et al. 2011, Ghosh & Padgett 2011, Kumar & Gardoni 2014, Titi & Biondini 2016). The loss cost assessment of ageing highway bridges, however, has received little attention despite the effects of climate change (the change in yearly temperature and relative humidity over the course of the bridge service life) brought about by global warming. The representative concentration pathways for several future climate scenarios are considered in this study, which provides insights on the modelling of chloride-induced degradation under the influence of climate change. The seismic life-cycle cost (SLCC) of ageing highway bridge structures under the effects of climate change is then evaluated using a novel framework. An example case study multi-span continuous steel girder bridge in Charleston, South Carolina, part of the Central and Southeastern United States (CSUS), serves as the basis for this framework's demonstration. The paper concludes with key findings and discussions.

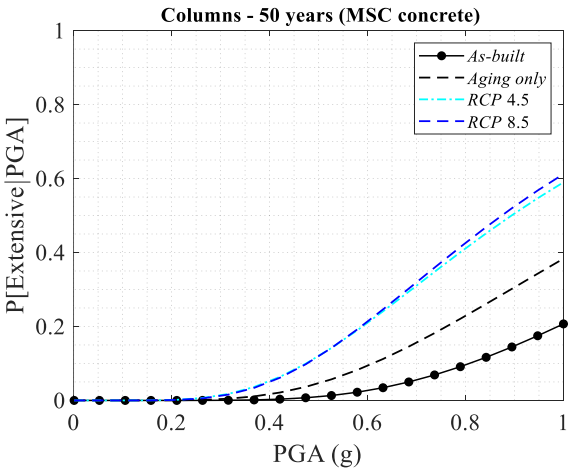


Figure 4. Seismic fragility comparison at different points in time across the deterioration paths under consideration for MSC concrete bridge columns

References

[1] Bastidas-Arteaga E, Schoefs F, Stewart MG, Wang X. Influence of global warming on durability of corroding RC structures: A probabilistic approach. Engineering Structures. 2013 Jun 1;51:259-66.

ID-648

Understanding Social Engineering and Disaster Resilience of the Rural Roads Sector for Sustainable Development

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Abstract

With the rising number and increasing severity of natural disasters globally, there is a growing need to engineer solutions to facilitate climate change adaptation and systemic disaster resilience. This is especially for the rural roads sector: when road embankments, culverts and bridges are affected by changing rainfall intensity and patterns, marginalised and poor vulnerable communities in rural areas lose access to basic infrastructure services such as roads connectivity thereby suffering the most from inundations and induced damages to their lives, livestock and livelihoods. Through the analysis of various innovative case studies, the authors highlight poverty alleviation centric approaches, materials and technology for building disaster resilient infrastructure in the rural roads sector.

Keywords: Disaster Risk Reduction; technology choice; infrastructure resilience; community contracting; nature-based solutions; innovative local resource-based approaches; rural roads asset management

ID-652

Modular Steel Panel Bridges for Optimal Emergency Response to Distressed Bridges on National Highways in India.

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Abstract

Bailey Bridges which were very successfully used in World War II may be considered the first generation of Modular Steel Panel Bridge (MSPB) and have been the only solution for emergency response to distressed bridges in India. These have today become unsafe with increase in axle loads and act as chokepoints on double-lane roads leading to huge economic losses.

A look at the improvement in this technology shows the world has graduated to 3rd Generation MSPBs. The first such bridge was launched in India in 2016 under challenging conditions, which is well documented. An overview of this gives a good insight into the capabilities of this bridge.

There is an impressive range of possibilities of using such bridges both as permanent bridges and as temporary detours in emergencies. The way forward to speedy 'Disaster Mitigation' and timely response to critical bridges in distress, is to create ready stocks of such bridges closer to where they are likely to be required. It is an important step which needs planning and preparation. One must move towards making these bridges in India with a conscious strategy of closing the existing capability gap quickly and incentivising manufacture of better modular bridges in the country. This can be speeded-up by overcoming resistance to change. Understanding these blocks in introducing new technology is an important lesson learnt from this first-hand experience in introducing 3rd Generation Modular Bridges for the first time in the country and exploring further use.

Keywords: Modular-bridges; MSPB; bailey-bridges; continuous-span; permanent-bridges; emergency-bridges; Acrow; detours; ROBs; restricted-launch.

Session 5

Sustainability in Built Environment

ID-74

Construction Materials and Green House Gas Emissions in India

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Abstract

Construction materials consume lot of mineral resources. The prime construction materials like cement, steel, bricks, glass, aluminium etc., during their production contribute to substantial emission of Green house gases (GHG) in to the atmosphere.

Construction sector in India contributes around 8% of its GDP and is also the largest employer of workforce in India after the agriculture sector. The construction sector consumes huge amount of natural resources than any other manufacturing sector.

The united nation frame work convention on climate change (UNFCCC) held in Paris stipulates that the global average increase in temperature shall be limited to 1.5 degree Celsius with respect to temperature existed in the pre industrial era . The UNFCCC states that to limit global warming to 1.5°C, it is necessary to reduce greenhouse gas emissions by 45% from 2010 levels by 2030 and to reach net zero by 2050.

UN SDG (Sustainable Development Goals) has prescribed goal no. 11 as Sustainable cities and communities, 9 as Industry, innovation and Infrastructure and 13 as Climate action. In order to adhere to UNSDG and to achieve targets set forth by UNFCCC the natural resource utilisation should be optimum in such a way that emissions resulting from construction are limited.

Emission of greenhouse gases includes apart from CO2, Methane, Nitrous oxide, and other gases CO2e is a common unit to describe the global warming potential(GWP) of gases in terms of the emission potential of CO2 gas.

Construction Industry contribution to the C02e emission is substantial and the emission is mostly attributed to the production and the use of prime construction materials such as Cement, Steel, Bricks, Glass, Aluminium etc., in India.

Main GHGs that are emitted due to construction are CO2, CH4, HFCs, PFCs, SF and NF etc., . It is noted that the GWP of HFCs, PFCs, SF and NF are very much higher.

Cement is the most consumed construction material in India. India produces around 502 million tonnes of cement per annum and is the second largest producer of cement in the world. Production of cement is responsible for 0.9 tonnes of GHG per tonne of its production. Emission of cement can be reduced substantially by the use of secondary cementitious materials and the use of alternate materials to concrete.

India is the second largest manufacturer of steel in the world at 107 million tonnes of crude steel iron .Process of manufacture of steel involves heating at smelting process during which GHGs are released. Steel Industry releases about 2.50 kg of GHG for every Kg of steel production. Emission due to steel Industry can be reduced by adopting eco friendly technologies in the production and by the use of scrap iron in the manufacturing process.

Aluminium and Glass are also emitting several GHG in to the atmosphere. However Glass and

Aluminium are 100 % recyclable and therefore recycling of steel and aluminium in the production could reduce the emission of GHGs considerably.

India is also the second largest manufacturer of brick in the world at 250 million bricks annually. The process of manufacturing of bricks releases emissions such as CO2,CO,C(PM2.5),NO2,SO2 etc.,. Most of the brisk kilns are coal fired and thus responsible for emissions .Hence bringing brick industry in to the formal sector, encouraging the use of alternative building blocks, adopting technological enhancements and sensitation and training of manpower will reduce the emission due to brick industry.

The construction sector should contribute greatly to the control of emission due to greenhouse gases. The GHG emissivity potential of each construction material especially finished products like steel and cement are very much higher therefore technological enhancement through R&D shall be achieved in order to make them more environmentally sustainable. Alternate construction materials to Cement shall be put in to use by advancing ongoing research.

ID-93

Material Selection for Minimum Carbon Footprint in Structural Design

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Abstract

For quantification of the environmental impact of a project, life cycle assessment is the common and suitable approach, allowing comparison of different design solutions and selection of the most advantageous option. However, as data on environmental impact is typically presented relative to arbitrary reference units, e.g., volume for concrete or tonnage for steel, direct comparison of structural performance versus environmental impact cannot be directly read from the available data. Particularly in the conceptual stages of structural design, material selection should be understood as a multi-objective optimization, where typically a wide range of criteria must be met. These criteria include structural performance such as strength and stiffness, physical properties such as density and thermal conductivity, economic factors such as local availability and cost, and now – in recent decades under the emerging thread of climate change – environmental impact and carbon footprint. For the identification of the most climate-friendly material choice for any given set of structural requirements, the authors propose a systematic approach using graphical representation of the required data of building materials commonly used in structural engineering. Analysed materials include various types of concrete from normal strength to ultra-high-performance-concrete, steel sections and strands, various types of timber, natural stone and industrially manufactured masonry units, as well as fibre reinforced polymers. Presented data is based on a thorough review and selection of life cycle assessment data, addressing gaps of knowledge in existing databases as well as systemic risks in the use of industry-average or product-specific data. With the presented graphical tools for material selection for minimum carbon footprint in structural design, the authors aim to provide the reader with a helpful tool for identification of the most climate-friendly structural solution for their given design problem.

Keywords: structural design; material selection; carbon footprint; global warming potential; life cycle assessment.

1 Article Summary

In the study presented in this paper, the authors adopt a methodology for material selection with graphical representation of materials data [1] and apply it to structural design problems of minimising carbon footprint while maximising structural performance. For this, they compile data on the environmental impact of materials, their structural performance as well as their cost. Based on this database, diagrams (Fig. 1) are developed that are used for systematic material choice matching the design objective, e.g. maximum compressive strength, tensile strength or stiffness (E-Modulus). Various examples are given in the full paper to demonstrate the material selection methodology.

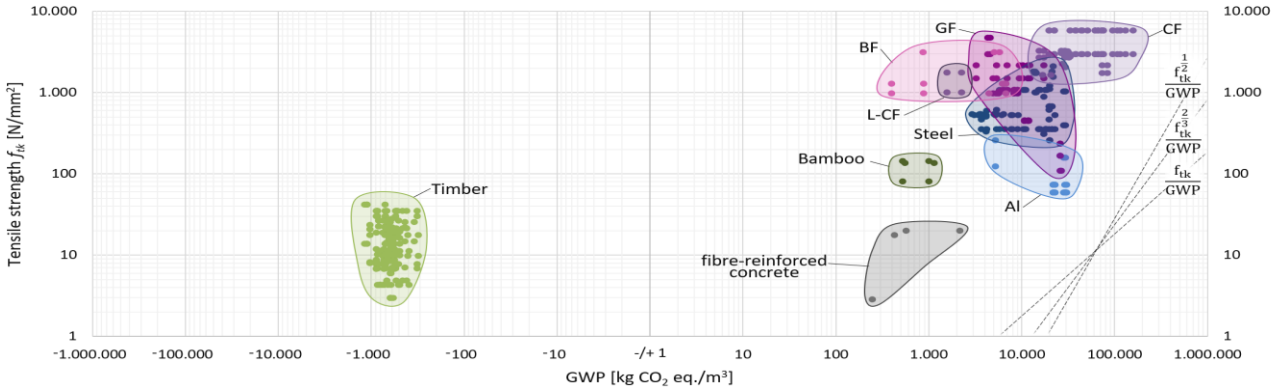


Figure 1. Material chart for minimum carbon footprint and maximum tensile strength f_{tk}

The data collection process reveals, that despite the urgent need to quantify and minimise carbon emissions in construction, data is still incomplete and inconsistent in many parts or not easily and publicly available. There is a need for transparent sharing of emissions data by manufacturers, as well as systematic collection and review of the data by official bodies. The database compiled in this study is also, admittedly, far from complete and should be expanded and improved in the future. The presented material selection approach, however, can be universally applied to materials data from various regions and industries.

The developed material charts illustrate, that natural materials like timber and natural stone, which do not involve significant process emissions in their production and treatment, have a much lesser carbon footprint than industrial materials like steel and concrete. They also show that fibre reinforced polymers can be a good material choice, when their superior structural properties outshine their carbon footprint. Especially heavy materials should be sourced, processed and used locally, as transportation can contribute significantly to a structures environmental impact.

An example showing conflicting design objectives clarifies, that reducing carbon emission does not always come for free but might lead to higher costs in a project. The authors present an approach for solving such optimisation tasks, which requires the designer to put a price tag on carbon emissions. Accounting both for monetary as well as the factored environmental costs, materials with low carbon footprint are more likely to be chosen in the design process. The same principle as in theory applies also in the real-world construction industry. This is why engineers should also acknowledge the role of and support market policies, which are designed to internalise the environmental costs of construction into their monetary costs.

Climate change will be the defining challenge for this generation of structural engineers. In a world, where every percent of emissions leads to higher temperature, extreme weather events and drastic changes to the ecosystems, many activities that we have been accustomed to for many years will have to be adapted. It will require open and inquisitive minds to come up with the best solutions to the many challenges that we will face along this path. Engineers should, however, not despair or give up in the light of this immense task. After all, humans have been building zero-emission structures for many centuries, before they discovered and started to use fossil fuels. They will likewise be able to build them, if and when the era of fossil fuels comes to an end.

2 References

[1] Ashby MF. Materials Selection in Mechanical Design. Elsevier 2011.

ID-121

Experimental Analysis on The Sustainable Effects of Magnetic Water In Self Compacting Concrete With Partial Replacement of Constituent Materials

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Abstract

1 Introduction

Self-compacting concrete[1] (SCC) is the concrete that flows through the reinforcements and compacts under its own weight without any external compacting forces. A well graded SCC is highly flowable in nature which aids to its filling ability, passing ability and resistance to segregation. In recent years a variety of materials have been used to partially replace the constituent materials of SCC and have been tested so as to make the mix more sustainable - both in monetary and environmental aspects. In this experimental analysis we intend to test the SCC mix made with Magnetic Water[2] in which cement is partially replaced with Flyash[3] at 10, 20, 30, 40 & 50% while sand is replaced with Copper Slag[4] at 10, 20, 30, 40 & 50% and Glass Powder[5] at 5, 10, 15, 20 & 25%.

1.1 Magnetic Water

Magnetic water is the water which is passed through a magnetic field. The term Magnetic water does not mean that the water has gained magnetic properties. It merely means that the water which is passed through a magnetic field has some of its properties altered. Magnetic water is used in a variety of fields- Medical, Domestic, Automobile, Industrial, etc. Once the water is passed through the magnetic field, the scattered molecules of water tend to align in one direction, which changes the hydrogen-oxygen bond angle from 104.5^{o} to 103^{o} between the molecules which leads to smaller clusters of 4-6 rather than 15-20, thereby improving the waters viscosity making it thin. The usage of Magnetic Water in a concrete mix would improve the durability, compressive strength, accelerate hydration, improve hardened properties and freeze and thaw resistance. For the same water-cement ratio higher workability can be achieved.

1.2 Preparation of Magnetic Water:

The water used in making of MSCC is passed through Permag N406 which has a power of 8000 Gauss. The water is made to pass through the Permag for about 60 minutes so as to induce the magnetic flux and also to maximize the exposure time of the water to the magnetic capabilities of the instrument using a submersible water pump.




Figure 6 & 7 : Preparation of Magnetic Water

2 Mix Design

Since there are no hard guidelines for SCC in Indian Standard Codes the following mixes were prepared in accordance with EFNARC guidelines (2002), I.e, (1)Coarse aggregate < 50% (2)Water

powder ratio 0.8 – 1 (3)Total powder content 400-600 kg/m3 (4)Sand > 40% of mortar (5)Sand < 50% of paste volume (6)Sand > 50% by weight of aggregate (7)Paste > 40% of volume of mix (8)Maximum water content 200 liters.

After careful calculations, deliberation & Trail and error, the following mix ratios were obtained:

Mix	Ratio				
	C	F.A	C.A	W/C ratio	Admixture
SCC	1	1.66	1.66	0.38	2.6%
M SCC	1	1.66	1.66	0.38	2.3%

3 Tests Conducted:

3.1 Fresh Concrete tests:

A. Slump Flow Test (Flowability)

B. T_{50} Slump Flow Test (Viscosity)

C. J Ring Test (Passing ability)

D. L – Box Test (Passing ability)

E. U – Box Test (Filling ability)

Note: CS 50% mix failed.

GP 25% mix failed.

FA 50% mix failed.

3.2 Hardened Concrete Tests:

All the concrete samples were tested for Compressive and Split Tensile Strength on 7, 14 and 28 Days. The cubes and cylinders casted were demoulded after 48 hours of placing them in their respective moulds.

Note: CS 50% mix failed.

CS 40% mix failed in curing.

4 Conclusion:

From the detailed analysis of the results obtained from a wide variety of tests performed on different mixes the following conclusions can be drawn:

a) Due to the use of **Magnetic water** the **workability** of concrete **increased** significantly for the same water-cement ratio when compared to control mix, because of which **9.95%** increase in slump flow was obtained. Which means it can flow into tighter spaces and achieve better coverage, resulting in less energy, material waste and lower carbon emissions, giving better long-term performance and fewer repairs.

b) Using magnetic water in SCC **increased compressive strength** by **12.61%** and **split tensile strength** by **12.91%** when compared to conventional SCC resulting in more efficient use of constituent materials.

c) It was found that **13.04%** of super **plasticizer** dosage was **reduced** by the employment of magnetic water in SCC, which means the **cost** of production can be **reduced** significantly.

d) Due to the use of Magnetic Water in the preparation of SCC in which:

I. **Sand** was partially **replaced** with **copper slag** the **compressive strength** and **split tensile strength** effectively **increased** by **19.45%** and **19.63%** at **30% replacement** for 28 days when compared to conventional SCC.

II. **Sand** was partially **replaced** with **Glass powder** the **compressive strength** and **split tensile strength** effectively **increased** by **14.16%** and **14.47%** at **20%** replacement for 28 days when compared to conventional SCC.

III. When **Cement** was **replaced** with **Flyash** there was an **increase** in **compressive and split tensile strength** for 10% and 20% replacements but did not attain target strengths at 30% and 40%. **20% replacement** gave best results of **17.02%** and **17.31%** increase in compressive and split tensile strengths when compared to conventional SCC and is recommended.

Better results were found in replacing sand with copper slag in terms of strength and economy when compared to glass powder and is recommended.

ID-1160

Water transport properties and Life Cycle Assessment of low-grade fly ash based cementitious materials

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Abstract

In this study, a medium volume of fly ash (35 % by volume of cement) is used to replace cement in mortar to find its impact on durability indicators and the environment regarding greenhouse gas emissions. Four different mixtures were tried in this study i.e., M1 (Control 1 0% FA), M2 (Control 2 0% FA), M3(OPC + 35% FA-1) and M4(OPC+ 35% FA-2). Mixtures were prepared with different water to cement ratios, i.e.., 0.45, 0.50 and constant fly ash replacement level with cement. Sand to cementitious materials ratios for all the mixture was kept 2.2. Different tests were performed to find strength and water transport properties of the mortar mixtures. Since, fly ash is a industrial waste materials, its impact on green house gas emission related to construction materials were also studied. The first part of the present study focuses on the strength and capillary transport of water through mortar which is a function of the w/cm ratio, pore size distribution, and curing period of mortar. The capillary sorption process showed a very complex time-dependent relationship. The absorption rate (sorptivity) and absorption of cement mortar are found at different w/cm ratios and fly ash replacement. Sorptivity of the porous concrete structure provide an engineering measure of microstructure and properties important for the durability of the concrete subjected to various detrimental environment conditions. Various research is being conducted to make concrete more durable. Mineral admixtures also affect the absorption properties of cement-based materials. Sorptivity is more general phenomenon as compared to permeability of the porous medium because it occurs when unsaturated paste, mortar and concrete are subjected to water or air moisture whereas permeability of the structure is the ability to transport fluids through its interconnected pore. Sorptivity is also known as capillary suction, is the transport of liquids in porous solids due the surface tension acting in capillaries of the mortar or concrete structure. Moisture transport in porous media plays a crucial role in the premature degradation of the material through the ingress of deleterious materials like chloride penetration. Cement-based materials are being used worldwide to construct dams, highways, buildings, and other infrastructures. In general, people thinks that cement-based materials have excellent durability, but their durability is a function of the properties of their constituent materials and their content in the mixture and the aggressiveness of the external environment. In this study, fly ash replacement showed a negative impact on compressive strength as well as on the penetration depth and water absorption due to its same particle size as compared to cement. Nawaz et al. stated that the porosity and water absorption of the mixes decreased with the increased amount of fly ash this effect was observed because the fly ash particles are finer than cement. It was found that the pore structure of fly ash concrete provides a greater resistance to chemical attack. Fly ash decreases the pore volume of the fly ash cement-paste as compared to the coarser fly ash. The secondary absorption rate was lower than 85~88% compared to the initial absorption rate for all the mixtures at 28 and 90 days.

In the second part of this study, impact of cement replacement with fly ash was studied. The global sustainability focus is converging towards carbon neutral communities within the next decade and to achieve more environment friendly products and process continues in different sectors i.e., construction sector. Reduction of cement in the production of concrete is one of the biggest challenges to the

construction industry. Production of cement release almost equal amount of carbon dioxide to the environment. So, it is important to curb the usage of the cement in the construction industry without compromising the strength and durability properties of the materials used for the construction. Even a very few percentages reduction of cement usages can create a big impact in terms of sustainability. From the last four decades various research are being conducted to curb the usage. This is only possible with the use of supplementary cementitious materials. Different supplementary cementitious materials i.e., fly ash, silica fume, rice husk, and ground granulated blast furnace slag are being used in concrete to improve its mechanical and durability properties. Since these materials are industrial by product, there usage in concrete not also improve concrete properties but also add to the sustainability.

Among all the mineral admixtures, Fly ash is one of the most popular mineral admixtures used in concrete replacing a substantial part of the virgin cement also reducing the carbon footprint on the environment. Fly ash is a by-product of coal -fired power plants. A large quantity fly ash is produced after burning of coal, close to half of the coal used. Every year approximately 900 million tonnes fly ash is created globally.

As the emissions related to the construction industry are primarily caused by the combustion of fossil fuels, the current study only considers carbon dioxide, nitrous oxide, and oxide methane as the GHG emissions. However, according to the Kyoto Protocol, six categories of greenhouse gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and hexafluoride (SF_6) are subject to regulation. Through conversion using global warming potentials, all emissions are converted to CO_2 equivalent (CO_2-eq) and $kgCO_2$-eq/m^3 of mortar is chosen as the functional unit. The resulting GHG emissions of different mortar types observed in this case study are depicted in Figure 10. According to obtained results, type M3 and type M4 mortar records ~27% reduction of GHG emissions as compared to control mortar mixture i.e., M1 and M2. This is due to the reduction in the cement usage in type M3 and M4 mortar mixture. Since all the materials were readily available locally, the study does not take transportation-related emissions into account. The main factor contributing to the decrease in emissions for mortar mixtures of types M3 and M4 is the fly ash lower emission rate when compared to cement.

ID-1177

Different Strategies for Setting Requirements for Sustainability

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Abstract

The construction industry significantly impacts climate, environment, and society and should consider how best to respond to the present challenges. This paper aims to investigate what requirements clients are setting for sustainability and to discuss what strategies might be more efficient when setting those requirements. The paper draws on findings from screening sustainability requirements in recent tenders for large infrastructure projects. It has been analysed to what extent clients tend to add specific project requirements and focus on collaboration to reduce the project's CO_2 footprint. This is supplemented by findings from a case where a client changed the collaboration model to partnering to achieve a more sustainable project. The different strategies have different benefits and consequences, which should be considered in relation to the project context.

Keywords: Sustainability, collaboration, innovation, requirements, carbon reductions.

1 Introduction

The construction industry has a huge impact on our society and environment. It is recognised that the professionals in the industry have much knowledge of how to build cleverly and efficiently. Optimisation makes it possible to significantly reduce the amount of material in our projects and substitute with less carbon-heavy materials.

To ensure this knowledge is utilised, clients should consider how to include specific tender criteria and how to set the framework for collaboration and optimisation of the project.

This paper presents a screening of requirements identified in tenders for infrastructure projects. Furthermore, the paper presents a specific case where the client chooses not to set any specific requirements for sustainability but instead focuses on setting the frame for collaboration.

This paper aims to kick-start a discussion: **What requirements can clients choose to intensive the supply chain to make projects more sustainable?**

2 Methods

The screening aimed to understand what clients require regarding CO_2 management and reduction within infrastructure projects in Scandinavia and the UK. All tender documents were targeted towards contractors for major infrastructure schemes. 11 recent bids and project requirements were analysed, and specific requirements were identified.

The case example was an extension of a terminal's quay at a port in Denmark. The client had a strong focus on sustainability, particularly in this case to reduce CO_2 emissions, and therefore set requirements for collaboration and optimisation of the project.

3 Findings

Table 8. Requirements made by clients in tenders to reduce the CO_2 footprint of the project.

Requirement	Included in % of bids
Requirements for parts of the project E.g., Environmental Product Declaration (EPD) or max emission factor for concrete	45%
CO_2 calculations or Life Cycle Assessments (LCA) of the full project but without target	45%
CO_2 targets for part of the project E.g., max emission factors on Concrete	27%
Targets for the full project E.g., fixed carbon budget or target for x% reduction	45%
Requirements to energy used to drive machinery. E.g., HVO or electric machinery for machinery under xx tonne	63%
Requirements for the process E.g., partnering contract or innovation process	36%
Requirement to sustainability certification of the project E.g., BREEAM Infra class xx	27%
Economic incentives for reducing carbon. E.g., xx DKK per saved tonnes CO_2	18%

The screening showed that all tenders included in the screening had some degree of requirements included to reduce CO_2.

This means that of the 11 projects, only 1 project neither had any requirements to a full CO_2 calculation for the project nor had set a target for the full project.

89% of the identified requirements could be measured or documented (everything but the process requirements). 11% of the requirements were set towards enabling more collaboration or innovation.

3.1 Case: Collaborate to reduce CO_2 emissions

The client strongly focused on reducing the CO_2 emissions from materials and construction processes. To this end, it was decided to use a partnering contract with the main partners (the engineer and the contractor) and use open-book accounting. The partners were selected based on overheads (20%), personal references (30%), and organisation and collaboration (50%), the last two with a specific focus on sustainability.

"We had initially hoped for a 10-15% reduction of CO_2 if it went well" (Client 2). The project resulted in a 40% reduction of CO_2 emissions compared to the reference design, a significantly stronger quay than prescribed, and the project was delivered on time and within budget.

4 Conclusion

Based on the screening of CO_2 requirements in tenders and a case example, it was highlighted that the clients shouldn't be afraid to set requirements to CO_2, as this is quickly becoming the norm. This also means that learning from project to project is not a sufficient pace of learning. More cross-industry analysis of tender requirements and their impact is needed.

Setting specific requirements is suitable when the client has extensive knowledge within the area and knows what is needed. Setting the frame for collaboration is. However, a good strategy when the client does not have the knowledge to set specific targets or the project complexity makes it difficult to specify targets.

ID-1212

Steel Fibre Reinforced Concrete for Sustainable Construction

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Abstract

Steel Fibre Reinforced Concrete (SFRC) has gained significant popularity in the construction industry due to its enhanced mechanical properties and cost-effectiveness compared to traditional reinforced concrete. The use of SFRC has increased in recent years in various applications, such as industrial floors, tunnel lining segments, precast elements, and special load bearing structures such as foundation rafts on ground or on piles. The aim of this paper is to provide an overview of SFRC in today's Finnish construction industry, highlighting its benefits but also the challenges. This paper also deals with the sustainability of material, with the efforts that are being made to introduce green steel fibres made with recycled material and their production from green source of energy, which in the end will have less embodied carbon footprint.

Keywords: SFRC; steel fibres; green steel fibres; recycled steel fibres; GWP; sustainability

1 Introduction

Our planet faces multiple environmental challenges and one of this is certainly excessive use of natural resources threating the sustainable development [1]. Use of material such as steel (7...9 %) and concrete (7 %) are big part of CO_2 emissions. To reduce the amount of steel material and to use it even more effectively alternatives to conventional reinforced concrete the steel fibre reinforced concrete (SFRC) has been extensively studied in recent years, and numerous research works have been carried out to investigate its mechanical properties, durability, and behaviour under different loading conditions.

To give a concrete example of material reduction, let's take an example of 3m deep 500 mm thick raft on piles under the road carrying a pipeline is subjected to approximately 125…150 kPa of vertical ULS distributed load. The amount of steel necessary to satisfy all the design requirements, we typically need around 125...150 kg/m^3 of conventional rebar steel. The same structure under similar loading conditions can be carefully designed with a dosage rate of end-hooked high-performance steel fibres of range 40...55 kg/m^3 which makes it roughly 1/3 of conventional steel quantity.

2 Design workflow for load bearing structures

What comes to Finnish market, there's some challenges in using SFRC in load bearing structures. For example, designers, clients and contractors are not familiar with the design process. There's also no common European standard on using SFRC in infrastructure projects. These problems should be solved, with the introduction of design of SFRC structures in next generation of Eurocodes. For now, extensive knowledge needs to be gathered by designer, and communicated to client. Despite the challenges, multiple load bearings structures have already been constructed in Finland, but the availability of common European standards would certainly help in taking more decisions in favor of SFRC solutions.

Once designed and approved, the execution before and on site needs to be carried out carefully. Here the key players are fibre manufacturer, concrete plant and contractor. There's not much experience in Finland regarding testing, casting and quality assurance of SFRC in

Finland, although national standards and instructions are available.

3 Case study

Table 2. GWP impact of different options.

Option	A1...A3	A4	A5	A1...A5
	[CO_2e-tn]			
0	638,0	7,5	12,3	657,8
1	578,7	7,5	12,3	598,5
2	601,7	7,2	12,3	621,2
3	542,4	7,2	12,3	561,9
4	512,4	7,2	12,3	531,9

4 Sustainability potential of SFRC

The fundamental effect achievable with utilizing SFRC is reduction in steel quantities, or even getting rid of all bar reinforcement. This inherently means reduced exploitation of non-renewable resources, i.e., mining of iron, and impacts related to steel production, e.g., climate impacts. In addition, the reduction in quantity can lead to decreased cost. For example, in case study, SFRC solution was 35 % cheaper.

Another interesting aspect of utilization of SFRC, compared to traditional RC, is that there's no need to install the reinforcement. This means avoiding one whole construction activity on site, leading to reduced labour cost, and even potential improvements of project schedule. Here's also potential safety aspect, especially in deep excavations, as the work done in dangerous conditions is minimized. Further, this also adds to potential cost savings, as the dimensions of excavation can be smaller.

ArcelorMittal, one of the major steelmakers in the world, has developed two years ago a fully new steel, named XCarb®, made of recycled steel and using exclusively renewable energy, and this included the brand new XCarb® Steel Fibres. The steel fibres allow to reduce the global CO2 footprint when used in a concrete structure, and this contributes to the decarbonization of the construction projects. [16]

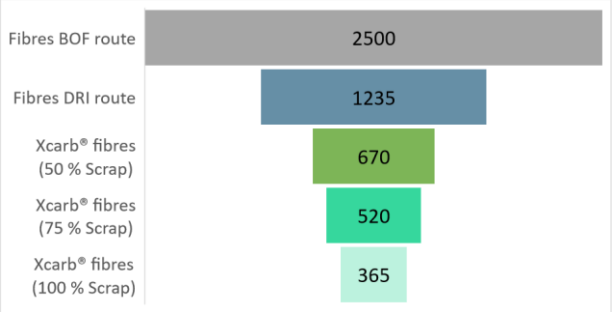


Figure 18. ArcelorMittal XCarb® steel fibres solutions. [16]

XCarb® Steel fibres are produced from wire rods made of recycled steel only, so following the Electric Arc Furnace route (EAF), whereas the standard way to produce the wire rods is the Blast Oxygen Furnace route (BOF) which is using iron ore and carbon coke that are melted to obtain steel. BOF route uses substantially more CO2 than the EAF route.

GWP value of 100 % recycled XCarb fibres is 365 CO2e-kg/tn. Replacing general Finnish data for fibres with this, option 4 can be developed from option 3. Results calculated in ZeroInfra are presented in table 2. In option 4, emission reduction would be 19 % compared to option 0 and 11 % compared to option 1.

5 Conclusions

For example, in load bearing foundation rafts on piles, SFRC can be used code-compliantly, even in the future Annex L from the upcoming new Eurocode 2, whilst achieving reduction in emissions and cost, and potentially even improving the safety and schedule in project, with no identified disadvantages compared to traditional RC solution. Material with this kind of potential to be holistically sustainable should be used, where suitable.

Despite its advantages, SFRC still faces some challenges, such as the lack of standardization. However, with the advancement of technology and the growing demand for sustainable and resilient infrastructures, SFRC is expected to play a significant role in the construction industry in the coming years.

Session-6

Heritage Structures

ID-16

Methods for Ensuring the Sustainability of Steel Heritage Bridges

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Abstract

This paper describes the results of the NAKI II project of the "Methods for Achieving Sustainability of Industrial Heritage Steel Bridges" which has been carried out over the last 5 years. It deals with the diagnostics results presents the overview of the load tests done and assessment results, including the coating application. The strengthening methods are presented, with the focus on the SMA materials. It is shown, that we have still many hidden reserves in the load capacity of heritage bridges, and if proper methods are chosen, the durability can be much longer, then predicted 100 years.

Keywords: Industrial heritage, steel bridges, load test, fatigue.

1 Introduction

Bridges are part of every route, whether for rail, highway, cycle or pedestrian traffic. They are large structures that complement the landscape or urban character of cities. The second half of the 19th century brought a boom in railway transport in the Czech republic. It was at this time that many railway bridges were built. They were stone or brick bridges with small spans. For larger spans, steel bridges were made. Some of them are still in use today. Mostly they are found on local lines or less frequented routes.

Approximately 400 bridges are protected, four bridges are national cultural monuments and others within urban heritage protection areas. However, age has left its mark on many bridges, particularly in the form of corrosion or the development of cracks. Many valuable metal bridges are not listed and, as a result of their rapidly declining physical integrity, an important footprint of our nineteenth and early to mid-twentieth century industrial heritage is in danger of being irretrievably lost. These bridges have fulfilled their purpose in terms of their required service life, but by no means all of them can be replaced by new bridges. From the point of view of preserving our industrial heritage, it is, on the

other hand, desirable to conserve at least some of them, and to maintain them in a worthy condition. An example is shown on the Fig. 1.



Figure 17. Bridge in Skochovice

In many cases, these are beautiful and unique structures that are no longer commonly encountered in the contemporary world. They are the pride of our bridge engineering from the Austro-Hungarian period and from Czechoslovakia before WWII. The high level of expertise of the engineers of that time, the extent of developed industry, and the quality of work in the production and construction of steel bridges were the prerequisites for the fact that some of these bridges have survived until now. It is, therefore, our duty to preserve this industrial and cultural heritage to an appropriate extent for future generations. However, this means that we must take care of selected representatives of old steel bridges so that they can serve their main purpose – carrying traffic, albeit with some restrictions in usage, for several decades to come. Steel bridges that came into service 100 years ago and earlier do have a different structural design compared to modern bridges. The main characteristic of old steel bridges is the practice of riveting. Individual members that could not be made by rolling were at that time made by riveting. Even the joints in the main structure were riveted. It was not until the second half of the 20th century that welding technology became customarily used in the construction of steel bridges.

In order to maintain the functionality, safety, and protection of these structures in the face of increasing traffic volumes, it is necessary to develop new methods of survey, assessment, and strengthening of these structures. Therefore, from 2018 to 2022, the Ministry of Culture of the Czech Republic supported project DG18P02OVV033: The Methods for Achieving the Sustainability of Industrial Heritage Steel Bridges.

In cooperation with the National Heritage Institute and the operators of railway and road infrastructure, the project developed methods and technologies for the surveying and assessment of historic cast iron and steel structures, with a focus on failures due to corrosion and fatigue. Non-invasive and reversible strengthening procedures for elements and joints, new technologies for surface treatment of historic bridges, and innovative corrosion protection systems using nanotechnologies were developed. Technical inspections of steel bridges were carried out as part of the project, following the results of the comparative mapping of industrial heritage.

The multidisciplinary project is based on the cooperation of leading experts from the Faculty of Civil Engineering, Faculty of Architecture (including the Industrial Heritage Research Centre), Faculty of Mechanical Engineering, and the Klokner Institute of the Czech Technical University with experts from the National Conservation Agency.



Figure 18. Book cover "Methods for Achieving Sustainability of Industrial Heritage Steel Bridges

The critical catalogue, Fig. 2, is the result of this five-year period of research, and recapitulates both its results and the state and outlook of historic riveted bridges in the Czech Republic.

ID-123

Revitalization of the historical bridge over the Mała Panew River in Ozimek – the oldest chain suspension grey cast iron river-crossing on the European continent

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Abstract

Renovation methodology applied to protect the historical chain suspension bridge made of grey cast iron and erected in the years 1825-1827 over the Mala Panew river in the vicinity of Opole is presented and discussed in detail. This bridge crossing, of unique structure, is currently recognized as the oldest cast iron suspension bridge erected on the European continent (excluding British Isles). Special attention was paid to analyse the weakening of main bearing components induced by gradual degradation of the material properties during their extremely long service time. Replacement of several worn out and cracked links in the bearing chains proved to be necessary. As a result of the conducted works the bridge has been sufficiently strengthened and due to that protected against the detrimental influence of possible vibrations. All joints have been renewed and cleaned as well. Currently the bridge is accessible only for pedestrian traffic of limited intensity.

Keywords: cast iron; suspension bridge; renovation; revitalization; material weakening; load chains; cracked links.

1 Introduction

The royal "Malapane" steelworks in Ozimek near Opole was founded in 1793/1794. Already at the end of XVIII century it became known for making cast iron structural bridge elements. In 1824, due to the changes in water levels on Mała Panew River, a need arose for a modern dam. It was to supply sufficient quantity of water to the Works to power mechanical devices. Two new bridges had to be erected over the channel leading to the Works. These were made of grey iron based on well-known and tested structure. The royal machine master Karl Schottelius, who at that time supervised the machine shop at the Works, designed the bridge and supervised its erection [1]. This bridge survived till our times and constitutes the object of analysis presented in the paper (Figure 1). The bridge was finished in 1827 and this date can still be seen today on the beams crowning both pylons.

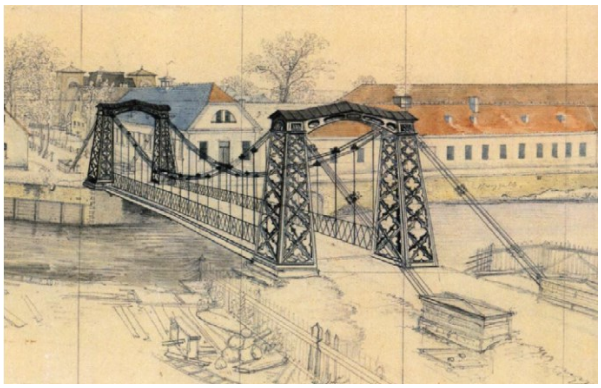


Figure 1. Bridge in Ozimek in the 1st half of the XIX century – a litograph by Knippel.

2 Evaluation of the technical condition of the bridge

The inspections conducted on the bridge in 2006-2008 revealed, that its technical condition constitutes a direct threat to the safety of users [2]. This was a result of damages to the pylons, abutments, bearing cables, hangers suspending the deck and the deck itself, as observed during inspections. Advanced structural deterioration induced by corrosion has been observed in main bearing structural elements of the bridge. Usually this was a result of insufficient maintenance. Maintenance was lacking during wars, it has also been neglected during the post-war period, when the bridge lost its original importance as a river crossing. In many spots, especially those critical for safe load transfer, the initially applied rust protection was completely chipped away. The destroyed covering over pylons in practice did not prevent the progress of corrosion. The rainwater, at leaky coverings made of partially rotten timber, accumulated easily in the anchorage niches.

3 The bridge after renovation

Before reassembly of the bridge both abutments have been thoroughly renovated. The loose topmost external layers have been replaced, while the filled cavities have been strengthened with reinforced concrete cappings fastened to the base with steel anchors embedded in epoxy resin. Bearing footings with bearing blocks were formed on the top parts of the abutments. The fractures in pylons have been fixed by traditional cast iron repair method. This method guarantees the full strength of the material without leaving permanent traces of the repair in the fixed elements. Both pylons, after cleaning, received a new rust protection treatment. The so far existing, leaky roofing protecting the horizontal transverse openwork beams crowning both pylons has been replaced as well. The renovation of the dismantled chain links and joining elements comprised of cleaning, straightening and applying a new rust protective coating. In the case of very advanced degradation, these segments have been replaced with purpose made new ones. These elements have been replaced as well, when the magnitude of deformation precluded effective straightening. The components of joints between chain links, exhibiting defects in material have also been replaced. The anchoring blocks of both load bearing cables have been renovated as well, and the protective niches of these blocks have been covered with new watertight caps. Particularly large changes affected the deck of the bridge. The timber stringers used so far and replaced many times during the life of the bridge have been replaced with steel stringers made of rust resistant steel. All the bolted joints after reassembly of the bridge have been kept in their original form, that is with square headed bolts. During the renovation works on the bridge, following additional static and strength analyses it had been found out, that the bearing capacity of the existing structural cables is insufficient. Therefore these cables have been strengthened with additional steel lines.

4 Concluding remarks

The renovation procedure described in the paper fits into a broader discussion on the effective restoration of historic buildings made of grey cast iron to modern use. In such situations special attention and care has to be paid, taking into account atypical properties of the structural material, and in particular its susceptibility to brittle fracture.

5 Selected references

[1] Juros J.T. Suspension bridge from Royal Prussia “Malapane” Steelwork in Ozimek (in Polish), *Wiadomosci Konserwatorskie*. 2007; **22**: 106-108.

[2] Grabowski L., Jakiel P., Farbaniec P., Gerlich A., Widera K. and Szymanski P. *Technical documentation of the renovation (construction and conservation) of the historic suspension bridge over the Mala Panew river on the Hutnicza Street in Ozimek* (in Polish). Opole; 2008: 74 pages.

ID-311

Femtosecond Pulse Laser Cleaning for the Preservation of the Sydney Harbour Bridge

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The Sydney Harbour Bridge is a heritage-listed bridge located in Sydney, New South Wales, Australia, and is made of a steel arch flanked by massive granite-clad pylons on each side of the shore. It is considered a national and international icon and is a vital part of Sydney's transport infrastructure with more than 200 trains, 160,000 cars and about 2,000 bicycles crossing the Harbour every day. The maintenance of such a structure is a monumental undertaking, and the current conservation work involves sandblasting. Many restrictions and challenges make the process difficult.

Current conservation work involves sandblasting dirt, rust, and the existing paint, and applying new paint to protect the structure. However, the iconic Bridge arches hide 7.2 km of tightly confined tunnels with perforated bulkheads every 18-m that are inaccessible to humans and where sandblasting is impossible due to the large dust loads. Restricted operating space, changes in orientation, visibility, and transport of the removed material are all serious challenges here. Traditional sandblasting is not suitable inside the channels because it creates a lot of dust in the confined space that makes it impossible to see the cleaning in progress and is hard to remove. A further need is to remove staining from the granite pylons of the Bridge in such a way that future soiling rates are minimised, thus reducing cleaning frequency.

Cleaning with laser light has become a popular technique for the removal of unwanted surface layers. Nanosecond pulse lasers are the most widely used, and already commercially available with portable units deployable on-site. Those lasers offer various benefits compared to more conventional cleaning methods like sandblasting, such as avoiding the use of abrasives and eliminating problems of chemical toxicity, corrosive residues, and erosion or loss of surface detail. However, those lasers rely on thermal mechanisms of ablation, which generate heat and shock waves that can result in undesirable side-effects such as melting, formation of cracks, exfoliation of flakes from the surface, and annealing/softening of thinner sections of the bulk material.

Femtosecond pulse lasers offer a remarkable alternative to nanosecond pulsed lasers and provide an effective solution to these problems. The non-linear nature of the interaction with materials results in a process called 'cold ablation', meaning no or very limited heat transfer to the material. The physical reason is simple – the electromagnetic energy of laser radiation is deposited into the material so fast, that electrons, which absorb the energy from the laser field, have no time for transferring their energy through collisions to the ions. As a result, a very thermodynamically nonequilibrium two-temperature condition occurs where electrons are heated to a very high temperature above the ionisation level while the ions are still cold. As a result, the mechanism of removal of ions from the surface is changing to a non-thermal, electrostatic regime of ablation. Thus, laser ablation with powerful femtosecond laser pulses eliminates

heat-related effects on the materials such as charring, surface melting, cracking, and chemical modifications.

The Sydney Harbour Bridge is a unique case study for the development of femtosecond pulse laser cleaning. The range of contaminants to be removed includes paints, spray paints (graffiti), dirt, biofilms, and rust. We explored the cleaning treatment of the steel from the arch and of the Australian Moruya granite, made of quartz, plagioclase, potassium-feldspar, biotite, and hornblende, used in the cladding of the pylons. The effects on the treated surfaces and the cleaning efficiency were assessed using multiple analytical methods including optical and scanning electron microscopy, profilometry, and Raman and FTIR spectroscopy. We demonstrate efficient cleaning results in a damage-free treatment, illustrating the significant advantages of femtosecond pulse lasers for the maintenance and preservation of assets around the world.

There is an obvious question about the indication of the completeness of the cleaning process in case the ablation threshold of the material to be removed is higher than that underlayer to be preserved. The way to control the laser removal of surface contamination, and particularly – when to terminate the process, is still under investigation with Sydney Harbour Bridge samples. However, the most successful way to determine the stopping moment is through monitoring of atomic and ion line emission spectra from the laser ablation surface and ablated plume, so-called laser-induced breakdown spectroscopy (LIBS).

Finally, we discuss the need of developing a portable femtosecond laser unit for cleaning historical monuments. It involves a multi-step process that requires careful consideration of the cleaning needs, laser parameters, design, safety protocols, testing, and deployment. In the case of the Sydney Harbour Bridge, the deployment of a femtosecond pulse laser cleaning unit could be an ideal solution for addressing the different challenges of undertaking such a massive endeavour.

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ID-319

Conservation of Caves Cut in Volcanic Breccia, Jogeshwari, Mumbai

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Abstract

Ancient trade routes connecting the western coast of India to the east coast along Sapura and along north south routes along the Western Ghats boasts of some of the most magnificent works of cave architecture and includes the world heritage sites of Elephanta, Ajanta and Ellora. Much of the work, which has survived the vagaries of time, was chiseled in the basalt of the Deccan plateau. Surrounding the stable rock formations, one finds many caves or features of caves carved out in volcanic breccia or tuff. Kanheri, Mandapeshwar, Jogeshwari, are some of the sites in Mumbai where many crumbling caves/ features carved in volcanic breccia survive at the periphery.

Rock-cut cave architecture in India is a significant cultural heritage that showcases the country's architectural and artistic achievements. These rock-cut structures were primarily built between the 3rd century BC and the 12th century AD and were used for various purposes such as temples, monasteries, and residences.

One of the challenging aspects of building rock-cut caves is the varied rock conditions in different regions of the country. One such challenging rock condition is the volcanic breccia, which is a type of rock formed from volcanic ash and debris.

Volcanism is an important geological process that has shaped the Earth's surface and played a significant role in the evolution of life. India has a rich history of volcanic activity, with several volcanic provinces located across the country. The Deccan Traps is one of the largest volcanic provinces in the world.

Deccan Traps, volcanic tuff, and volcanic breccia are all types of volcanic rocks, but they have different origins and characteristics. Deccan Traps is composed of basaltic lava flows, volcanic tuff is composed of consolidated volcanic ash and other pyroclastic materials, and volcanic breccia is composed of consolidated volcanic fragments that have been ejected during explosive volcanic eruptions.

Jogeshwari caves (5th century CE) marks the transition from Buddhist rock-cut to Hindu rock-cut architecture. It is a predecessor to Elephant and Ellora. Most of the finer features of carvings have not been able to survive thanks to the softer and erodible volcanic breccia. Further complicating the conservation effort is the reinforced concrete retrofits done in the earlier part of the 20th century and the drains emanating from the informal settlements, which had proliferated around the caves.

The study of cave typology is important for several reasons. Firstly, it provides insights into the history, culture, and art of the people who created and used the caves. It also helps in understanding the technical skills and knowledge required to excavate and carve the rock, as well as the tools and techniques used in

the process. Moreover, the study of cave typology helps in understanding the evolution of architectural styles and their regional variations.

The Jogeshwari Caves in the city of Mumbai are a particularly important site for the study of cave typology. These caves are located in the Western Ghats, a UNESCO World Heritage Site known for its rich biodiversity and geological diversity. The Jogeshwari Caves are one of the few surviving examples of rock-cut architecture in Mumbai, and provide insights into the history and culture of the region.

The Jogeshwari Caves are also important from an architectural perspective. They are carved out of layers basaltic rock and volcanic breccia and tuff formation, and display a distinctive architectural style that is characteristic of the Western Ghats region. The caves are notable for their elaborate facades, intricate carvings, and well-preserved interiors.

To assess the damage caused by improper conservation measures, thr authors have used a visual inspection, condition mapping and petrographic analysis. Non-destructive testing methods such as ground-penetrating radar and ultrasonic pulse velocity measurements are yet to be conducted. These techniques would help identify areas of weakness or damage, as well as the underlying causes of erosion.

Conservation of such sites require multiple expertise including civil, structural, geological and environmental. The paper outlines the research and documentation process, presents the documentation, which has used representational and analytical tools like BIM; identifies the concerns/ issues and suggests the possible conservation approaches. Strategies and methods developed for conservation of these caves would also lead to a more reliable approach in the conservation of similar sites. The subject calls for further research and awareness within the engineering and architectural pedagogy and profession.

Keywords: rock-cut caves, urban heritage, Mumbai history, archaeology, ASI

ID-344

How an Architectural Gem from 1900 Became "Building of the Year 2020": Alter Wall 2-32 at the Heart of Hamburg, Germany

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Abstract

The listed building complex Alter Wall 2-32 built in 1910 is located at the heart of Hamburg between the landmark City Hall and the canal Alsterfleet tunneled by the railway. During the extensive revitalisation and structural expansion the historic building substance had to be preserved and reused for load bearing as extensively as possible. The listed historic facades were secured by a spatial steel structure, which was reintegrated for load transfer after the erection of the new supporting structure. Behind the historic facades five new basement floors were built under the protection of a deep trough pit withstanding high water pressures and avoiding any but slightest deformation during the excavation process. About 10.000 m² of retail space and around 18.000 m² of office space were created. For these efforts the planning team won the "Building of the Year Award" in 2020.

Keywords: Listed buildings, deformation, trough building pit, diaphragm walls, plug-in girders, multi-layer bracing, spatial steel construction, wooden piles, pedestrian bridge

1 Deep Trough Building Pit

Behind the street-side facades of houses 10-32, five basement floors were added, which were built in the protection of a deep trough building pit.

The building pit had to withstand high water pressures from the adjacent canal and high groundwater level of only approx. 2.5 m below ground level. Interventions in the groundwater balance had to be kept to a minimum because of the partly still existing wooden pile foundations of the adjacent listed buildings and facades.

In addition, the pit was only allowed to exhibit the slightest deformation during the excavation process in order to ensure that the listed facades would not be damaged. Moreover, the directly adjacent underground tunnel system of the railway, which is in active operation, was not to be impaired.

This trough building pit consists of vertical, tight enclosing walls and a horizontal barrier layer, which is present in the construction area due to the natural layer of marl. During the excavation process the remaining earth cover was used as a surcharge for the floating safety of the natural barrier layer.

Diaphragm walls with a thickness of 1 m were built down to a depth of 50 m in the 18 m deep excavation pit on an area of approx. 2.700 m² with a length of approx. 95 m and a width of approx. 28 m in order to securely reach the natural barrier layer of marl.

In order to minimize the deformation of the retaining wall by water and earth pressures the construction pit was braced using a two-layer steel construction made of tubular braces. Multi-layer bracing levels were installed along the excavation depth down to the load-bearing ground. Additional vertical auxiliary bracing was required.



Deep trough building pit with diaphragm walls, multi-layer tubular braces and anchors

During the construction work the adjacent railway tunnel, the listed remaining facades and the listed adjacent City Hall were permanently monitored with the observation method according to Eurocode 7. The essential criterion for the displacement differences is the tilting, which causes constraint in the building part that leads to cracks.

2 Preservation of Historic Facades

The historic listed facades had to be secured using a spatial steel construction, which was integrated in the construction of the new supporting structure for load transfer.

The special construction processes and schedules for the above-ground dismantling of the existing buildings and their interaction with and impact on the securing of the facades of the listed buildings and the underground dismantling of the existing basements during the construction of the building pit had to be taken into close consideration by the structural engineers.

The dismantling that was to take place behind the facade after the facade had been secured had to be planned thoroughly so that the listed facades and the directly adjacent buildings were not damaged.

The integration of the existing facade into the new structure could be proven mathematically based on load reserves (load balance), system reserves and design reserves based on the current standard.

Approximately 6 m are required for the external and internal bracing of the facade by scaffolding and safety towers to absorb the listed facade's horizontal loads.

3 Filigree Pedestrian Bridge

The building is now also accessible from the water side, for which purpose a very slender, filigree pedestrian bridge with a span of approx. 33 m and a width of 3.5 m was built over the canal, which was equipped with vibration absorbers after complex dynamic calculations. Due to the limited space in the inner-city area, the bridge was prefabricated and floated in via the waterway and pushed up using hydraulic presses.

The planning team consisted of Art-Invest Real Estate Funds (project developer), gmp (architects) and GuD Planungsgesellschaft für Ingenieurbau (structural engineers).

ID-357

Femtosecond pulse laser cleaning of Makrana marble and semi-precious stones for the preservation of the Holy Samadh

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Abstract

Laser cleaning has emerged as a promising method for cleaning cultural heritage sites and artifacts due to its precision and minimal environmental impact. In this study, we used a femtosecond pulse laser emitting at its fundamental wavelength of 1029 nm to clean marble surfaces from the Soami Bagh Samadh temple in India and explored the interactions of the laser with various types of semi-precious stones constituting the sculpted inlaid stonework, including jaspers, jade, lazurite, agate, and malachite. Femtosecond pulse lasers offer several advantages, including better precision, less thermal damage, and lower risk of shock wave formation compared to nanosecond pulse lasers.

We investigated the ablation threshold of marble and cleaning of environmental soiling from the stone surface. To evaluate the effects of laser processing and cleaning on the marble surfaces, we used multiple analytical techniques, including scanning electron microscopy, energy-dispersive X-ray spectroscopy, and Raman spectroscopy. We found that no damage was done to the marble under 1.3 J·cm^{-2}. Cleaning did not cause any significant damage to the marble, and, in fact, helped to remove the environmental soiling that had accumulated on the surface over time, with all the dust and superficial dirt ablated from the substrate. The method was also successful at treating angles and complex geometries by carefully rotating the sample in front of the laser beam. Given the successful results of the femtosecond pulse laser cleaning on the marble surfaces of the Soami Bagh Samadh temple, it would be advantageous in a next step to integrate the laser into a portable unit for on-site treatment of cultural heritage sites.

We then investigated the interaction of the laser with the semi-precious stones. We found that no damage occurred on lazurite for fluences up to 1.6 J·cm^{-2}, and the ablation threshold of agate to be at 0.9 J·cm^{-2}, whereas some semi-precious stones such as jaspers were more sensitive and required much lower fluences, around 0.05 mJ·cm^{-2}. Strong discolorations occurred above those values on the semi-precious stones, which may be due to interactions of transition metals with laser irradiation, such as oxidations. These highly undesirable changes seem linked to the laser wavelength rather than the pulse duration. Further research is needed to understand those mechanisms better and find an appropriate solution to preserve those stones during the cleaning treatment.

In conclusion, our study demonstrates the potential of femtosecond pulse laser cleaning as an effective and sustainable method for cleaning marble surfaces of cultural heritage sites. However, additional research is needed to determine the optimal laser parameters for cleaning semi-precious stones, which have lower ablation thresholds than marble and showed strong discolorations with the femtosecond pulse laser. With further research, femtosecond pulse laser cleaning could potentially be applied to a wider range of materials and surfaces in cultural heritage preservation.

Session-7

Sustainability in Transportation Structures

ID-128

Bridge Management Analytics Focused on Sustainability and Economic Growth

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Abstract:

The transportation sector is facing the challenge of sustainable development. Bridge experience failure. Sufficient data is available for analysis and comparison between different bridges. Scares data is available on the contribution of the bridge towards economic growth over the years. Life cycle cost analysis [LCCA] for bridges is carried out before actual construction to decide on the commercial viability of bridge construction. LCCA also needs to reflect the changes in the scenario emerging from dynamic behaviour in bridge structure. This dynamism of the bridge is captured within Global Analytics for Bridge Management [GABM]. GABM is oriented towards fulfilling the objectives of sustainability along with economic growth. GABM has maintained the focus on rehabilitation intervention which helps in the evaluation of the impact on sustainability. Tangible and intangible IRR ensures sustainability is maintained without compromising economic growth.

Keywords: Global Analytics for Bridge Management**,** Unified Bridge Management System, LCCA, Sustainability.

1 Introduction

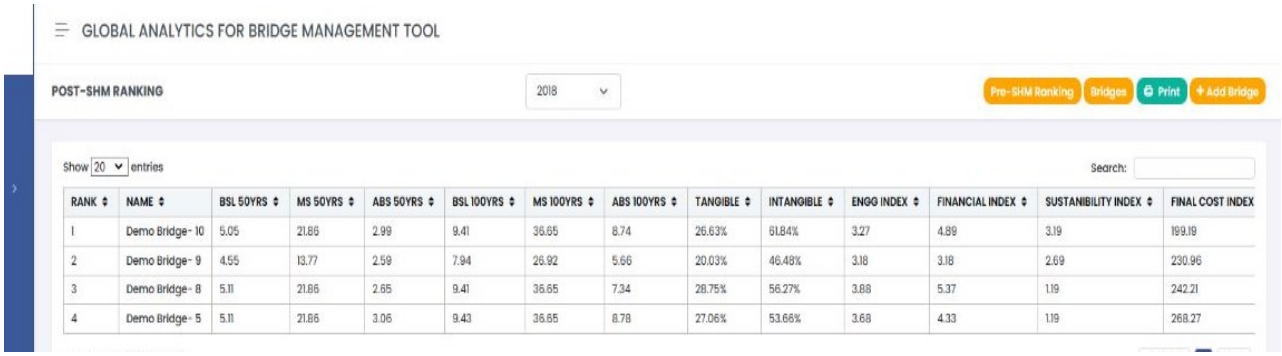
The life-cycle cost analysis (LCCA) approach is used to calculate the overall cost of infrastructure ownership. LCCA includes all costs associated during the life cycle of the bridge. The goal of LCCA is to evaluate the total costs of project and to select a cost-efficient design. To reduce life-cycle costs, LCCA should be performed early during the design process, when there is still time to alter the design. One of the primary objectives of the Bridge Management System [BMS] is to optimize fund utilization by maintaining a balance between sustainable environment and economic benefits of bridge. The application of LCCA provides sustainability management throughout the life cycle. If the advantages of Social, Economic, and Environmental aspects of the bridge project are also considered, LCCA becomes more viable. GABM enables us to achieve the delicate balance between sustainability and economics. This is a major emphasis area for GABM. The research resulted in a system that employs algorithms to optimize fund allocation, manage life cycle costs and ensure sustainability.

This analytics module provides a feasible solution by ensuring bridge infrastructure sustainability without jeopardizing the region's economic growth potential. “Sustainable development of bridge is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs." GABM facilitates the management of the bridge's life cycle while enabling the application of sustainability. LCCA helps to prioritise investments in the assets that need them the most. Sustainability means planning, designing, constructing, and managing bridges that maintain a balance between the three pillars of sustainability: social, economic, and environmental considerations.

Various factors influence the bridge’s Sustainability. Planning is the key to maintaining Sustainability. Regular Inspection and recording of the bridge status is the starting point. From the scrutiny of the historical data emerges clarity about the long-term distress affecting the bridge

structure. Deterioration modelling is possible once these factors are identified. From the deterioration model, the best-suited remedial intervention can be designed. GABM application empowers the user to attain very high standards of Sustainability. The graphical data from the deterioration model provides clarity on this critical aspect to ensure Sustainability. The presence of the Socio-Economic parameter inside GABM records the changing scenario of the social and economic elements as a result of the bridge's existence. Intangible costs and benefits within LCCA calculations, as well as the consequent Internal Rate of Return (IRR) and Benefit-cost ratios, are demonstrated to be more dynamic and realistic in the GABM system. The long-term integrity and safety of bridges rely heavily on their sustainability. The LCCA is a decision-making tool that is notably useful from the time the bridge is designed until the time it is decommissioned. LCCA enables us to prioritise investments on the bridge asset that requires them the most. It also allows for the cost-cutting essential to ensure the bridge's operation for the entire length of its designed service life. A risk-based study is utilised to identify cost-effective expenditures during the conceptualization, design, construction, and entire operational service life of the bridge to ensure optimization. LCCA enables us to avoid the construction of Bridges with high negative impact.

The priority and ranking procedure in GABM determine the priority assigned to a specific bridge among a group of bridges in need of rehabilitation intervention. Numerous infrastructures and services are currently facing challenges, including increased annual maintenance expenses, ageing equipment, and the consequences of climate change. The given reliability-based life cycle analysis of the ageing structures model's main purpose is to fulfil the required performance. This must also consider and guarantee the economic, social, and environmental consequences of various maintenance and safety measures. The use of the LCCA tool to study the costs and benefits during the service life then is applied to the decision-making process. Under GABM, data on a variety of socioeconomic aspects are continually updated. Sustainability emphasis is incorporated into the decision-making process. This strategy also protects sustainability goals. This procedure assures that Bridge meets current needs without jeopardizing future generations' capacity to meet their own. A sustainable Bridge maintains the balance of social, economic, and environmental concerns. We ensure that the different economic and sustainable objectives are met by utilising GABM's Bridge Management Analytics. The main advantage of GABM Bridge Management Analytics is that it can be used in conjunction with any current Bridge Information System/Bridge Management system. Minimum fundamental data record requirements are either accepted from the current BMS or submitted by the user.



RANK	NAME	BSL 50YRS	MS 50YRS	ABS 50YRS	BSL 100YRS	MS 100YRS	ABS 100YRS	TANGIBLE	INTANGIBLE	ENGG INDEX	FINANCIAL INDEX	SUSTAINIBILITY INDEX	FINAL COST INDEX
1	Demo Bridge- 10	5.05	21.86	2.99	9.41	36.65	8.74	26.63%	61.84%	3.27	4.89	3.19	199.19
2	Demo Bridge- 9	4.55	13.77	2.59	7.94	26.92	5.66	20.03%	46.48%	3.18	3.18	2.69	230.96
3	Demo Bridge- 8	5.11	21.86	2.65	9.41	36.65	7.34	28.75%	56.27%	3.88	5.37	1.19	242.21
4	Demo Bridge- 5	5.11	21.86	3.06	9.43	36.65	8.78	27.06%	53.66%	3.68	4.33	1.19	268.27

GABM Analytics provides a comprehensive answer to current challenges in any Bridge Management. Integrating LCCA allows GABM to provide a very comprehensive ranking and priority procedure which is so flexible and with one click can change the preference between three parameters namely Engineering Index, Financial Index and Sustainability Index. An overall impact of all three indexes is incorporated in the Final Cost Index. GABM ensures Sustainability without compromising the potential for Economic growth.

ID- 188

Sustainability and Innovation in Design of Major Bridge Substructures

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Abstract

Major bridge substructures like anchor blocks for suspension bridges and large offshore foundations for bridge towers and piers are generally exposed to very significant loads. Therefore, to achieve sustainable and resilient solutions for design of such structures, careful optimization of material consumption and adaption to the actual boundary conditions are needed. Also, accidental loads like earthquake and ship impact can be important design drivers.

This calls for adaptation and innovation to find sustainable, resilient, and durable substructure solutions which can also be constructed fast and efficiently. This is illustrated by examples from COWI's history of substructure designs comprising a variety of solutions ranging from caissons to pile foundations and open dredged foundations.

Keywords: Substructure; sustainability; caissons; piles; suspension bridge; cable stayed bridge.

2 Introduction

For major bridges especially crossing deep waterways, optimization in the design to reduce quantities and construction equipment as well as construction time is essential.

3 Caisson foundations

Concrete caisson foundations have been used for several major bridge. For the **Great Belt suspension bridge** with a main span of 1624m Bridge in Denmark the foundations for both the towers and the anchor blocks (**Error! Reference s ource not found.**) are based on caissons.

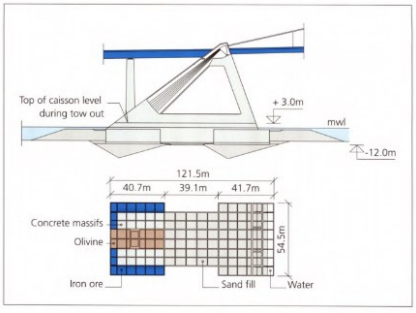


Figure 3-1 Caisson for Great Belt East Bridge anchor block

For the **Osmangazi Bridge** with 1550m main span and the **1915 Canakkale Bridge** with the world record main span of 2023m, the foundations for the towers are based on caissons (Figure 3-2).

For both bridges the foundation comprised a lower part consisting of a large cellular concrete box structure and an intermediate part with two hollow composite cylindrical shafts extending to the waterline and finally two solid plinths connected by a box type cross beam above the water line.

The overall foundation concept is very resilient towards high horizontal forces from ship impact and seismic events since there is no direct contact between the piles and the caisson allowing the caisson to slide.

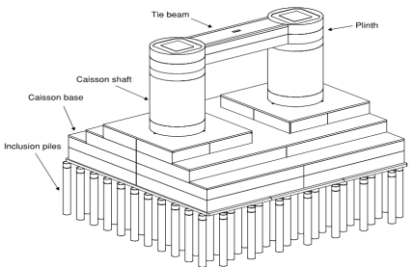


Figure 3-2 Caisson for 1915 Canakkale Bridge

For the **Øresund Bridge** between Denmark and Sweden, having a world record main span of 490 m for a cable stayed combined road and rail bridge, the foundations for the towers are based on caissons. The caissons are mainly ballasted with sand, but also mass concrete to resist local ship impact loads. Due to favourable soil conditions in the form of competent limestone it was decided to use under base grouting instead of placing the caissons on screeded gravel beds.

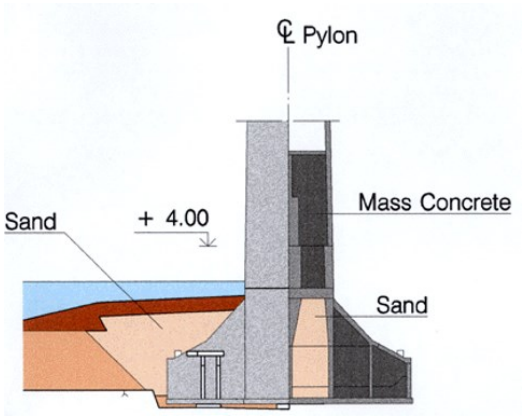


Figure 3-3 Caisson for Øresund bridge towers

For the **Busan-Geoje Link** in South Korea two major cable stayed bridges with main spans of 475 m and 2 x 230 m the tower foundations are based on caissons as shown in Figure 3-4.

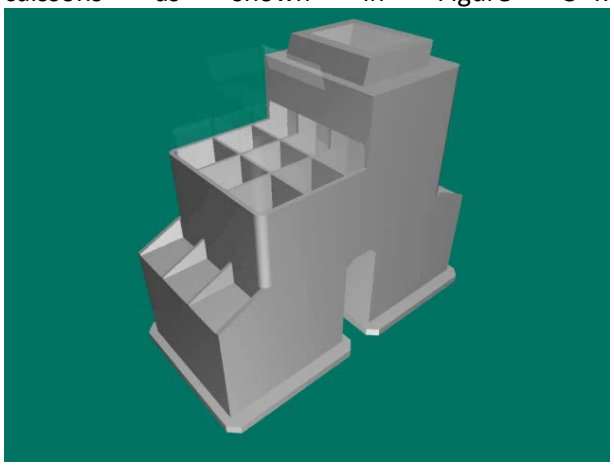


Figure 3-4 Caisson for Busan-Geoje Bridge

The caissons for the 6,000m long **Great Belt West Bridge** with girders spanning 110m have also been installed by a floating crane. The caissons are placed at up to 30m of water using a purpose-built floating crane.

4 Pile foundations

4.1 Prefabricated large diameter piles

For a fixed link between Qatar and Bahrain prefabricated concrete mono-piles with 3.5m diameter are designed. The piles consist of 5 to 8 m long sections which are posttensioned together. The pile is installed in a predrilled hole and the annulus between the wall of the hole and the pile is grouted. The concept has recently been transferred to offshore wind farm foundations.

4.2 Raking piles for deep water piers

The traditional vertical bored or driven piles are vulnerable towards horizontal forces if they have a large unsupported length. Alternative solutions using raking piles have been successful applied for the Busan-Geoje Bridge.

5 Open dredged foundations

For the **Osmangazi Suspension Bridge** in Turkey the anchor block and the side span piers are place on a "guitar" shaped foundation. Excavation is done inside the diaphragm walls.

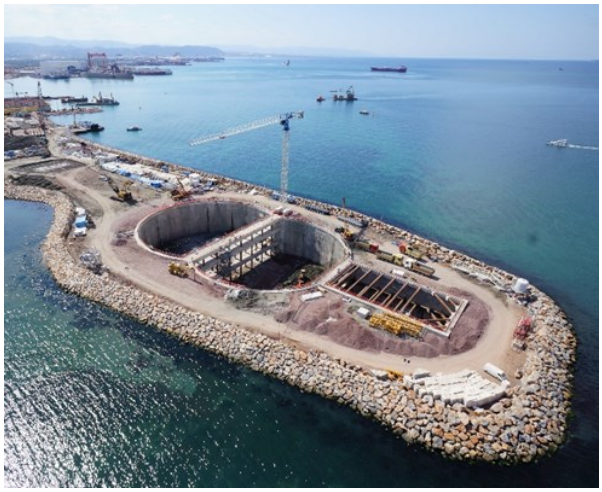


Figure 5-1 Open dredged foundation for Osmangazi Bridge anchor block

Open dredged well foundations used for many major bridges across large rivers in India. For instance, the **Naini cable stayed bridge** has a double D to support the towers.

ID-193

Halsafjorden Suspension Bridge on Floating Foundation. Design and CO2 emission.

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Abstract

Halsafjorden is an about 2100m wide and 490m deep fjord part of the Ferry free E-39 project in Norway. A two-span suspension bridge supported by a Tension Leg Platform is proposed for the crossing. Reducing the span compared to an ordinary long span suspension bridge opens for use of a conventional single box aerodynamic bridge deck, instead of a twin box deck needed for long span suspension bridges. Thus, the overall weight of the superstructure is reduced, while the complexity and material use increase for the substructure due to the floater system. The proposed design covers all relevant loads, including ship impact. Metocean loads were derived from a long-term analysis based on the extensive wind and wave measurement campaign started in 2017 and still ongoing. Wind tunnel test of the deck were performed to obtain aerodynamic input for the analysis. Local FEM analysis was used to verify complex areas of design. The design was done in close collaboration with the architect to secure a visually attractive structure. Offshore foundation design was challenging, but a reliable design was possible due to performing offshore ground investigations. Based on proposed design and construction method and EPD material data, CO2 emission was calculated and compared to reference projects.

Keywords: Suspension bridge; Multi-span bridges; Tension Leg Platform (TLP); Quantities; CO2 emission; time domain analysis.

The structural elements are mainly designed by a combination of static loads such as self-load and traffic, and environmental loads. Self-load and traffic are often well-defined loads, and contribute a lot to the total, while there is greater uncertainty about dynamic effects from environmental dynamic loads. from waves, wind, and currents. The impact of adding a pedestrian and bicycle lane have been assessed.

The design is based on a lifespan of 100 years and is designed in accordance with the Norwegian Public Roads Administration's handbook series, Eurocode and DNV codes for offshore structures. Loads from wind, wave and current is based on an extensive measurement program started in 2017 and still ongoing. The measurement program has also mapped the fjord floor and carried out

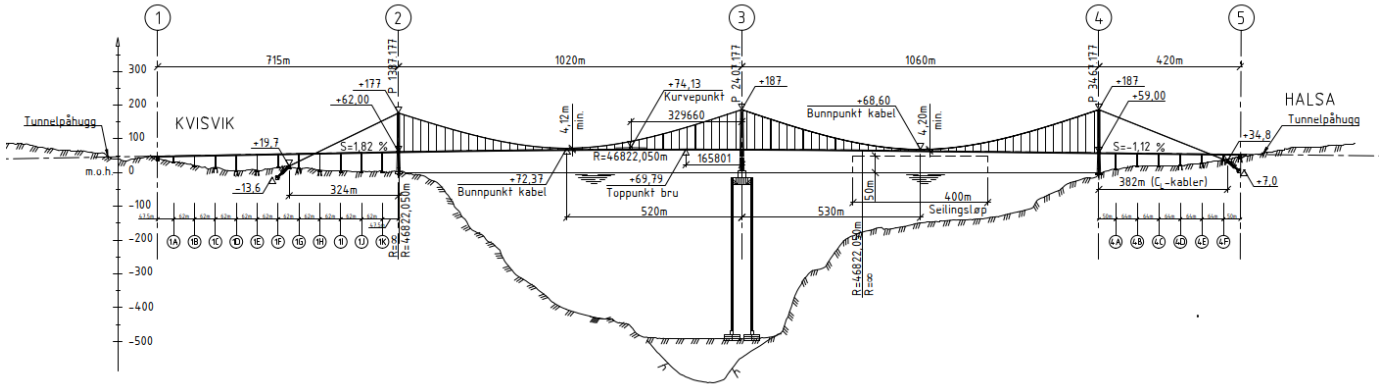


Figure 0-1 General arrangement.

offshore ground surveys so that foundation conditions and the natural load climate are well defined.

The bridge deck is an aerodynamic, wind tunnel tested, steel box girder designed to reduce wind load. Due to low traffic volume the deck without a pedestrian lane is only 12m wide, while the case with a pedestrian lane is 16m.

The towers on land are of concrete and foundations are dry on rock. The towers in the fjord are made of steel to minimize weight, as these stand on the TLP floaters.

Due to challenging ground condition the TLP anchorage was of a gravity type and need to be left for 6-12 months to settle before applying additional load.

Construction method for this bridge follows the same principles as for a suspension bridge on fixed foundations. The special construction sequence is offshore operations linked to establishing the TLP system. The construction time is estimated to 7 years,

The design work led to estimation of quantities within an estimated accuracy of +/-20%. A database of CO2 emission properties based on each materials Environmental Product Declaration (EPD) and necessary transportation distances were established. The calculation shows that material production is the main source for CO2 emission, while transportation only contribute with 4% of the total.

Calculated CO2 emission value can be compared to literature values. E.g., Collings has compiled data of more than 200 pedestrian, railway and highway bridges. Figure 0-2 show highway bridge CO2 emission from this dataset, plotted versus bridge area. The plot shows that the CO2 emission calculated for this structure is a little higher than the dataset trend, due to the more material intensive TLP foundation.

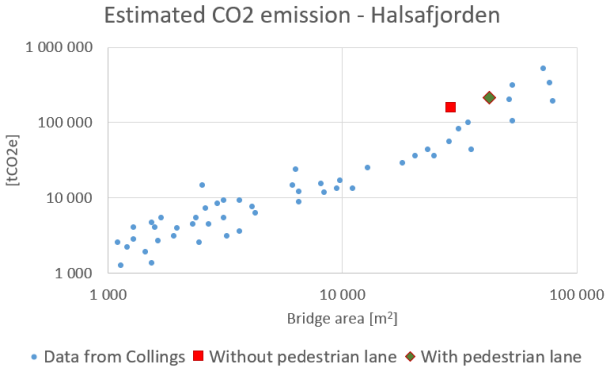


Figure 0-2 Calculated emission pr m² bridge based on emission data for 2023.

6 Acknowledgement

This work has been performed for the National Public Road Administration in Norway by the AMC group, consisting of Aas-Jakobsen AS, Multiconsult and Cowi A/S

ID- 197

A Comparison of The Resource-Efficiency of Different Reinforcement Concepts Motivated by Tunnel Segments

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Abstract

In view of ongoing climate change and the limited availability of resources and energy, efforts in optimizing newly built structures are crucial to improve the resource-efficiency of the construction sector. Tunnels with a segmental lining offer great potential for such efforts. Therefore, the Institute of Structural Engineering at TU Wien developed a reinforcement concept to increase the ultimate load of a tunnel segment by adding butt-jointed reinforcement bars in the longitudinal joint.

To evaluate the beneficial effect of the new concept, cylindrical specimens with varying reinforcement concepts and materials, respectively, were tested at TU Wien. By putting the results on the ultimate load in context with the global warming potential (GWP), the performance of concepts with butt-jointed reinforcement bars and confining reinforcement compared to plain concrete or concrete with steel-fibers is quantified.

Keywords: reinforcement concepts; material input, ultimate load, global warming potential (GWP), resource-efficiency

1 Introduction

The construction sector accounts for a significant share of the world's resource and energy consumption, which has a major impact on the environment. To reduce the sector's impact on global warming, attempts to optimize the use of materials in new constructions play an important role in planning and designing. Nevertheless, in infrastructure projects, the optimization of individual structural elements is rather uncommon, as the structures are characterized by a high degree of individuality. Tunnel structures constructed with a segmental lining consisting of a huge number of identical elements, however, offer great potential in improving the overall resource-efficiency by optimizing the prefabricated tunnel segments. Accordingly, the design of tunnel segments and the longitudinal joint, especially, are subject to ongoing research.

At the Institute of Structural Engineering at TU Wien a reinforcement concept has been developed that allows the load-bearing capacity of a tunnel segment to be increased by installing butt-jointed reinforcing bars in the longitudinal joint. For further technical details on the concept and its application, the reader is referred to [1, 2 and 3]. The longitudinal reinforcement bars of the TU Wien reinforcement concept not only influence the load-bearing capacity but also the resource consumption. Taking this into account, the question arises how the performance of the concept compares to others.

The aim of this paper is to show how the performance of different reinforcement concepts can be compared. Therefore, a series of cylindrical test specimens with varying reinforcement concepts and materials, respectively, are analyzed.

2 Investigations

The test specimens, which had the same external geometric characteristics, differed in concrete mixture and reinforcement layout, ranging from

unreinforced and fiber reinforced via conventionally reinforced to hybrid reinforced specimens (see Figure 3). A total of 14 tests were performed in which a uniaxial compression load was applied in a vertical testing rig.

The resource consumption for the materials employed is calculated using Global Warming Potential as indicator for the environmental impact. GWP data (expressed in kg CO_2- equivalent per declared unit) are taken from Environmental Product Declarations (EPDs). To enable a comparison of resource efficiency – and not only resource consumption – the GWP data is further related to a quantity on the resistance side, for example the ultimate load F_{exp}.

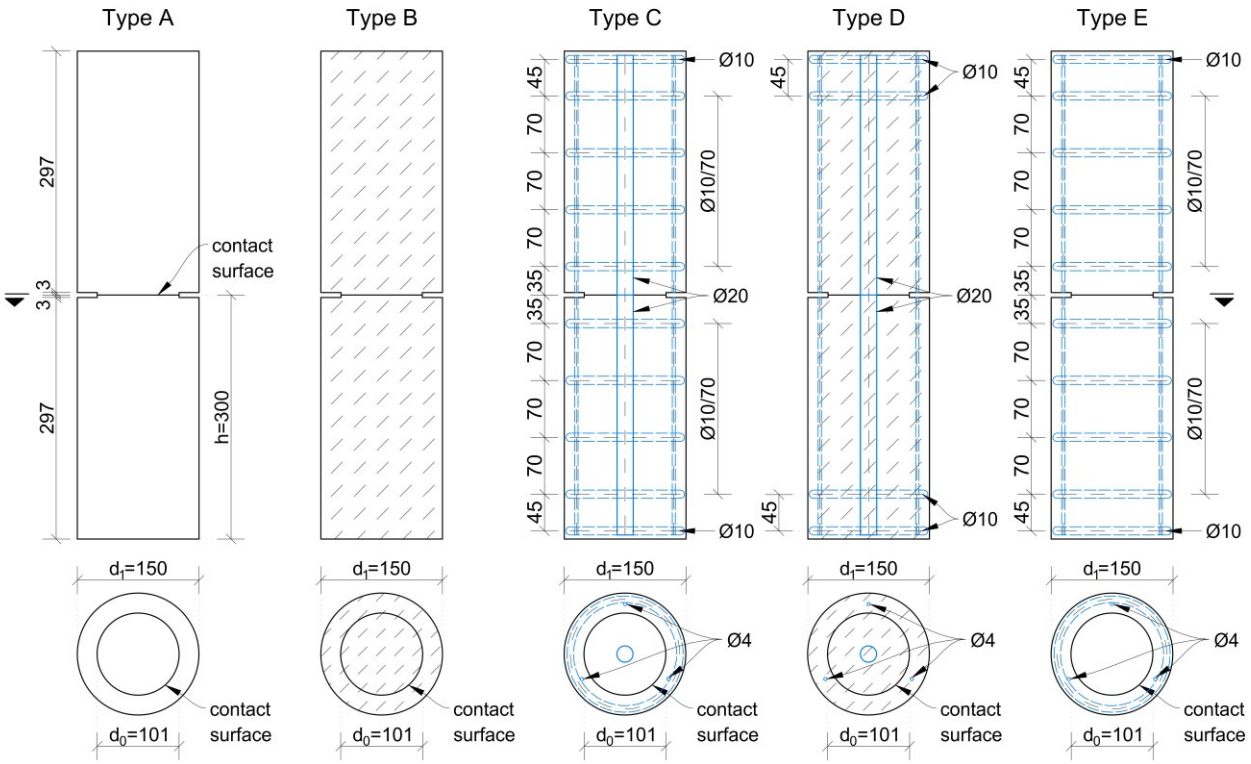


Figure 3. Specimen geometry and reinforcement layout [dimensions in mm]

3 Conclusions

Results on the resource consumption are put into context with the experimentally determined resistances, showing the beneficial effect of confining reinforcement and butt-jointed reinforcement bars. With both concepts a considerable increase of the load-bearing capacity can be achieved with only a moderate increase in resource consumption compared to plain concrete.

References

[1] Kollegger J, Proksch-Weilguni C, Wolfger H, Decker M. *Tübbing aus bewehrtem Beton*. A 50433/2019 (AT patent application), submitted on 14th May 2019.

[2] Kollegger J, Proksch-Weilguni C, Wolfger H, Decker M. *Reinforced concrete tubbing*. PCT/AT2020/060030 (PCT Patent application), submitted on 4th Feb. 2020.

[3] Wolfger H, Proksch-Weilguni C, Kollegger J. Longitudinal joints of tubbings with newly designed high-strength reinforcement. *Structural Concrete*. 2021;22(3): 1708–1719. https://doi.org/10.1002/suco.202000670

ID-551

Environmental Assessment of Road Construction Projects in India: A Novel Approach

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Abstract

India is expected to witness a significant surge in road construction activities in the coming years due to the growing population. However, this could pose a threat to the country's progress in achieving its national sustainable development goals (SDGs) related to the environment and its commitment to the Paris climate agreement. The road sector is one of the basic pillars for national economic growth owing to its role in movement of goods and people across a vast country such as India and can contribute positively towards several sustainable development goals (SDGs). On the other hand, road construction using conventional methods can jeopardize the country's progress towards climate action and several other environmental related SDGs owing to huge raw material requirements, fuel demand and pollution associated with it. The well-known adage, "what gets measured, gets managed," highlights the importance of identifying the environmental impact of different materials, processes, machinery, and stages involved in road construction to develop strategies for transitioning towards sustainable practices with minimal environmental footprint. Life cycle assessment (LCA) is a useful quantitative tool to figure out which products and processes are responsible for majority of road's environmental impact at different stages. However, the use of LCA in road sector in India has been hampered by lack of access to detailed materials inventory data and their environmental characterization factors. Here we propose a novel approach to overcome these limitations by connecting the road's bill of quantity data with publicly available analysis of rates document and India-specific construction materials environmental footprint database. We demonstrate the new approach using a case study on environmental impacts of a 49 km Indo-Nepal border road on six domains of the environment. The environmental impacts per kilometre of the road section came out to be 11.8 million MJ energy use, 702 tons CO2eq. GHG emissions, 6 kg CFC-11 eq. ozone depletion, 173 tons SO2eq. acidification, 20 tons PO4eq. eutrophication and 60 tons ethene eq. of photochemical oxidant formation. Results show that out of 62 materials use, the conventional natural coarse and fine aggregates, Portland cement, steel bars, bitumen and diesel are responsible for majority of impacts. The analysis indicates that road construction activities in India have a substantial environmental footprint, which could negatively impact the country's progress towards achieving various Sustainable Development Goals (SDGs) by 2030. If India aims to improve energy efficiency (SDG-7), it needs to reduce the energy consumption associated with road material manufacturing. The high global warming potential of road construction activities, with about 700 tons of CO2 equivalent emissions per km, contributes to anthropogenic greenhouse gas emissions and could lead to adverse consequences for humans and ecosystems, hindering progress towards SDG-13 (Climate Action) and India's commitments to the Paris Climate Agreement.

The eutrophication potential (0.41 tons PO4 eq./km) associated with the road reflects the release of macronutrients (e.g., nitrogen, phosphorus) by the factories in the surface waters during the road materials production stage causing water body's oxygen levels to dip and making the water unfit for aquatic biodiversity and human use. This has negative bearing on SDG 6 (Clean Water and Sanitation) and SDG 14

(Life Below Water). The acidification potential of the road means the release of acidifying pollutants such as sulphur and nitrogen oxides that lead to negative effects on aquatic life, soil, ecosystems, plants, and even buildings. This in turn has adverse effects on human health and progress towards SDG-3.

Road construction has a high Photochemical ozone creation potential (POCP) due to the production of nitrogen oxides and hydrocarbons which, in the presence of sunlight, can form secondary air pollutants such as ozone, harming human health and plants. Compared to other environmental categories, road construction has a relatively small ozone depletion potential due to lower emissions of chlorinated, brominated compounds, and chlorofluorocarbons, resulting in a lower risk of harm to the ozone layer in the stratosphere that protects the Earth from harmful ultraviolet rays.

Our approach can act as a template for conducting LCA of roads in India in future and the information generated can then be utilized by decision makers in selecting greener alternative materials and technologies to reduce the overall footprint in future.

Keywords: LCA; Roads; India; Environment; Climate change; Sustainability

ID-689

Innovative Box girder having Footpath at Bottom of Box Girder by Cantilevering Soffit Slab

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Abstract

Innovative structural forms for medium span bridges are a challenging effort for bridge design engineers especially in built-up area locations, where social impact plays a crucial role. Box girders are flexible forms compared to conventional 'I' girders, in the sense that they can have curved plan as well as varying shape of cross sections. Padaharam bridge at Alappuzha district of Kerala state is such a bridge planned, designed and under construction with superstructure having walkways/pedestrian way underneath cantilevering box girder. This ensued less land acquisition, environmental and social impact. In this paper, the planning, design, and construction of this bridge are introduced. The cross-sectional features of the box girder, the structural analysis of the superstructure and its constructional techniques are discussed in this paper.

Keywords: Box girder; Land acquisition; National Water Way; High Embankment; Land Span.

1 Introduction

There have been relentless efforts from Bridge Engineers to provide cost-effective structural solutions. Box girders are efficient form of bridge construction because they minimise weight, while maximizing flexural stiffness and capacity.

Waterway transportation play a vital role in Kerala. The 633 m long west cost canal includes the 163km National Waterway-3 (NW3) from Kollam to Kottapuram. This paper presents the design features of Padaharam bridge across Pampa River under construction across the NW3 at Alappuzha having peculiar box girder form for superstructure reducing overall width and the aesthetic features.

2 Challenges in Planning the Bridge

As per the norms of Inland Water Authority of India (IWAI), a vertical clearance of 6m above high flood level and a horizontal clearance of 40m between piers is mandatory for bridges to be constructed across NWW in Kerala. Box-girders are cost-effective for spans range above 30 metres. As a result, there was a demand for constructing high embankment on soft soils for approach roads. Also, the approaches are to be constructed through a built-up area and the presence of the high embankment will create social issues among residents as it divides the local communities. Hence, approach spans were proposed to overcome the above issues.

Hence, to reduce land acquisition and associate social impact, an effort has been made to narrow the overall width (carriage way: 7.5m + crash barrier: 2x0.5 m). Hence, the walkway underneath cantilevering box girder was adopted, in which pedestrian path was placed by cantilevering the soffit slab of the box girder. Several residences of the sides of approach road were preserved due to the adoption of narrow box girder.

3 General Arrangement Design

The entire river width is provided with three spans of 45.0m Prestressed concrete box girder as per the requirements of IWAI. For the superstructure of the land span, three spans of Prestressed Concrete box girders having 35.0m overall length on either side are provided to eliminate the high embankment on soft soil. The span arrangement for the bridge is 3x35 + 3x45m+3x35m. At the abutment points, the walkway blends with the surrounding landscape.

3.1 Geometric Details

The box girder is having an overall width of 8.50 m featuring two webs. The overall width includes 7.50m carriageway and 0.50m crash barrier on either side. The webs are placed vertical having outer to outer dimension of 4.50 m. The footpath is provided at soffit slab location by cantilevering the soffit slab on either side. The walkway position has headroom of 2.50 m and a total depth of 3.10 m is proposed for the box girder. In order to improve aesthetics, a sloping roof that extends from the crash barrier with ornamental columns that resemble Kerala architecture was added to the design. The box girder was prestressed using twelve numbers of 19T13 tendons. To transfer the load from the superstructure to the substructure, pot cum PTFE bearings are provided.

The grade of concrete used for box girder is M45. High yield strength corrosion resistance steel of grade 500/500D conforming to IS: 1786 is considered for steel reinforcement. Pre-stressing steel provided are stress relieved Class II 7 ply strands of low relaxation type conforming to IS: 14268.

4 Structural Analysis

MIDAS Civil was used for the longitudinal and transverse analyses. Whereas IdeaStatica was used to analyse the end diaphragm.

The longitudinal analysis of box girder was done using MIDAS civil finite element software. To model the bridge, beam elements were utilized. The cross section of the box girder is created using general section designer tool in MIDAS civil.

Two lane of Class A loading or Class 70R loading is applied as moving load in addition to the super imposed dead loads and footpath live loads and governing forces and moments of these two is considered for design. The various loads are combined as per IRC6: 2017 for the critical load, and a stress check and design are performed on it.

The segment is modelled transversely to represent a box girder segment for transverse analysis. One-meter length segment is modelled using beam elements. The end diaphragm of the box structure was modelled separately in IdeaSatica finite element software.

5 Construction

First, the reinforcing work for the soffit slab and web is finished after the supporting arrangement and formwork for the bottom slab are put in place. The soffit slab, including the cantilever section, is then cast. After setting up the web's and diaphragm's formwork, the web and diaphragm is then cast, not later than four days after the bottom slab was cast. After casting the web and diaphragm, formwork is placed for the top slab and reinforcement work is completed. The top slab is cast no later than seven days after the web and diaphragm. After 28 days following the casting of the top slab, prestressing is completed. The staging and supporting setup are taken down after prestressing. Following that, the casting of the crash barrier, handrail post, ornamental works, etc.

6 Conclusions

An innovative concept of box girder by providing footpath at soffit slab location is presented in this paper. The challenges faced during planning stage for arriving the form of box girder were first presented. The structural analysis of the superstructure was then introduced in detail. key points of the construction of box girder were also discussed. It is the belief of the authors that walkways underneath cantilevering box girder will help to narrow the superstructure compared to the conventional one and which will in turn reduce the land acquisition in built-up areas.

Session 8

Case Studies in Sustainable Materials,

Technology and Practices

ID-117

Innovative solution for an Extradosed Bridge over River Beas in Hilly Terrain of Himalayas

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Abstract

Road Network of Himachal Pradesh, a northern state in India requires number of long span bridges across valleys and rivers due to its hilly terrain. One such bridge across river Beas at Hanogi has a total length of 119.2m. Proposed span arrangement at the location of this bridge is 97.2m + 22m. National Highway (NH-3) runs perpendicular to the bridge. The bridge is located in a constrained location with approach road on one side and a hillock with NH-3 at its toe on the other side. It was proposed to build an extradosed bridge of span 97.2m with pylon only on abutment A2 side and back stay cables anchored in hillock formed of rock.

This paper presents design aspects of the extradosed superstructure and cables, back stay anchors, Abutment A2 and staged construction analysis. The construction of the bridge is carried out by cantilever method with form traveler. This paper also covers construction methodology of the superstructure, ground Improvement and stability check at abutment A2 and Hillock where the stays are anchored.

This is one of the unique extradosed bridge where long span on one side is supported by cables on single pylon and back stay cables are anchored to the rock.

Keywords: Extradosed Bridge, Rock Anchored, Ground Improvement, Cantilever Construction.

1 Introduction

The proposed bridge connecting the remote Seraj area with the National Highway – NH3 is the state of Himachal Pradesh's first extradosed bridge. Built at a cost of approximately 25 crores (USD 3 Million) this bridge will benefit more than 25 thousand people by reducing the travel distance by approximately 50 to 60km. The bridge was inaugurated and opened to the public on 28th Sep. 2022.

This paper discusses the unique structural form and innovative design and construction aspects adopted for the extradosed span of the bridge.

2 General Arrangement of the Bridge

The location of the bridge has a constraint with NH-3 across the bridge alignment, at the toe of a hillock and it was required to have a span of about 95m over the river. The concept finalized in coordination with the contractor is shown in the general arrangement sketch (Figure 1). The total length of the bridge proposed was 119.2m with two spans of 22m and 97.2m as shown in Figure 1 below.

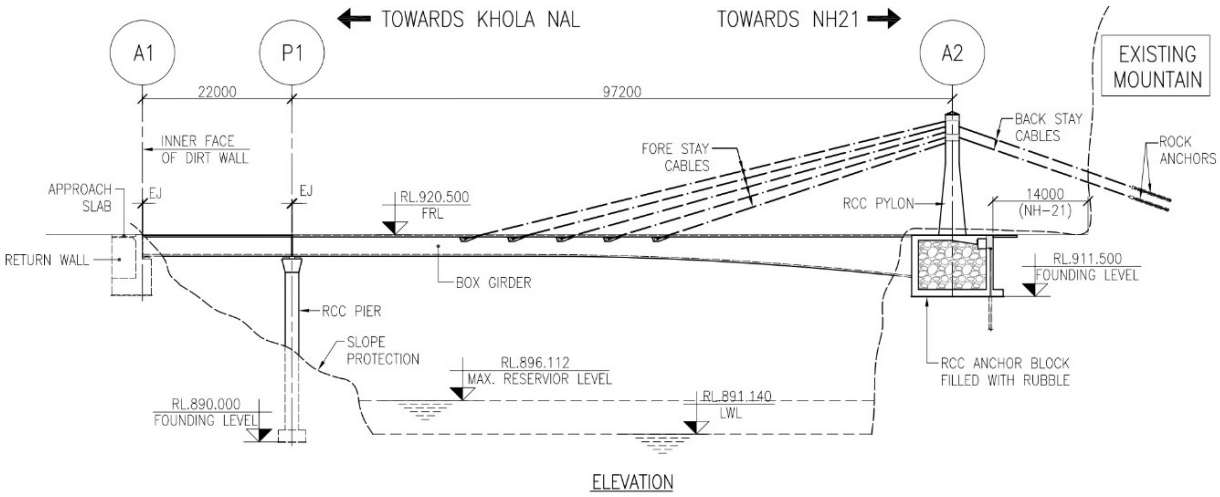


Figure 1: Bridge Elevation

The superstructure for 22m span is a prestressed concrete box girder supported on elastomeric bearings on both Abutment A1 (at Khola Nal/Hanogi) side and Pier P1.

The 97.5m span is proposed as an extradosed span with prestressed concrete box girder. Superstructure and Pylon of the extradosed span is made integral with the box type abutment A2 on Manali/NH side. Pier P1 supports extradosed span on opposite side with Pot PTFE bearings, allowing for its longitudinal movement. Abutment A1 & Pier P1 are the locations for the expansion joints. There is no balancing span on the other side of the main span due to the presence of the hill face hence the back stay cables are rock anchored into the hillock. The width of the bridge deck is 8.5m with carriageway of 7.5m and 0.45m crash barriers on each side catering for 2 lane vehicular traffic as per IRC:6-2017.

2.1 Superstructure and Stay Cables

The superstructure consists of two cell prestressed concrete box girder with extradosed cables and back stay cables. The depth of the box girder varies parabolically from 6m at the abutment A2 interface to 2m at distance of 49m from the abutment A2, beyond which superstructure depth is 2m. Prestressing consists of 48nos of 12T15 cables on the top, 12nos.of 12T15 cables on the bottom. Total 4 pairs (8nos) of extradosed cables on the main span and 8 nos. of back stay cables are provided. The top prestressing tendons are stressed and anchored as per the construction sequence in the rear end of the abutment A2 as the cantilever construction of the box girder progresses. The analysis and design of superstructure is carried out as per IRC:112-2011 and the adequacy of extradosed cables are ensured as per requirements of fib 89.

2.1.1 Substructure & Foundations

Reinforced concrete abutment (A1) with return walls and solid RCC pier (P1) are adopted with open foundations. Abutment A2 is multicellular box type, monolithic with the pylon and the superstructure box girder. The pylon is rectangular, provided on both sides of deck to support 2 planes of extradosed cables. Both pylons are connected by a tie beam at the top. The total height of the pylon above the deck is 14m. The pylon section varies from 1.3m x 4m at the base to 1.3m x 2m at a height of 10.5m above which cross-section is kept constant. The cells of the abutment A2 are filled with plum concrete and passive rock anchors are provided in the rear wall of the abutment to ensure overall stability of the abutment during all the extreme events.

Back stay cable anchorage blocks are fabricated in structural steel. Each anchorage block is anchored in the hillock by means of 6 inclined rock anchors on each side. 4 back stay cables are installed and anchored in each anchor block.

2.2 Ground Improvement Techniques.

As the rock strata encountered at Abutment A2 founding level was fissured it was treated with cement grout to improve the safe bearing capacity. From the slope stability analysis carried out it was evident that the slope of the valley side was susceptible to failure. Shotcrete & Rock bolts at a spacing of 2m center to center were installed to enhance to stability of the slope. The foundation of pier P1 was stabilized by carrying out bank protection works.

3 CONSTRUCTION ASPECTS

Cantilever method of construction using form traveler was adopted for casting of the superstructure for a length of 63m from the abutment A2 beyond which the superstructure was cast on truss supported on brackets cast along with pier cap of pier P1 and structural steel supporting frame erected on segment S19.

Construction stage, pre-camber analysis was carried out in SOFiSTiK software. Pre-camber was provided as per the construction sequence to achieve the final desired geometry of the superstructure.

ID-204

Development of Extraordinary Suspension Bridge Solutions for Sulafjord in Norway

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Abstract

The crossing of Sulafjord on the Ferry-free E39 project in Norway with a bridge solution is an extremely challenging task. The fjord is 3 to 4 km wide, 450m deep and located in a harsh weather environment with strong and heavy winds and waves. The AMC group (consulting companies Aas-Jakobsen, Multiconsult and COWI with subconsultants) has recently developed four different suspension bridge solutions for this crossing in an extensive preliminary design phase. Client for the project has been the Norwegian Public Roads Department (NPRA). These four alternatives involve a world record singe main span of app. 2700m as well as two long-span double span suspension bridge solutions on GBS (Gravity Base Structure) foundation and a triple span floating suspension bridge solution on TLP (Tension Leg Platform) foundation.

Keywords: Record breaking, suspension bridges, preliminary design, creative foundation methods, harsh environment.

The Sulafjord crossing is a part of the Ferry-Free E39 project, connecting the communities of the island Hareidlandet to main land Ålesund. It is an important project to better work commuting across the fjord. A comprehensive preliminary design was performed in 2021-2022 in order to be able to choose concept for construction.

The designs are based on an extensive site investigation scheme involving offshore soil investigations, wave, current and wind measurements as well as wind tunnel testing of various bridge deck sections, and involves many advanced structural analyses. Investment cost estimates, LCC analyses as well as CO2 emission analyses and environmental impact analyses have also been vital parts of the project.

These analyses will together with the technical, functional and aesthetical goal achievements for the preliminary design performed, act as the decision basis for choosing one bridge solution option for preparation of tender documents for construction. The paper describes the work performed within four alternative solutions, all based on suspension bridge technology:

- A single span suspension bridge with a main span of 2710m and with a total length of 3770m including viaducts. The main span towers have prefabricated caisson

foundations at 50m water depth placed om rock. The main span will be the world's largest if chosen, and therefore a lot of effort is put on documentation of the structural integrity in this harsh environment.

- A double span bridge with two main spans of 1545m each and with a total length of 3700m including viaducts. The main span mid foundation is at 450m depth with a GBS (Gravity Base Structure) solution, see figure below. The spans are in line with some of the world's longest suspension bridges and the water depth requires a GBS that is as large or somewhat larger than the world's largest and deepest GBS from the North Sea, the Troll platform.
- Another double span suspension bridge with two main spans of 2035m each and with a total length of 4475m including viaducts, also founded at a mid-fjord GBS foundation at 450m depth.
- A triple span suspension bridge with three main spans of 1220m each and with a total length of 4150m including viaducts. The main span mid foundations are hull floaters tied to the 450m deep fjord bottom by means of steel tension legs (Tension Leg Platform solution).

The conclusion from the preliminary design, is that all four alternatives are feasible even if the scale is large compared to other bridge projects. The material costs and carbon footprint differ quite a lot between the alternatives. Different scenarios for future development of sustainable materials and power sources are however outlined in the project. The choice of solution will be done by NPRA after internal processes are performed, according to the initial plans within 2023.

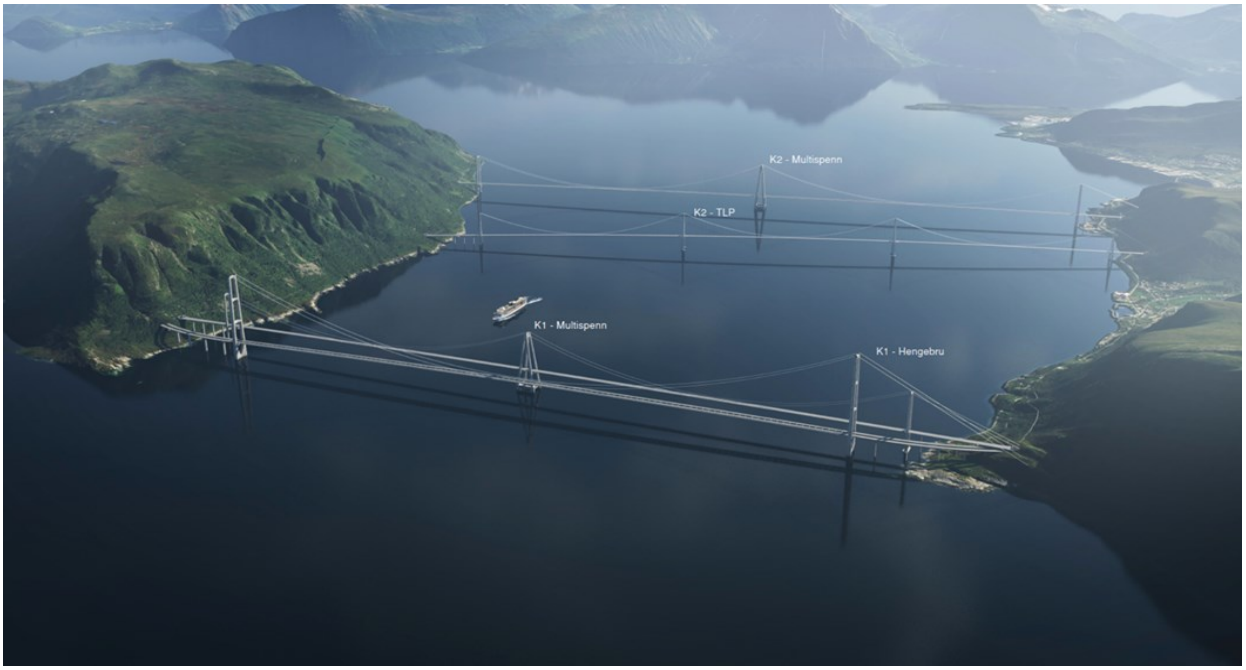


Figure 4. Overview of all alternatives (Illustration: AMC/Dissing+Weitling

ID-208

Innovation in the design and construction of Temburong Bridge, Brunei

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Abstract

The Sultan Haji Omar Ali Saifuddien Bridge is the longest bridge in Southeast Asia connecting the Temburong district to the Brunei-Muara district which were historically isolated by the Malaysia, and therefore reducing the journey time from 2 hours to 30 minutes. The bridge included a 14km marine viaducts, two cable stayed bridges and a 12km swamp forest viaduct. This paper focus on the innovation of the design and construction of the bridge and discuss the values they bring.

1 Introduction

Brunei has been physically separated into two parts by the Malaysia since 1890, significantly affecting region's economic development. Arup carried out Feasibility Study followed by Detailed design and procurement support services. The project was procured as traditional engineer-design bid build arrangement under four contract packages to permit an early start to the construction works.

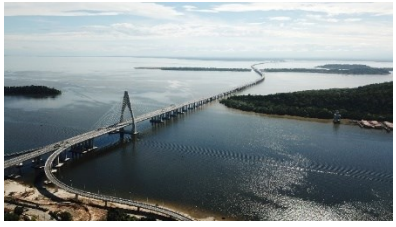


Figure 5. Overview of Temburong Bridge

2 CC2 Marine Viaduct

Given the overall 14km length, precast concrete segmental box girders with span-by-span erection was chosen during design with 50m span length was found to be most optimal solution to achieve the critical speed of construction. Additionally, to maximise the potential benefit of competitive tenders, the design was detailed in such a way that either multiple segment or full span segment erection methods could be used.

The viaducts are predominantly located over shallow waters and top strata of soft clay at seabed. The adoption of high damping rubber bearings (HDRBs) enabled use of slender precast concrete spun piles instead of raked pile alternative, thus allowing rapid pile installation, minimal piling barge manoeuvres and minimal amount of dredging required in such shallow waters and the environmental impact.

To enhance the durability of spun piles, calcium nitrate corrosion inhibitor was specified. The cast-in-situ pile caps used precast shell as permanent formwork. Stainless steel reinforcement was used in foundations within splash zone.

During construction phase, an innovative launching gantry was used to erect two 50m long precast box girders concurrently (Figure 2). This allowed two

adjacent spans to be erected in a single day, resulting in completion of 26km viaduct decks in 25 months.

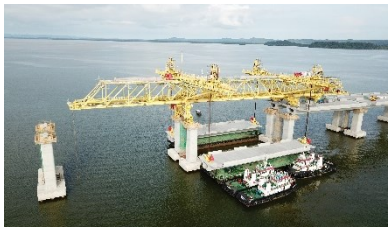


Figure 2. Launching Gantry and Girder Erection

3 CC3 Navigation Bridges

There are two long span navigation bridges along the marine section of the crossing – Brunei Channel Bridge (BCB) for domestic waterway and Eastern Channel Bridge (ECB) for International waterway allowing bigger vessels. The BCB is a single tower cable stayed bridge with two main spans of 145m (See Figure 1) and ECB has 2 towers with a main span of 260m. The deck is concrete ladder beam and is held by stay cables anchored through the edge girders.

Both the bridge main towers are sculpted A-shape, supported on bored pile foundations and kept conceptually the similar. The tower is the unique element and inspired by Islamic architecture forming gateway arches to and from Temburong.. The arch is framed with a ribbed feature and long window which symbolises the four districts of Brunei and their unification.

The side legs have a mostly hollow section and becomes solid only near the stay cables to resist the increasing localized compression at the saddles. In addition to making the structure lighter, this also provides an inspection access. The geometry of the curvilinear shape of the tower legs were resolved for both bridges structurally with straight lines and constant radius curves. This allowed well established formwork methods to be used for construction.

4 CC4 Temburong Viaducts

The main challenge with these 12km swamp forest Viaducts was that it crosses soft peat ground overlying soft marine clay with depths exceeding 70m. The peat material has very little strength and is unable to support any large construction machinery or plant. Due to these challenging ground conditions and in order to safeguard the environmental impact on endangered flora & fauna, top-down construction method was developed, with all construction activities and material delivery only from the already constructed deck as shown in Figure 3.

With a limited construction period and only 4 work fronts, a 3-day construction cycle for each span had to be catered. To achieve this, an innovative precast concrete solution for spun piles, pile caps and deck beams spanning 12m was designed for erection by normal crawler cranes and connected in-situ later as the workfront proceeds, and not affecting the critical path.



Figure 3. BCB Tower (left); CC4 construction (right)

5 Conclusions

Application of innovative ideas in design and construction of this 27km lead to significant reduction in carbon footprint, fast track construction while keeping high standards of durability. As a result, the bridge was opened on 17 March 2020, ahead of schedule, to allow residents to travel freely as Malaysian borders which were shut due to COVID19.

ID-244

Mechanisms for New Lifting Railway Bridge on Pamban Island, India

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Abstract

New Railway Pamban vertical lift bridge will replace the more than 100 years old strongly deteriorated Scherzer Rolling Bascule Bridge, connecting Pamban Island with the mainland of Tamil Nadu State, in India, promoted by RVNL, Rail Vikas Nigam Limited. The 77.5m lifting span weighs around 650 tons and can be raised 17 m in approximately 3.5 minutes.

Mechanisms will be located at the top of the two towers, with a 250kW motor per side. Gear box set will reduce the motor 750rpm to 0.5rpm rotation speed of the 3m diameter sheaves, with the operation controlled by variable speed drives. Electrical supply is ensured by an 800 kVA compact substation and two 625 kVA diesel generators as backup system. Lighting protection and an adequate earthing system is provided.

Keywords: movable bridge; lifting bridge; mechanism; gear box; metal casting.

1 Introduction

Pamban Island, in Tamil Nadu State, Southern India, has been connected to Mandapam in mainland by a railway bridge since 1914, when a 2057 m long bridge was inaugurated. The bridge included 145 spans 12.2m long, and a bascule Scherzer rolling bridge, allowing a navigational channel 57.2 m wide, manually operated. Having endured a sever cyclone in 1964 and the strengthening because of the broad gauge railway conversion in 2007, the bridge has been on duty until January 2023. The strongly deterioration state due to corrosion in one of the harshest environments in the world advised to stop the service, after several years of close monitoring.

Rail Vikas Nigam Ltd (RVNL), promoted the replacement of the bridge by a vertical lift bridge, with a movable 77.5m long span, allowing for a clear navigational channel of 72.5m and 22m of vertical clearance. The vertical movement will take 3.5 minutes to raise 17m, planned to be operated 4 to 6 times per day. An international Joint Venture TYPSA+MC2+STUP was in charge of the design, and Ranjit Buildcon Ltd is constructing. Inauguration is expected by 2023.

2 New lifting bridge

The lift span 77.5m long will be formed by two open lattice arch girders, connected by regularly spaced cross girders. The bridge superstructure shall be lifted through a winch operation fixed on a steel constructed tower of about 35m high. The tower shall be provided with longitudinal stay to cater the lateral forces due to wind and earthquake. Total weight lifted is around 6700kN, through 12 ropes 46mm in diameter per side connected to proper counterweights.

3 Mechanical design

Main power for the lifting operation is provided by a 250kW electrical motor, rotating a 750rpm. A primary gear box with a reduction factor of 9.33 and two secondary of 20.93 reduce the rotation speed up to 3.8rpm. A further reduction is achieved through a pinion to the sheaves set connection, with an additional reduction factor of 7.5, to get a final 0.5rpm. The 3m diameter sheaves will raise the lift span at a 4.8m/min maximum linear speed.

The motor is connected through a clutch. A spare motor with same capacity is installed, that can be used in case of malfunctioning of the principal unit.

Two braking system are planned. The motor brake is installed at the primary gear box and will control the operation velocity, with a 2000N·m torque capacity. The machinery brakes, at the output of both of the secondary gear boxes, will function as emergency brakes, with 150kN·m torque each.

A main pinion 440mm in diameter is placed at the output of each secondary gear box, powering the main ring gear 3300mm in diameter and 240mm wide. The ring gear has 150 teeth, while the pinion has 20 teeth, with a 22 module. The chosen material is 42CrMo4 for the ring gear and 20MnCr5, casted and mechanized.

These are assembled with the 3000mm sheaves set, with six units each, mounted on a shaft 500mm in diameter. Sheaves are also casted and mechanized, using 20MnCr5.

4 Electrical Design

A separate building to allocate the electrical equipment is built on piles, attached to the approaching viaduct. External power supply is provided with 11kV voltage. A compact substation with a dry-type 800 kVA transformer, with a back-up set of two diesel generator 650 kVA each.

Earthing rods are installed attached to the piles at the electrical building and at each tower, including separate earthing for the lightning protection.

Main board and protection cells are located at the electrical building, while secondary boards are installed at each of the machinery rooms, at top of the towers. The control of the speed, i.e. acceleration and deceleration ramps, is ensured through variable speed drives.

Monitoring devices and a SCADA is foreseen to control the operation safety and durability of the components.

5 Acknowledgments

The authors want to thank Rail Vikas Nigam Ltd (RVNL) the opportunity to participate, and the confidence relied on the design team.



Figure 6. Pamban lifting bridge layout.

ID-352

Wind Tunnel Testing and Aerodynamic Consulting for Indian Bridges Today

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Abstract

It has been many years since the wind engineers of RWDI provided aerodynamic consulting for the Anji Khadi Arch Bridge in Jammu and Kashmir, India. Wind tunnel testing and aerodynamic consulting in India has advanced considerably since 2005 as everyone would expect. The authors will revisit the methodologies used then and what would be done today to ensure climate resiliency for the desired design life of the structure far away in the future.

Although the Anji Khadi Arch Bridge was eventually rejected in favour of a cable-stayed bridge which is currently under construction the site is the same. It is anticipated that the complex topography of the site would have a major influence on the bridge microclimate which in turn could have been modified considerably due to climate change affecting this mountainous area of India.

The authors will revisit this project and detail the state-of-the-art analysis and wind tunnel testing that can now be carried in India thanks to a newly built and commissioned bridge test rig for cable-stayed bridges, suspension bridges, arch bridges, and cable-supported pedestrian bridges.

Keywords: Bridge Aerodynamics, Aerodynamic Stability, Wind Tunnel Testing, Wind Loading

1 Introduction

In support of the economic growth that is envisaged for India in the next decade, important investments in transport infrastructure have been initiated in several regions of the country or are at the planning phase by the local authorities, structural engineering firms and bridge contractors. Among these investments, several medium and long-span bridges are considered.

Bridges that are supported by cables; or have fundamental frequencies lower than 1 Hz; or with a span-length-to-deck-width ratio larger than 30 are considered sensitive to the dynamic actions of the wind. In many cases, wind loading is the dominant source of loading and special attention needs to be paid to capture wind effects, to prevent aerodynamic instabilities and to develop site specific wind loading patterns to complete their design.

In support of the development of India's transport infrastructure, RWDI has recently designed, built, installed, and commissioned an innovative bridge sectional model test rig for its wind tunnel facility

in Trivandrum, Kerala in the south of India. This test rig is the first of its kind worldwide and constitutes a major step forward in the field of bridge aerodynamics for India and the Asia-Pacific region. It is the fruit of a major effort to combine sound physical aerodynamic modelling and state-of-the-art measurements techniques, to enhanced repeatability, automation and productivity. It is based on RWDI's 50 years of experience in wind tunnel testing and bridge aerodynamic studies.

Through case studies this paper will illustrate the type of wind tunnel experiments that are carried out today for the design of wind sensitive bridges. A parallel will also be made to show how such experiments have evolved between the time the Anji Khadi Arch Bridge was studied and how such studies are carried out today and will be carried out in India.

2 RWDI's New Sectional Model Test Rig in India

Figures 1 to 3 present views of the test rig in RWDI's boundary layer wind tunnel facility in Trivandrum.



Figure 7. View from downstream of the new bridge sectional model rig in RWDI's boundary layer wind tunnel in Trivandrum, Kerala, India. The rig is divided in two parts that are anchored to rigid frames embedded directly within the walls of the wind tunnel.



Figure 2. External view of one side of RWDI's bridge sectional model rig embedded within the wind tunnel walls.

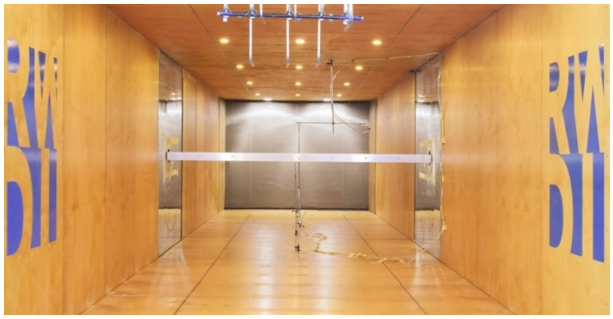


Figure 3. View from downstream of a bridge sectional model in RWDI's bridge test rig in the boundary layer wind tunnel in Trivandrum.

A detailed description of the test rig will be provided in the paper and its benefits to India's bridge design community will be illustrated through case studies.

ID-1117

Case Study of Rochdale Canal Bridge Assessment using Non-Linear Finite Element analysis

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Abstract

Rochdale Canal Bridge is a single skew span railway under bridge to be assessed under Civils Assessment Framework Agreement 2020-2024. The scope of work is limited to the decks supporting the railway lines.

The methodology used to develop a finite element model that accurately represents the structure, the complexities of the structure due to load effects from neighbouring decks etc., are also discussed in the paper. Furthermore, material non-linearity was considered along with geometric non-linearity. The most onerous buckling mode derived from linear Eigen value buckling analysis is used for the initial geometry imperfection of structure. Non-linear analysis was carried out at both SLS and ULS to identify the failure modes through excess stress, strain, yielding and buckling. Through this study, the reserve strength of the structure was captured and is found to be adequate for the current loading which is an improvement from previous assessment.

Keywords: underbridge; finite element; material non-linearity; geometric non-linearity; Eigen value buckling analysis; Non-linear analysis; stress; strain; yielding; buckling.

3 Introduction

3.1 Project Background

Atkins, a member of the SNC Lavalin Group, was appointed by Network Rail Limited to provide consultancy services to assess various bridges and report their current load carrying capacities under Civils Assessment Framework Agreement 2020-2024. Rochdale Canal Bridge is one of those bridges in the work bank.

3.2 Description of the Structure

Rochdale Canal bridge is a single skew-span underbridge with 7 subdecks carrying: High Level Road; a single track of the Rochdale to Manchester Victoria Metrolink line; three tracks of the Manchester Victoria West Jn. to Hebden Bridge line; and a disused area. The structure crosses disused land, which was formerly a canal (now infilled).

The skew angle varies between the different subdecks from approximately 5 to 18 degrees.

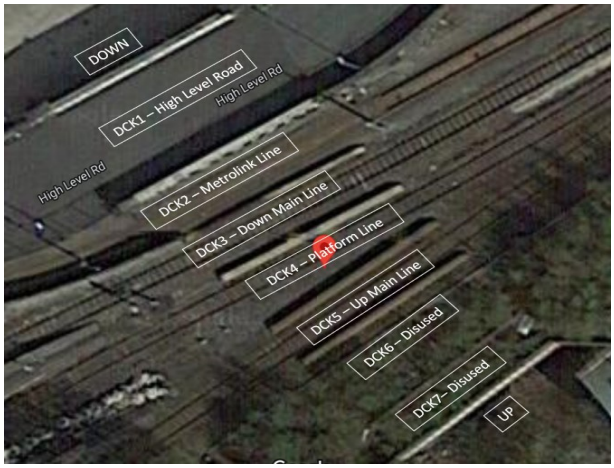


Figure 8. Plan of Rochdale Canal Bridge

3.3 Scope of Work

The scope of the assessment carried out is limited to the part of the superstructure carrying the railway lines (DCK3, DCK4 and DCK5).

3.4 Details of the Structure under scope of work

Girders MGI2, 3, 4 and 5 are riveted wrought iron plate. There are 10 No. cross girders in DCK3 and 4 while there are 9 Nos. cross girders in DCK5. The cross girders of adjacent subdecks are connected to the main girders at the same location which forms a partial continuity across the subdecks. Each subdeck has 2 Nos. rail bearers which support the deck plates along with cross girders. DCK3 comprises of concrete sleepers, DCK4 has timber sleepers while DCK5 has steel sleepers.

3.5 Previous Assessments

The construction date of the original bridge is unknown, but it was reconstructed to its current form circa 1887. Ever since, several assessments have been undertaken. This assessment has been undertaken based on the condition information gained from the Inspection for Assessment carried out in 2017, Detailed Examination Report (2015) and the Visual Examination Report (2021).

The findings of these reports indicate the presence of structurally significant loss of section. The section losses for subdecks under the current scope of assessment have been identified and applied in the finite element model.

4 Assessment

4.1 Methodology of Assessment

Load Transfer System: from rail to deck plates to rail bearers to cross girders to main girders and finally to the bearings that transfer the load to the soil through abutments.

The workflow for the assessment included 7 critical stages as outlined below and are discussed in detail in the paper.

Stage 1: Linear Elastic Analysis was performed as a sensitivity study to determine the effect of live load in each subdeck on each girder.

Stage 2: Identifying the critical points on each of the girders like locations with section loss, curtailment points, mid span, support locations etc.

Stage 3: Linear Elastic Analysis for MGI2 was undertaken to identify live load positions of Metrolink line that produce most onerous load effects at critical points of MGI2.

Stage 4: Linear Elastic Analysis was done for the entire structure to identify the load positions of NR lines that produce most onerous load effects in girders MGI2, 3, 4 and 5.

Stage 5: Linear Elastic Analysis was taken up to understand the mesh sensitivity and identify the appropriate mesh size for finite element analysis.

Stage 6: Eigenvalue buckling analysis was performed to investigate if any structure elements are theoretically susceptible to local and global buckling failure, thus highlighting potential problem areas for further analysis using the non-linear model.

Stage 7: Non-Linear Yield Analysis was undertaken to identify the yield regions and resulting stress contours (SE) over shell elements for ULS and SLS.

4.2 Modelling in LUSAS

A 3D model of subdecks DCK3, 4 and 5 which include girders MGI2, 3, 4 and 5 was modelled and imported to LUSAS, and shell elements were generated from the imported lines. This method not only helped in validating the model but also to capture divisions at locations of interest without having to slice the geometry repeatedly.

5 Conclusions

This assessment indicated that the assessed capacity at ULS is a significant improvement from that of previous assessment as the actual behaviour and capacity of the structure and the stress distributions were captured with higher degree of accuracy depicting the actual condition of the structure in this assessment.

Although the structure is inadequate for current route availability in SLS, SLS failures are not usually considered for taking up strengthening or mitigation measures. Since there are no visible signs of fatigue observed on the bridge during the inspections, effects of fatigue were considered not critical for the assessment.

Session-9

Analysis, Research and Standardisation

ID-140

Proposed Seismic Design Methodology for Steel Pier-Pile Integrated Structure Considering Dynamic Soil-Pile Interaction and Ductility Performance of Elongated Members

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Abstract

This paper discusses the seismic design policy and the design results for a novel pier-pile integrated rigid frame bridge, herein, denoted as the Pier-Pile Integrated Structure. The novelty of the structure lies in its foundation as the footing is eliminated leading to reduced substructure size, in turn, leading to reduced cost, construction time, and the need for topographic modification. The traditional design methodology for foundations with the assumption of fixed support or a rigid member at the footing does not hold for these structures. Hence, a novel seismic design methodology is proposed that considers the ambiguity in the failure mechanism and the ductility performance of ERW SKK 490 steel. Additionally, the seismic response and performance objective are set according to related past studies to form a comprehensive seismic design methodology for practical design. The proposed methodology is then applied for design of a road bridge and a comparison to the conventional design philosophy is presented.

Keywords: Pier-Pile Integrated Structure; Nonlinear Winkler Foundation; SKK steel; seismic design.

1 Introduction

The multipolar rigid frame bridge is a structure with a pier-pile integrated substructure supported directly on soil and superstructure, all connected by rigid joints (fig. 1). In this paper, a novel seismic design methodology for pier-pile integrated structure is proposed that can be applied to members with slenderness ratio, λ in the range of $0.2 \leq \lambda \leq 1.0$, takes into account the ambiguity in the failure mechanism and the ductility performance of ERW steel. Additionally, the seismic response and performance objective of such structures are set according to the related past studies to form a comprehensive seismic design methodology for practical design.

2 Target structure

The bridge structure consists of pier-pile members (SKK490), pier head block, main beams, cross beams (H700-SMA490, H588-SMA400), reinforced concrete deck, and abutments (fig. 2). The bridge length is 31.4 m, deck has a curve of R=60 m in plan and a girder width of 9.371~9.200m with soil class I (JRA V). Since the bridge is classified as importance class A2, the seismic design is aimed to not exceed limit state 3 Level 2 earthquake motion.

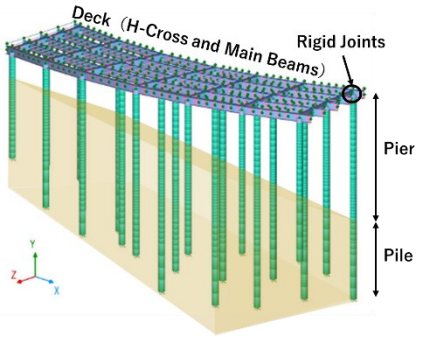


Figure 32. General arrangement of a multipolar pier-pile integrated structure

3 Design challenges for seismic design

The design of pier-pile Integral structure cannot follow the design methodology in JRA V since the member slenderness is out of the applicable range

of $0.2 \leq \lambda \leq 0.4$, the structure has no footing, the load bearing and ductility performance of ERW steel does not follow the JRA standards and the design criterion considering the collapse mechanism of pier-pile integrated structures is not established in the standards.

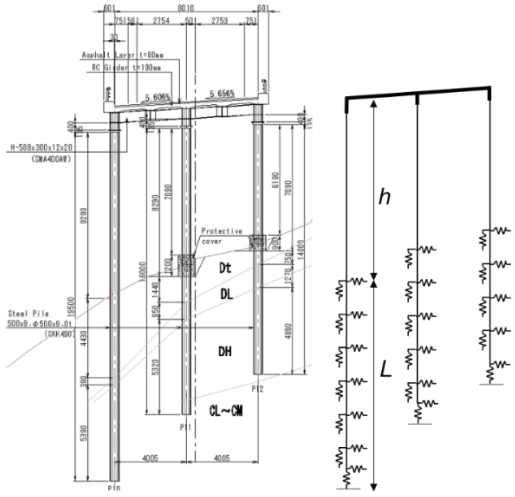


Figure 10. Cross section and analysis model

4 Seismic design policy and standards

In addition to the limits set in JRA V, the following 3 limits are newly proposed to reflect the recent related research.

1) The limit value of curvature response is based on the strain ϵ_a and is given by:

$$\epsilon_a = 12.50\epsilon_y \quad ; \left(R_t\bar{\lambda} \leq 0.009\right)$$
$$\epsilon_a = \left(20.78 - 920R_t\bar{\lambda}\right)\epsilon_y \; ; \left(0.009 \leq R_t\bar{\lambda} \leq 0.018\right)$$
$$\epsilon_a = \left(4.67 - 25R_t\bar{\lambda}\right)\epsilon_y \quad ; \left(0.018 \leq R_t\bar{\lambda} \leq 0.070\right)$$

This formula can be applied to SM material (roll steel for welded structure) and the application scope is $0.03 \leq R_t \leq 0.07$, $\bar{\lambda} \leq 0.4$ and $N/N_y \leq 0.2$, or $0.4 \leq \bar{\lambda} \leq 1.0$ and $N/N_y \leq 0.15$.

2) The limiting compressive stresses are given by $N/N_y \leq 0.15$ given by the scope in 1 above.

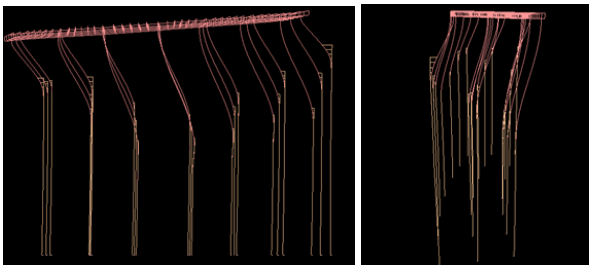
3) The collapse mechanism, in the case of pile-pier integrated structure can be assumed to be either pier-pile preceding type or ground preceding type [2]. In the current design, the pier-pile preceding type collapse mode is targeted to avoid brittle failure and to achieve satisfactory seismic performance.

5 Analysis with the soil-pile interaction

For the analysis, 3D frame models based on the Beam on Nonlinear Winkler Foundation (BNWF) concept are developed for analysis using TDAP III software [1]. The bridge deck and superstructure are modelled as elastic beam elements, the substructure (piers, piles) is modelled as beam elements with the nonlinear M-ϕ properties, and the ground is modelled as a spring-node system that considers the nonlinear, dynamic interaction between the pile and the ground.

6 Analysis results

Figures 11a and b show the deformed shapes of the structure. The design was governed by the curvature response of short columns with the pier head as the critical section. In the transverse direction, the structure vibrated with significant deck rotation with maximum deformations concentrated towards one abutment. The deck rotation was reduced, but not eliminated, by making the transverse axis the plane of symmetry with respect to the member stiffness.



(a) (b)

Figure 11. Maximum deformation due to loading in (a) longitudinal and (b) transverse directions.

7 Lessons from the design

1) After obtaining convergence in analysis, it is important to also check the convergence in values of effective buckling length for an acceptable design.

2) Due to the concentration of stresses in pier-piles with short pier lengths, no specific impact on the overall design was identified due to the modified ϕ_a.

3) With the soil-pile interaction enabled model, the ground displacement seismic response could be captured at the surface. This was more pronounced at the short pier-piles, where the ground plasticity is higher, and consequently let to

higher pier-head displacement and curvature response near abutment A2.

4) In the current design, the critical sections (maximum demand/capacity 0.82) lie in the pier whereas the pile elements remain relatively safe (maximum demand/capacity factor 0.58).

8 Conclusion

Compared to the conventional design that covered a limited range of slenderness ratio, did not have a target collapse mechanism, and did not consider the dynamic soil-pile interaction, an accurate seismic design could be achieved using the proposed design methodology.

ID-150

A Longitudinal Isolation System with Elastoplastic Cables for Single-Tower Cable-Stayed Bridges

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Abstract

For single-tower cable-stayed bridges, a longitudinal isolation system with elastoplastic cables were proposed, and calculation expressions based on dynamic concepts were established for the design of this system. Based on the Jinsha River Bridge, a performance comparison was conducted on the elastoplastic and elastic cable systems. The girder displacements under wind and braking force, as well as the damping effects under earthquakes, were analysed for both systems with the most economical parameters. The results demonstrate that both elastoplastic and elastic cables can effectively reduce the longitudinal displacement of the girder compared to a floating system under normal service conditions. However, elastoplastic cables have a higher material utilization rate, larger restraint stiffness, and a wider range of applicable parameters than elastic cables. In addition, elastoplastic cables can effectively dissipate energy and have a better damping effect.

Keywords: single-tower cable-stayed bridge; longitudinal isolation system; elastoplastic cable.

1 Introduction

Currently, the single-tower cable-stayed bridge has become a popular choice for bridges with main spans ranging from 200m to 400m. In high-intensity earthquake areas, cable-stayed bridges typically adopt fully or semi-floating systems. To control the large seismic displacement, additional constraints or energy dissipation devices are often installed between the tower and girder, and the most commonly used device is the viscous damper. For classic two-tower cable-stayed bridges, the floating system with an additional viscous damper is a reasonable system. But it is not ideal for single-tower cable-stayed bridges, because the viscous damper cannot provide the tower-girder constraint under normal service conditions. Early cable-stayed bridges built in Japan mostly used the tower-girder constraint system with elastic cables. Elastic cables can provide a certain level of constraint under normal service conditions and allow for large girder displacement during earthquakes. However, elastic cables don't provide energy dissipation and have a poor damping effect. Therefore, a longitudinal isolation system with elastoplastic cables for single-tower cable-stayed bridges was proposed in this paper, and the corresponding design method was established based on dynamic concepts.

2 Elastoplastic cable system and corresponding design method

The longitudinal elastoplastic cable isolation system is shown in Figure 1.

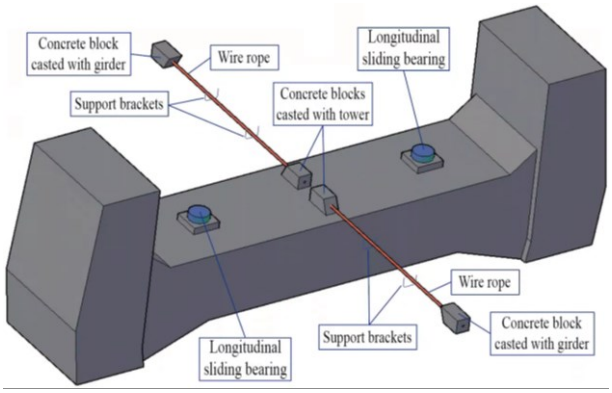


Figure 1. Schematic diagram of elastoplastic cable isolation system

Two main parameters of the elastoplastic cable, including the section area A and the length L, can be determined by the following inequalities:

$$\begin{cases} \lambda L \geq \dfrac{MS_c}{k_i + k_c}\eta_\xi \\ mF_e \geq \sigma_y A \geq \alpha F_s \end{cases} \quad (1)$$

Where, λ is the design ultimate elongation; M is the effective mass of the bridge; S_c is the spectral acceleration; k_i is the total stiffness of the tower and stay cables; k_c is the equivalent stiffness of the elastoplastic cable; η_ξ is the damping adjustment coefficient; α is the strength improvement coefficient for fatigue checking of the cable under non-seismic actions; F_s is the maximum axial force of the cable under non-seismic actions; m is the reduction demand coefficient of seismic shear force transferred between the tower and girder; F_e is the maximum seismic shear force of the bearings at the tower under the longitudinal fixed system.

3 Performance advantages compared with elastic cable

Based on the Jinsha River Bridge, the effective design parameter ranges for the elastoplastic and elastic cables are as shown in Figure 2.

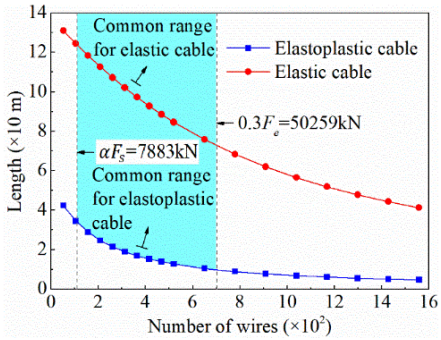


Figure 2. Effective design parameter range

The Figure indicates that the elastoplastic cable has a wider range of applicable parameters than the elastic cable and can better adapt to different seismic actions. Meanwhile, the elastoplastic cable has higher material utilization and better economy.

4 Finite element analysis for elastoplastic cable system

Figures (3-4) show the longitudinal displacements of the girder under non-seismic actions and seismic shear forces at the bottom of the tower for different systems, respectively.

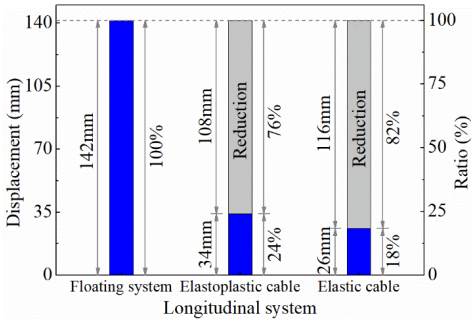


Figure 3. Longitudinal displacement of the girder

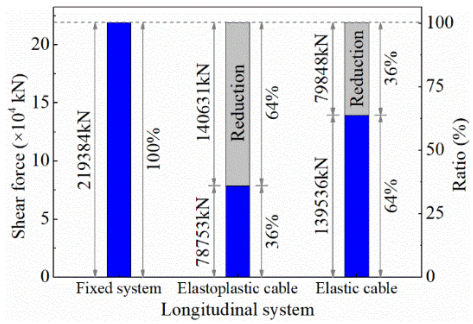


Figure 4. Shear force at the bottom of the tower

The elastoplastic cable can provide a good constraint on the structural displacement, similar to the elastic cable. But the elastoplastic cable has a significant advantage in controlling the seismic shear force and provides a better damping effect.

5 Conclusions

1) A new longitudinal isolation system can be created by using pairs of elastoplastic cables to provide longitudinal constraint at the girder-tower connection. The corresponding simplified design method for the elastoplastic cable based on dynamical concepts is simple and easy to use. **2)** The elastoplastic cable has higher material utilization and better economy, and provides greater stiffness than an elastic cable with the same area. Moreover, the elastoplastic cable has a wider range of applicable parameters and can well adapt to various seismic actions. **3)** Both the elastoplastic and elastic cable systems can provide effective constraint on the girder displacement. But the elastoplastic cable system has an obvious advantage in terms of controlling the structural internal force, and can provide a better damping effect for the bridge.

ID-161

Seismic Analysis of Integral Abutment Bridge – Comparison of Framed Abutment with Fixed Base and Hinged Base

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Abstract

Integral Abutment Bridge (IAB) is the bridge in which the superstructure and substructure is monolithically casted. The advantages of IAB bridge are: less maintenance, better seismic performance due to increased redundancy. In this study, the IAB bridge with 1.0 m diameter pile in 2x10 pile configuration is compared with 1.5 m diameter piles in 1x8 pile configuration. The limit equilibrium method as per IRC:SP:115 is used instead of soil structure interaction for backfill. Soil pile interaction is represented by the linear soil spring. The site - specific response spectra is used for Elastic Response Spectrum Analysis. Temperature loading, Creep, shrinkage, differential settlement; Live load and live load surcharge are applied in the model as per IRC:6-2017. The beam element is used to model the superstructure and pile. Plate element is used for pile cap and abutment wall. The time period of hinged base model is significantly larger than fixed base model. The pile top displacement and abutment top displacement is higher in hinged base model than the fixed base model.

Keywords: Soil-Structure Interaction (SSI); Integral Abutment Bridge (IAB); Pile Foundation; framed abutment with fixed base; framed abutment with hinged base.

1 Introduction

Integral Abutment Bridge (IAB) is the bridge in which the superstructure and substructure is monolithically casted. The IAB has no expansion joints and bearings. The advantages of IAB are less maintenance and better seismic performance.

Recently, Integral bridge have started gaining popularity in the seismic region due to its better seimic performance . The better performace during seismic event is due to the monolithic connection of IAB which increases redundancy. The soil pile interaction should be simulated in FEM model for the design of the IAB. IRC:SP:115-2018 is used as a guideline for the design of integral bridge. Depending on the type of pile foundation, IAB has the following types: framed abutment with hinged base; and framed abutment with fixed base. This study aims to compare the seismic response of the IAB with fixed base and hinged base.

2 General Description of Case Study

The scope of present study is limited to deal with the case study of IAB with 20 m span. The present bridge has been designed for Kathmandu Terai/ Madesh Fast Track (Expressway) Road Project Contract: KTFT/ICB/WORKS/R&B/078/079/3.

2.1 Description of Bridge

The length of the single span IAB bridge is 20 m in which twin superstructure of 11.8 m width each is supported on pile foundation. The final design of

Integral bridge has 20 numbers of 1 m diameter pile in 2x10 pile configuration which behaves as framed abutment with fixed base (Fig. 1). As alternate option, 8 numbers of 1.5 m diameter piles in single row pile configuration which behaves as the framed abutment with hinged base (Fig. 2).

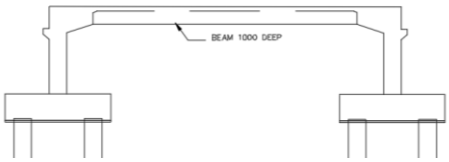


Figure 1 Elevation of Fixed base Model Bridge

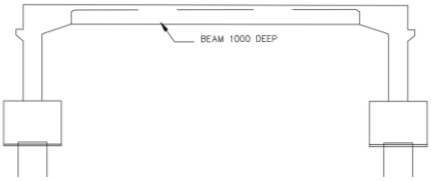


Figure 2 Elevation of Hinged base model Bridge

2.2 Soil Pile Interaction

The loads at the top of pile for normal, temperature and seismic case were used in L-Pile software to get the soil spring value. Reese model is used in the L-Pile analysis. The input parameter for the L-pile analysis are: angle of friction, soil density and horizontal soil stiffness.

2.3 Abutment Earth Pressure: limit Equilibrium approach

The framed abutment is integrated with the superstructure, forming a portal frame structure.

In this study, abutment backfill interaction with the simulation of soil spring is not done. IRC:SP: 115-2018 has mentioned that limit equilibrium method can be taken as alternatives to soil structure interaction in case of abutment backfill.

2.4 Site Specific Response Spectra

Elastic response spectrum method (ERSM) is used for seismic analysis as per IRC:SP:114-2018 using the site specific response spectra.

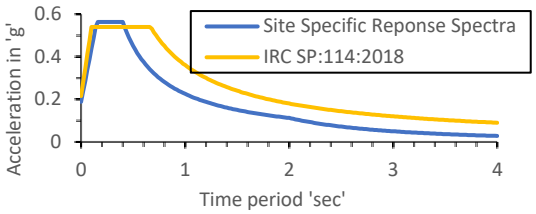


Figure 3. Site Specific Response Spectra and IRC SP:114-2018 Spectra for 5% modal damping

Temperature loading, creep, shrinkage, differential settlement, Live load and live load surcharge as per IRC:6-2017 are also applied in the model.

2.5 Description of Finite Element Model

The Global Finite element model was prepared in the MIDAS Civil. The beam element is used to model the superstructure and pile. Plate element is used for modelling of pile cap and abutment wall to account the bending. Soil pile interaction is represented by the soil spring assigned at the nodes of piles. For the capacity check of the pile, in fixed base model, 24 nos. of 25 diameter reinforcement (p=1.5%) is provided and in hinged base model, 36 nos. of 25 diameter reinforcement (p=1.0%) is provided.

2.6 Result

Modal analysis result was studied to understand the dynamic behaviour of the bridge. Modal time period of hinged base model is significantly larger than fixed base model.

The pile top displacement and abutment top displacement is higher in hinged base model than the fixed base model.

3 Conclusions

Based on the results, following conclusion are drawn.

- The IAB bridge with single row pile has significant increase in fundamental time period which indicates higher flexibility and lesser stresses.
- There is significant increase in the pile and abutment top displacement for hinged base model.

ID-389

Effect of bridge foundation stiffness on dynamic behavior of bridge structure

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Abstract

Problems involving the foundation of a bridge are always difficult to see because the structure is on the ground or covered by water flow. Scouring around piers and abutments can lead to unpredictable consequences that can result in sudden collapse of the structure. In this paper, the effect of foundation stiffness (before and after the bridge repair works) on the dynamic response of the bridge structure is investigated. The results will help to diagnose the bridge foundation in the future. Based on the results of span monitoring before and after repair works combined with numerical model analysis on a bridge in Vietnam, the effects of scouring at the bridge piers are determined. The research results reveal that the dynamic responses of the structure make it possible to detect damage to the foundation and determine whether scour is likely to occur in the vicinity of the bridge foundations.

Keywords: Dynamic behaviour, Foundation stiffness, Scour effects.

1 Introduction

The main cause of failure of bridges over waterways is scouring of the soil around the bridge foundations. Therefore, it is necessary to investigate scour phenomenon at the vicinity of bridge foundations and provide early warning of it. Many solutions have already been developed, of which vibration-based scour monitoring is the most concerned. This research focuses on the influence of foundation stiffness on the dynamic behaviour of bridge structures. Using measurements of structural vibrations before and after bridge pier repair and strengthening (after scour) in conjunction with the finite element model, comments and conclusions are given on the influence of foundation stiffness on the dynamic behaviour of the bridge span.

2 Approach method

The bridge pier in the working phase can be simplified as a beam with one end elastically connected to the foundation and the free end elastically connected to the span structure through the bridge bearing. Based on the simplification of the working diagram, the vibration frequency of the structure can be expressed according to Rayleigh theory. This theory shows that the

stiffness of the bearing has a significant influence on the vibration results of the span structure. The stiffness of the bearing depends on the stiffness of the foundation, and other studies have shown that the change in natural frequency due to the stiffness of the foundation is more sensitive than other local damage to span structures.

3 Case study

3.1 Introduction of the bridge project

In this study, Doan Hung bridge is used for the analysis. It is located in Doan Hung District, Phu Tho Province, Vietnam. In 2013, the bridge piers on the river (piers P2 and P3) were supplemented with 4 additional bored piles (D=1.2 m) at 4 corners. In 2020, both piers P2 and P3 were further strengthened with 4 bored piles (D=1.5 m) to increase the stiffness of the piers.

3.2 Field test

Bridge span vibration data were collected using 8 high-sensitivity accelerometers (PCB 393B12), and signal processing results were annotated. After repair, there is no change in the mode shapes of the span structure. The natural frequency values of the vertical bending and torsional modes are not significantly affected. For lateral motion modes, the corresponding natural frequencies have changed significantly: the first lateral movement mode changed from 1.85 to 2.15 (by 16.21%), and the second lateral motion mode changed from 4.658 to 4.992 (by 7.1%).

3.3 Numerical model

The finite element model of Doan Hung bridge after repair in 2020 is established. The model is updated to match the dynamic characteristics with the field measurements. The following scenarios are considered: (i) damage due to reduction in stiffness of the Prestressed tension span structure, (ii) scour damage at the piers due to the removal of the elastic bearings depending on the degree of penetration into the bottom of the piles. The results of the analysis are shown in Figure 12.

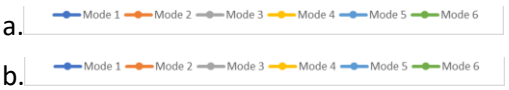


Figure 12. Change in natural frequency: a. damage to bridge span, and b. reduction in foundation stiffness.

When damage occurs to the span structure, the dynamic behaviour changes for all mode shapes. For the damage caused by the change in bridge foundation stiffness due to scouring, the natural frequency of the lateral mode shapes changes significantly, while the other mode shapes change little.

4 Conclusions

1. Scouring causes a reduction in the stiffness of the foundation, which in turn causes a change in the dynamic behaviour of the structure.

2. The natural frequency of a bridge with a pile foundation is more sensitive to the lateral movement of the bridge.

3. Two modes of failure of the bridge are considered in the numerical model. When the span structure is damaged, the frequency of all modes of vibration changes significantly. However, in the case of scour damage, the frequencies change mainly in the lateral modes of vibration.

4. In the case study of this article (pile foundation), vibration measurements can be used to determine the presence of scour.

ID-609

Study on Mechanical Properties of a Negative Poisson's Ratio Structural Bridge Block

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Abstract

This paper is based on the design concept of the block is not damaged under small earthquakes and can be used sustainably and in the medium earthquake does not fall, convenient structure replacement and it can be destroyed during a large earthquake, sacrificing itself to protect the main beam. Based on the characteristics of graded energy dissipation and the advantages of negative Poisson's ratio compared with traditional structures in energy absorption and impact resistance, an anti-seismic energy dissipation bridge block was designed. The mechanical properties of the block were studied by uniaxial loading test and finite element simulation. Through the comparative analysis of normalized curves, it is found that the block structure has a good limiting ability compared with other types of blocks, which can be multi-enhanced stiffness characteristics and excellent bearing capacity.

Keywords: bridge block; negative Poisson's ratio; energy absorption; uniaxial load test; finite element; normalized curves

1 Introduction

According to the characteristics of the NPR structure's load strengthening and energy dissipation advantage, a new type of anti-seismic energy dissipation block for the NPR bridge is proposed in this paper, see Figure 1 below. The block is composed of NPR monomer, rear end bearing member, and bottom plate, and all parts are made of steel plate. The installation of the block is consistent with the existing ordinary steel block, and the block is directly fixed on both sides of the bridge pier roof beam by bolts. With the increase of beam position shift, the NPR effect is formed through the inward rotation and deformation of both sides of the back-carrier member.

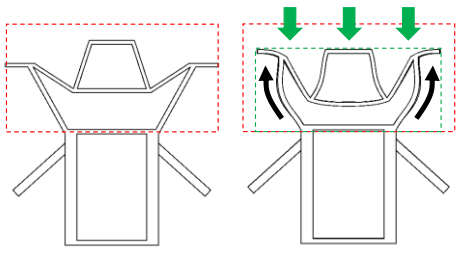


Figure 1. The NPR effect

2 Experiment process

Two identical specimens were prepared in the experiment, and the displacement-controlled uniaxial loading system was adopted to

analyze the limiting energy dissipation capacity and the change form of stiffness of the structure under the action of shear force. See picture 2 below for the site layout.



Figure 2. Experimental loading device

3 Normalized curves

As shown in Figure 3, compared to other types of blocks, the initial stiffness of the NPR block is small, the stiffness changes into multiple lifting laws and the displacement limiting ability is excellent. These characteristics can reduce the impact effect between the main beam and the block in an earthquake, limit the lateral movement of the main beam and protect it from being damaged. The variation law of multiple lifting stiffnesses can adapt to different earthquake environments well and achieve the purpose of graded energy dissipation.

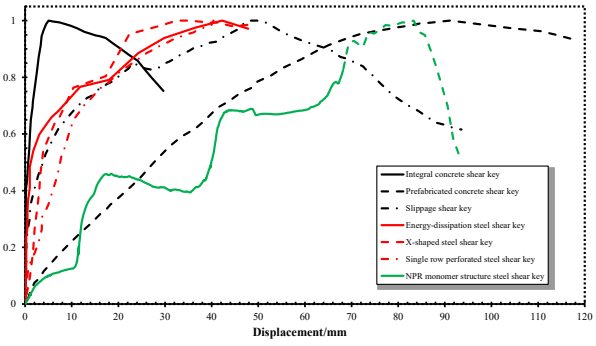


Figure 3. The normalized curve of different block

4 Numerical investigations

The finite element software ABAQUS was used to simulate the NPR block.

As shown in Figure 4, the numerical simulation analysis results of samples A and B were compared with the experiment to verify that both the numerical simulation results and the experimental results were three-step linear, and the changing position and trend of the curves were basically consistent. The numerical simulation model is the perfect symmetric deformation in the ideal case.

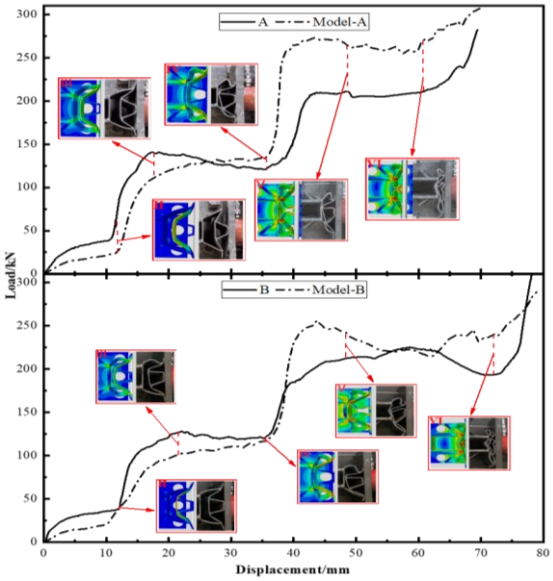


Figure 4. Comparative verification of results

5 Conclusion

(1) The NPR block shows three stages of platform in monotone loading test. The initial stiffness of the NPR block is small, and the overall stiffness of the structure gradually increases with the lifting of the load platform.

(2) Compared with other traditional blocks, the initial stiffness of this block is small. With the generation of NPR effect, the stiffness of the structure increases significantly from the second load platform. Under the premise of ensuring the bearing capacity, it can effectively prevent damage to the main beam.

ID-684

Thermal Performance of Sandwich Wall Panels with Core Insulating Material

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Abstract

Air conditioning systems account for bulk total energy consumption in buildings. The major phenomenon behind thermal insulation is the conservation of energy. In this paper, experimental analysis on the thermal performance of concrete sandwich wall panels (SWP) was studied by varying the core insulation material and was compared with conventional concrete wall panels (CCWP). Insulation materials used for analysis include expanded polystyrene (EPS), air cavity, paper boards, and wood sawdust. In the laboratory, the thermal conductivity of core insulation materials was quantified using Lee's disc apparatus. The thermal conductivity values of SWP specimens are entirely dependent on the thermal conductivity of core insulation materials. Field thermal performance is measured with the help of an infrared thermometer. It is found that the outer surface of SWP experienced high temperatures compared to the outer surface of CCWP. In the inner surface, the temperature increase is gradual in SWP and about 4^{o}C less compared to CCWP at maximum temperature.

Keywords: *Thermal conductivity, Sandwich wall panels, Expanded Polystyrene (EPS), Conventional Concrete Wall Panels (CCWP), Lee's disc apparatus, Infrared thermometer*

Introduction

India is a developing country with new infrastructure emerging throughout the nation. The construction industry consumes large energy and produces huge waste [1]. A large amount of energy is being utilized by the building mainly due to the air conditioning system. Building materials occupy a great proportion of the consumption of energy [2]. The usage of air conditioning gives comfort with the enormous negative impact such as the emission of greenhouse gas and creates energy demand. A thermal insulating sandwich wall panel reduces the energy cost of the air conditioning system and a reduction in carbon-di-oxide (CO_2) emission can be achieved [3,4]. A Sandwich Wall Panel (SWP) is a composite wall usually made of three layers: a low-density core and a thin skin layer bonded to each side. Research carried out in the recent past has been reviewed and the following inferences are made. The core insulation layer thickness is chosen depending on the required thermal resistance ('R') [2]. The core insulating material often used are foam, expanded polystyrene (EPS), cardboard, mineral wool, industrial and agricultural by products such as sawdust, bagasse, plastic, corn cob, etc. [5,6]. Wood is a naturally insulating material with a lot of air pockets within the cellular structure. Besides, it exhibits low embodied energy, and moisture buffering capacity thus helps to improve the indoor environment [5, 7]. Sawdust and EPS are effective cavity filler materials and the effective thermal conductivity of perforated brick is influenced by thermal conductivity, specific heat capacity, and density of the filler material [8]. A newspaper consists of 82% to 85% of cellulose and a large number of fibers with thermal conductivity of 0.230W/mK. The newspaper helps in lowering the thermal conductivity of Aerated Lightweight Concrete (ALC) panels and it allows the production of denser and stronger panels having low thermal

conductivity [5, 9].Higher temperature storage in the brick wall during daytime is expelled indoors during night time whereas in the SWP heat flux is nearly constant. Therefore the total heat transfer in the brick wall is greater because of the lower thermal resistance and during night time, the brick wall behaves like a heat source that releases the stored heat inside the room which was inverse in the case of Sandwich Wall Panel (SWP) [9]. A literature survey indicates that the heat gain or heat loss in the environment should be minimized. Sandwich Wall Panel (SWP) with core insulating material helps to decrease the energy consumption in the building.

In the present study, experimental analysis on the thermal performance of concrete Sandwich Wall Panels (SWP) were carried out by varying the core insulation materials and were compared with conventional concrete wall panel.

Materials and Methodology

Insulation materials used for analysis include Expanded Polystyrene (EPS), air cavity, paper board and wood saw dust. In laboratory investigation, the thermal conductivity of core insulation materials is identified. Then the thermal conductivities of insulated panel specimens (11 cm diameter and 50 mm thickness (10mm insulation)) and the concrete panel specimen (11 cm diameter and 50 mm thickness) is measured using Lee's Disc apparatus. In field the thermal performance measurement, Conventional Concrete wall Panel (CCP) (1mx1mx120mm) and EPS insulated SWP (1mx1mx120mm, 40mm thick insulation) are erected in exposure to direct sunlight. The surface temperatures of CCP and SWP are noted with the help of infrared thermometer from 6:00 AM to 10:00 PM at an interval of 2 hours for 15 days.

Conclusion

The thermal conductivity value of EPS insulated SWP, Air cavity insulated SWP, Paper Board insulated SWP and Sawdust insulated SWP are found to be reduced by 78%, 64%, 67% and 46% when comparing it with the thermal conductivity of concrete panel specimen. The decrease in thermal conductivity values of SWP specimens are not found to be in the decreasing order of the thermal conductivity of core insulation materials. It is found that the outer surface of SWP experienced high temperature compared to the outer surface of CCP. In the inner surface, temperature increase is gradual in SWP and about 4^{o}C less compared to CCP at the time when it experience maximum temperature.

References

[1] Iacob Florea and Daniela Lucia Manea. Analysis of thermal insulation building materials based on natural fibres. *Procedia Manufacturing,* 2019; 32:230-235.

[2] Eu S and Evans M. India's R&D for Energy Efficient Buildings: Insights for U.S. Co-operation with India. *Pacific Northwest National Laboratory*, 2015.

[3] Yang J., Wang G and Ding K. Thermal Performance test of the new sandwich insulation composite wall panels. *Advanced Materials Research*, 2013; 676 : 24-26.

[4] Zhou A., Wong K and Lau D. Thermal insulating concrete wall panel design for sustainable built Environment. *The Scientific World Journal*, 2014.

[5] Abdul Talib Din., Norzawahir Mohd Hafiz., Anika Zafiah Mohd Rus. Exploration to find green building materials from recycled solid wastes. *Journal of Advanced Research in fluid mechanics and Thermal Sciences,* 2018; 47(1):35-44.

[6] Ikbal Cetiner and Andrew D. Shea. Wood waste as an alternative thermal insulation for buildings. *Energy and Building;* 168 : 374-384.

[7] Kou L and Basalem M. Study of sawdust and Expanded Polystyrene as cavity filler material on the effect of Thermal Conductivity in Perforated clay brick. *Material science forum.2017; 890:* 411-414.

[8] Soon-Ching Ng, Kaw-Sai Low. Thermal conductivity of newspaper sandwiched aerated lightweight concrete panel. *Energy and Building,* 2010; 42:2452-2456.

[9] Hachim D and Abed Q. Thermal Analysis of Light Weight Wall Made From Sandwich Panels In the aspect of Thermal Insulation Design for Sustainable Built Environment. *6th International Conference on Thermal Equipment, Renewable Energy and Rural Development (TE-RE-RD),* 2017.

Session 10

Digital Initiatives (BIM, Artificial Intelligence, 3D Printing)

ID-55

Humanism Through Artificial Intelligence?

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Abstract

Today's key challenges for future construction are well known and little disputed. On the one hand, we should put the brakes on climate change; on the other hand, we must prepare ourselves for its probably serious consequences. Doing this without fossil resources currently still poses considerable problems for the construction industry. At the same time, digitization and artificial intelligence are creating major opportunities. Already 50 years ago, Jos Weber stated that computers should become self-learning, artificial-intelligence-developing teaching sources for architects. While the most significant discovery of the past year in the field of chemistry was made by a software program and is discussed to be proposed for the Nobel price, in civil engineering these technologies have been used in a rather rudimentary way so far. In this article, current approaches, tools and areas of application for optimization in structural design are presented, discussed and classified.

Keywords: climate change, artificial intelligence, structural optimisation.

1 Introduction

Since the Renaissance, humanism has been the term used to describe a cultural and philosophical movement aimed at giving humanity the ability to improve its own existence by promoting science, art, education and critical thinking. Several centuries have passed since the term was coined and its implementation seems a long way off. Due to climate change, which we are accelerating through the use of fossil fuels, we are threatening the preservation of biodiversity on Earth, and thus our own, instead of improving it. This is despite the fact that there are many renewable energy sources such as solar energy, wind energy, hydropower, geothermal energy and biomass, which could completely cover the world's electricity and heating needs.

2 A question of attitude?

While our prosperity has been growing steadily in Central Europe since the 1950s, the gap with those who do not benefit from this expansion is also growing steadily, so the people who benefit the least from our destructive approach to our environment suffer the most. Every now and then we are reminded that our prosperity can also be threatened, for example by the oil crisis in the 1970s, or the banking crisis in the 2000s. In the 2020s, it's not just our prosperity, but even our continued existence. Given these facts, one might wonder if it's because we don't want to change anything.

3 Would machine decide „better”?

In 2015, Amazon had introduced the "Same Day Delivery" service only for certain zip code areas of the USA. It hailed criticism, since this service was only available in districts in which predominantly rich people of light skin colour lived. Amazon defended itself, stating that the decision was based on an algorithm and that it did not know at any time about characteristics such as skin colour or gender of its customers. Artificial intelligences have long been making decisions for us, and about us. This underscores the power and potency of these

tools, while also highlighting their risks. The question arises whether we can also use these potent tools that we have at our disposal in this day and age to promote humanism.

According to recent studies, the construction industry consumes about 40% of the total energy consumption, the potential to save energy and thus create a more socially just world is high.

4 Tools in construction history

The use of tools such as the PC has a long tradition in the construction industry. An early example is Leonardo da Vinci's Perspectograph, which he is said to have used around 1480. In 1959, Professor Patrick Hanratty published PRONTO, a CNC cam system and the first software program used in the construction industry. A year later, Ivan Sutherland submitted his PhD thesis at MIT, which consisted of SKETCHPAD, the first CAD (Computer Assisted Drawing) program. About 10 years later, the first attempts to solve architecture and engineering problems with automation through algorithms were made. In 1971, Phillip Steadman published the paper ''The Automatic Generation of Minimum Standard House Plans''. In 1981 Fretsch presented the paper ''An Algorithm for Exhaustive Generation of Building Floorplans'' in which he described how floor plans are furnished using an algorithm.

5 What is actually the aim?

Basically, these tools, whether they facilitate drawing or create entire drawings, have one thing in common: they should optimize our work processes. However, it is not always easy to name the optimum. Negroponte said that if there is a best solution, it is only theoretical and subjective, and that optimization always involves a lack of context. Herbert Simon also found the term optimization inappropriate and preferred to speak of satisficing. This corresponds to the idea that there is not only one best solution, but an optimum can be different depending on the observer, time and many other factors.

6 AI in the AEC sector

Computer programs that could play chess were among the first machines with artificial intelligence and triggered a first wave of enthusiasm in the 1950s. After the initial hype that quickly faded, it was again a chess computer that triggered a new AI wave: in 1997, when Deep Blue defeated the reigning world chess champion Garry Kasparov. In 2022, the most significant discovery of the year in the field of chemistry was made by a software program and is to be proposed for the Nobel Prize, triggering a debate in the public. But what is the situation in the AEC sector? This paper showcases 3 AI tools of the current AEC generation will be briefly presented. All three methods share a basic idea that if humans spend less time on routine tasks, they can turn to more important work, such as protecting the climate. Furthermore, energy can be saved and the carbon footprint of a building can be reduced through structural and utilization optimization.

7 Controversy and outlook

The discussion of the risks of artificial intelligence is at least as old as the idea of artificial intelligence itself. The idea of making machines work for our well-being is described by Karel Capek in his 1920 book Rossum's Universal Robots, from which the word robot emerged. Days before finishing this paper AI heavyweights like Elon Musk, Steve Wozniak and the founders of Deepmind published an open letter which demands to pause AI development for half a year, till the effects on the society are manageable and positive. When the author asked the artificial intelligence ChatGpt, it responded that AI is not putting in danger humanity.

The most important thing for having a positive effect on the climate, in addition to better education that conveys the need for action, is collaborative action. The past has shown that when the global community pulls together, as after the hole of the ozone layer, it can work.

ID-77

MINIMASS: a new approach for low-carbon, low-cost 3D printed concrete beams

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Abstract

The construction industry is beset by two well-known problems – high carbon footprint and low productivity growth. 3D printing of concrete offers the potential for massive improvements in both those areas, if real structural uses can be found. This conference paper describes a new and innovative design method for creating 3D printed concrete beams, using external post-tensioning to provide bending and shear capacity. The results offer reductions of up to 70% of the embodied carbon compared to a similarly performing precast concrete beam, with the potential for up to 50% reduction in material costs. A series of physical prototypes have been built, with large-scale load testing carried out at the Technical University of Denmark (DTU) in Copenhagen, the results of which are presented herein.

Keywords: 3D printed concrete; beams; post-tensioning; long-span structures.

1 Introduction

Cost and carbon are the two defining metrics for modern construction projects. Whilst operational carbon has been a focus for some time, an understanding of embodied carbon is becoming more relevant. As the industry is responsible for a large portion of global carbon emissions, there is an urgent need for low carbon solutions.

Materials suppliers are rising to the challenge by leveraging their expertise in materials and processes. However, the commercial incentive for the design community to generate more efficient designs appears to be less effective, for reasons such as low fees or high insurance premiums. This paper describes a new approach to concrete construction, using 3D printing of concrete (3DPC), which allows for increased efficiency of material use through design optimisation and

manufacturing efficiency.

2 Design

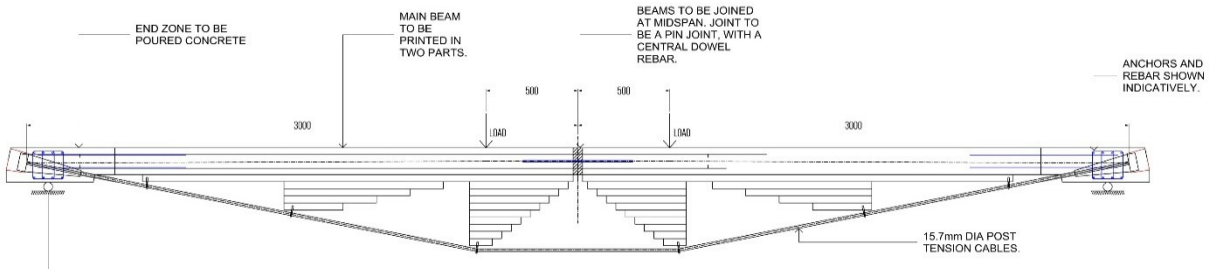


Figure 36: Beam design and load application points adopted in the experimental programme.

3D printing with concrete uses a layering approach to generate geometries. It has gained some level of acceptance within the residential market, for the creation of single storey housing, or 2-3 storey multi-occupation units. However, the boundaries of what is possible for structural components have yet to be exhaustively explored.

The minimass beam is an unreinforced, externally post-tensioned structural element, where the concrete is placed in a specific pattern to maximise the material efficiency. It follows well understood practice in terms of tension and compression within bending structures. However, the critical innovation is to generate a structure based on the principles of the Constant Force Truss, a particular case of structure described in the literature relating to the use of graphic statics. This guarantees compression in the top chord and webs of a truss, whilst guaranteeing a constant tension in the bottom chord. By following these forces, the top chord and webs can be printed concrete, unreinforced as they are in compression throughout, with the bottom chord applied as an external cable structure.

3 Modelling

Modelling is carried out in a two-step process. The first step is to use the graphic statics approach to generate a constant force geometry which responds to the applied loads. This is a simplification of reality as it assumes loads lumped at nodes and only axial forces operating in the system.

The second step is to take the centreline geometry just created and implement a more rigorous analytical approach, including distributed loads and frame elements with bending moments, shear force and axial force. Following the detailed analysis, it is then possible to verify the strength and stiffness performance using common techniques as defined by the relevant codes and standards, in this case Eurocode 2.

4 Experimental investigation

Three 6m long minimass beams were built, each from two half-pieces which were connected together at the midspan with a simple grouted compression joint, which acted like a pin. **Error! R eference source not found.** describes the typical elevation. These were tested under 4-point bending in the laboratory at the Villum Center for Advanced Structural and Materials Testing (CASMaT) at the Technical University of Denmark.

The cross-section and number of external cables varied for the three beams, such that different failure mechanisms could be explored. The first beam, the smallest, failed at a point in the shear span due to buckling which was instigated at the location of an imperfection created during the construction process. The second beam failed due to concrete crushing and splitting at the midspan and the third test experienced a failure of one of the webs through tensile splitting

5 Conclusions

This type of design has a high potential for generating efficient geometries with predictable strength and stiffness performance. The observed behaviour was well matched by the predicted performance following Eurocode 2, therefore it is possible to design such structures based on existing codes without the need for new methods.

Failure types and knowledge gained through the construction process indicate that consideration should be given to the brittle nature of the material, so reinforcement is to be part of future development.

ID-90

Material efficient WAAM Steel Construction Details

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Abstract

With the new manufacturing process Wire Arc Additive Manufacturing (WAAM), it is possible to produce new shapes that previously could only be manufactured with a great effort. The energy-intensive manufacturing process can be positively compensated by the sensible use in mainly material-saving components. In this article, the enormous potential is illustrated by the example of a conventional head plate. Here, 80 % of the material can be saved and waste is eliminated completely. The article furthermore presents the printing, the load-bearing tests and the numerical simulation of the novel structure. A homogeneous component behavior is shown, which can be predicted very well by finite elements.

Keywords: Additive Manufacturing, Carbon Steel, WAAM, Material Efficiency, Bolted Connection, Head Plate, Optimization, Steel Construction

1 Introduction

In today's world, we are feeling the effects of our reckless treatment of nature more and more acutely as extreme weather events become more frequent. The buildings and construction sector has made no small contribution to this. It is therefore essential to look at and develop sustainable, alternative building concepts, materials and shapes.

3D printing as an alternative manufacturing method has the potential to contribute to this change. It allows new structures to be made that adapt to the flow of forces, saving material without excessive waste production during fabrication.

For steel structures, Wire Arc Additive Manufacturing (WAAM) seems to be a promising process in this regard. Compared to other metal 3D printing processes, it is cost-effective and fast, and because it is an arc welding process, it can be easily implemented in conventional steel construction industry.

2 Optimized Head Plate

The large material savings potential of WAAM can be seen in the standard connection component “head plate”. The plate is subjected to high bending loads, especially in the tensile zone. As a result, a relatively thick plate must be selected.

Optimization can be used to search for other shapes. The method has already been used for the tensile area of a standardized head plate connection, resulting in a geometry that saves 60 % of the material compared to the original area of the head plate required for load transfer. The optimization results in a rather interesting structure (Figure 1, left).

In a very simplified way, the result can lead to the following geometry: A small thinner head plate that prevents punching through of the bolt and wings that form coming from the flange up to the level of the bolt to transmit the tensile force (Figure 1, right).

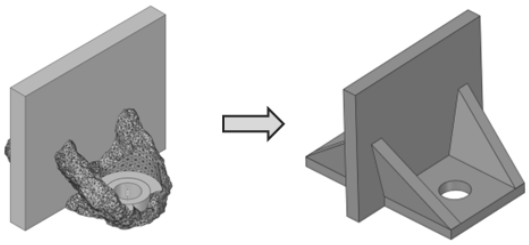


Figure 1. Simplified T-Stub-Model

If such a geometry is selected for the connection of the bolts in the tensile area, the head plate can be manufactured with only 33 % of the original mass, while almost identical ultimate load is achieved.

3 Experimental Load Bearing Tests

This design has been determined simulatively, assuming that the additively manufactured steel behaves like a conventionally hot-rolled steel. It will be shown in the article that the component also behaves as predicted by simulation.



Figure 2. Test setup before and after testing

3.1 Examined geometries

For this purpose, three variants of the optimized geometry (Variants O1-O3) as well as one geometry without wings (Variant R) were tested in destructive tests. The test rig is shown as an example for one specimen before and after testing in Figure 2.

3.2 Simulation with FE

With the material properties obtained from tensile tests, the experiments can be post-modeled using finite elements (FE). The results of the finite element calculation can be seen in the diagram (Figure 3) for two of the tested variants (R and O1).

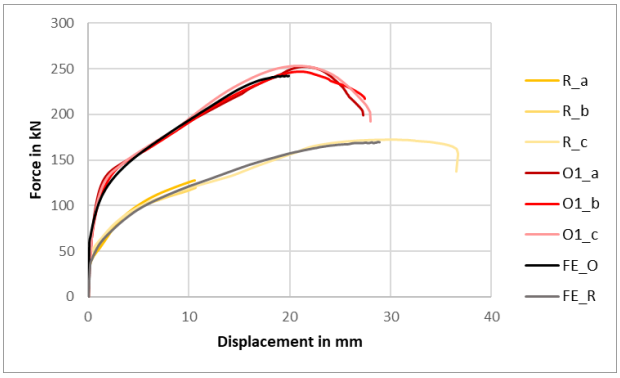


Figure 3. Tests vs. Simulation

3.3 Evaluation

The experimental investigations and the comparison with finite elements show on one hand that the load-bearing behavior of the additively manufactured structures can be well predicted. This means that additive manufacturing offers significant potential for material savings. On the other hand, the wings of the optimized variant stiffen the plate and cause a more favorable load transfer for the bolt, which enables greater ultimate loads.

4 Conclusion

With WAAM, it is possible to produce structures that could only be produced with great effort in conventional steel construction. This makes it possible to save material.

In the article, different geometry variants of a novel design are printed and tested to failure. A load-deformation behavior with low scatter is shown that is homogeneous for each geometry. The tensile specimens produced with the selected welding parameters also allow the material behavior to be defined in FE and the tests to be simulated very well. This shows that WAAM is very suitable for manufacturing steel structures and that the failure can be predicted very well.

The article is intended to encourage thinking about new shapes that are better adapted to the load flow and thus save material.

ID-110

A Holistic Digital Design Approach for a Metro Project in Portugal

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Abstract

The Ruby Line Porto is a new 6.5 km metro project connecting the urban areas of Porto and Vila Nova de Gaia in northern Portugal to be built in the upcoming years till 2025.

The authors have been responsible for the design of six main work packages including the new track, new roads, five viaducts, three underpasses, one pedestrian overpass, one top-down tunnel, multiple retaining walls, and the structures of seven new stations and platforms. Due to multiple collaboration needs with other parties, a consistent digital BIM workflow with a common data structure and alignment of sub-models was of utmost importance for delivering the project successfully.

The introduction and application of a new software tool was predestined for this ambitious plan to model the quite different parts of the project in a common digital environment. The paper shows, which techniques offered by the software had to be used for successful modeling.

Keywords: Metro Project, Sustainability, Digitization, Open BIM, Interoperability

1 Introduction

The two cities Porto and Vila Nova de Gaia situated north and south of the estuary of the Douro River are inextricably linked, with lots of inhabitants daily traveling between them.

The new Metro line will not only provide additional capacity, but also encourage more sustainable travel by shifting commuting habits from individual car traffic to using the Metro.

2 Project Characteristics

In total, the project includes seven stations, 3 emergency and ventilation shafts (PEV) (one of them equipped with a well and pumping system), 2 emergency shafts without ventilation function (PE), connection branches at the first and last stations, and the reformulation of urban avenues / surface space in areas where the new metro line is above ground or in station areas.

The track is approximately half underground and half above ground. Detailed design works were started in 2021, and construction is expected to take 2 ½ years.

3 BIM Procedure

3.1 Digital Environment

The Allplan software suite was chosen as central design tool and BIM platform for this project. This is a software that supports the BIM workflow inter alia by using IFC and LandXML. However, the choice was not only driven by the Open BIM functionality, but mainly considering the powerful parametric design options offered.

3.2 Bridges and Underpasses

The software provided the ability to both create new bridges and underpasses, as well as to adapt new solutions of existing bridges and viaducts. Through the parametric system, it was possible to generate solutions requiring regular adaptation to the urban morphology.

3.3 Tunnel Stretches

Where the depth is not suitable for NATM tunnelling method, these shallower tunnels were designed for top-down construction. Here, the team imported the LandXML axis using Bimplus again, and designed the cross-sections. We used Smart Parts to model the piles along the walls of these tunnel sections.

3.4 Station Buildings

The software was able to go further in terms of integrating BIM models from the company's different business areas. For the first time, we achieved modelling of bridges and viaducts together with metro subway station structures within the same software (Figure 1).

4 Modelling Techniques

4.1 Alignment of Objects

One of the main advantages is the advanced alignment feature. The axis is saved parametrically and can be changed at any moment.

4.2 Parametric Description

The parametric approach uses typical dimensions, planning criteria and development rules rather than actual geometry data. Basic parametric entities are *Alignment*, *Cross-sections*, and *Variations*. The latter (variations defined as mathematical functions or tables) are a speciality of the used software. They can be assigned to all numeric parameters.

4.3 Using Import/Export and Templates

A very useful functionality of the software solution is the possibility to export the information in TCL files (text files). These command language files can easily be edited by standard editors and re-imported after performing the required modifications or extensions.

In addition, QUADRANTE implemented a new parametric workflow to develop viaduct designs. They created a tool manipulating TCL files so that the user can create tables of the viaduct girders in Excel and consider these data in the model.

4.4 Open Exchange Formats

In accordance with the BIM EXECUTION PLAN, the interoperability between the multiple teams and the deliverables to the client, were made through IFC files. Thus, it was possible to combine the information in a comprehensive coordination model.

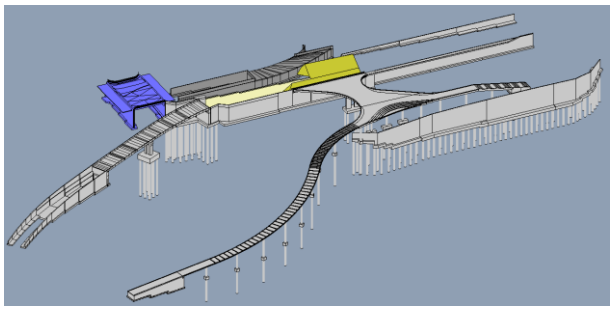


Figure 1. Coordination model of one viaduct + 3 retaining walls + 1 overpass + 2 existing structures

5 Summary

The move to doing Projects in BIM has initiated a mindset shift for the infrastructure team, leading to a considerable improvement of problem-solving capabilities in future projects.

ID-497

3D Printed Sandwich Structural Decks of Dual Corrugate Sheet with Mid Shear Layer (DCMSL) as Core Profile

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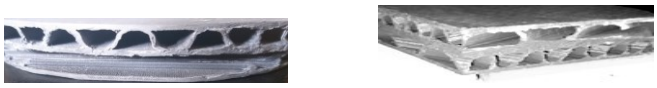
Abstract

structural sandwich panels, made-up-of Advanced Composites Honeycombs / PU-foams sandwich cores, are already in use, extensively in aerospace applications. Further, sandwich composite panels as structural deck units as found from the literature, are also deployed in many civil engineering applications as well. An example of one such application of these structural sandwich decks ardently may be sighted here as those several deck units were successfully deployed over an all Advanced Composites Foot Over Bridge (FOB) system which was then designed and developed earlier for pedestrian traffic by the Author and his team, at Composite Research Center of RDE(E), Pune, India. Prior to deployment of these deck units over this FoB, fabricated entirely in Glass Fibre Reinforced Plastics(GFRP), the development phase of these deck units included creating and conducting number of field trials on these decks in different types of sandwich core profiles and with different geometries and of different materials . Only, a most suited profile was then so spurred out was a single corrugate FRP sheet core profile, sandwiched between two flat co-bonded, co-cured top and bottom FRP laminates to form these sandwich decks. Mere assembly of hardware of these deck units also, turn out various sizes and forms of some temporary dwelling shelters also , these were all erected successfully in the field then. Literature reveals that many similar corrugate core profile sandwich panel development activities that includes the panel creation works in the construction mix materials have all been attempted by many researchers the world over. Use of then available any conventional methods for construction when employed for formation of sandwich decks, specially using the corrugate core profile in sandwich decks in construction mix materials, had however has been reported, only posed certain obvious difficulty that was widely experienced was pertained to achieving those sandwich without having any bond used therein. Having a fear of de-bonding failure perhaps, use of sandwich constructed through then available conventional construction methods, all attempts in the construction industry, thus invariably remained restricted and this very idea to use any of them in construction also remain almost abended till recently. It is only very recent, that additive technology as became well established and apparently those 3D printers have emerged out, thereby, development activities and utilization of sandwich decks idea turn-on further and more complex core profile in sandwich decks may become more apparent as the sandwich decks being monolithically 3D printed out with ease in the field. A few hardware for example, of such corrugated sheet core sandwich profile have already been monolithically 3D printed and successfully used in the field.

This work therefore became as an addendum to that earlier many efforts reported in the literature towards developing any sandwich panels for use in constructions. Thus possible more complex profile as deck cores when created also in the construction mix materials, it is believed to become ,an ideally suited deck/slab for deployment in future for any modern civil engineering construction. This so chosen type of complex core profile considered here and reported in this paper, has actually being an outcome of an experiment that was initially conducted in the lab on merely stacking and bonding of two separately 3D printed out single corrugate monolithic sheet core sandwich panels type already developed as described

above in the preceding lines. Many complex core sandwich decks configuration, as doubly corrugate sheets core profile having a flat mid plane for example, and many more such complex sandwich cores can therefore now be monolithically developed . In order to understand the structural behaviour better of this so look alike two layers of single corrugate sandwich units but actually has been a single monolithic profile, the required orientations of their respective axes of this dual corrugation as orthogonally to each other . These decks are then analysed using 'Advanced Composite Technology(ACT)' and it is reported here for any rectangular decks in this paper. A rectangular, sandwich deck in dual corrugate with mid shear layer core sandwich profile has been considered and the numerical results with different orientations of a simply supported decks for example, to ascertain a most suited orientation in any such sandwich core profile through this study has been obtained . A number of decks with such dual corrugate sandwich core profiles successfully so 3D printed out through FDM based 3D printers, were themselves taken and subjected to load trials in the experimental set ups. Monolithic 3D printing of sandwich decks with its complex profile as observed here, not only did facilitate eliminating any bonding requirements of any two or more separate single corrugate sandwich deck units together, but it also offers now the possibility to achieve any desired increase in depths that at times may be needed to build in decks for any civil engineering application with enhance load carry capacities since higher flexural resistance get in-built therein. Presence of the mid flat layers in these decks factually acts as suitable shear resistance continuous layer, therefore researchers now recommend such complex core profile sandwiches as suitable structural units for any future infrastructure developments, specially as will be 3D printed out in construction mix as well. Adopting therefore the proposed exclusive monolithic orthogonal, dual corrugate core profile with mid shear layer sandwich profile decks turns out as an optimal choice of sandwich decks, can now easily be developed also thus specially suit the situations when deeper section to enhance load carrying capacities but keeping weights to bare minimum with increase in shear stiffness yet reduce in construction costs as that would be need of the art in future civil engineering application projects.

Keywords: Monolithic profile, Sandwich Decks, Dual Corrugate, Advanced Composites Technology, 3D Printing.



(a) use as $\Theta = 0^\circ$ and 90° (b) use as $\Theta = 45^\circ$ or -45°

Recommended structural decks , Orthogonally laid dual corrugate ,monolithic sandwich core profile

ID-1232

Machine Learning Based Optimization Techniques for Predictive Strength of High Performance Concrete: Enhancing Sustainable Development

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Abstract

The pursuit of sustainable growth in the construction sector needs a precise forecast of material characteristics to optimize resource consumption. This research focuses on utilizing the capabilities of well-known XGBoost regression algorithms to forecast the compressive strength of High-Performance Concrete (HPC). In this study, 2171 datasets were collected from literature containing input parameters that influence concrete strength, thereby creating a robust predictive model. The performance indices were assessed using root mean squared error (RMSE) and R2 score. The findings indicate that the XGBoost model outperforms standard statistical techniques in predicting accuracy. This research intends to improve the precision of compressive strength estimation, facilitating the development of more durable and sustainable construction practices.

Keywords: High-Performance Concrete (HPC); Machine Learning; Prediction; XGBoost Regressor; Optimization Techniques; Compressive Strength; Sustainable Development.

1 Introduction

In recent years, the construction sector has seen a considerable paradigm change toward sustainable practices and environmentally responsible approaches. High-Performance Concrete (HPC) is vital due to its remarkable mechanical attributes and potential for improving construction durability and lifetime [1]. Accurate prediction of HPC compressive strength is critical for optimizing material utilization, assuring structural integrity, and reducing environmental impact. XGBoost Regression model have emerged as prominent choices because of their prediction abilities for optimization tasks [2]. This study aims to provide an effective predictive model for High-Performance Concrete (HPC) strength by utilizing established XGBoost regression algorithms. The accuracy of the model was measured using root mean squared error (RMSE) and R2 score, demonstrating that the XGBoost Regressor model outperforms traditional statistical approaches regarding predictive ability.

2 Methodology

A large dataset of 2171 nos was originally generated from the previous work [3]. The dataset was rigorously pre-processed before being fed into the models. Equation 1 denotes the function used for compressive strength prediction.

$$\text{Prediction}=\sum_{i=1}^{n} w_i + t_i(x) + B \quad (1)$$

Where B=Bias term, w_i= Weight for i_{th} tree

prediction, $t_i(x)$= Prediction made by ith tree with input features x, N=Number of trees.

3 Results and Discussions

In this research, the author utilized the XGBoost regression methods to increase the precision of compressive strength estimation of HPC. Figure 1 shows the heat map of the correlation matrix to investigate the prevalent and impactful input combinations with the output variable. Figure 2 depicts the distribution of different Compressive strength values. It has been seen that the histogram visually depicts the values of each variable's frequency distribution, giving information about their distribution.

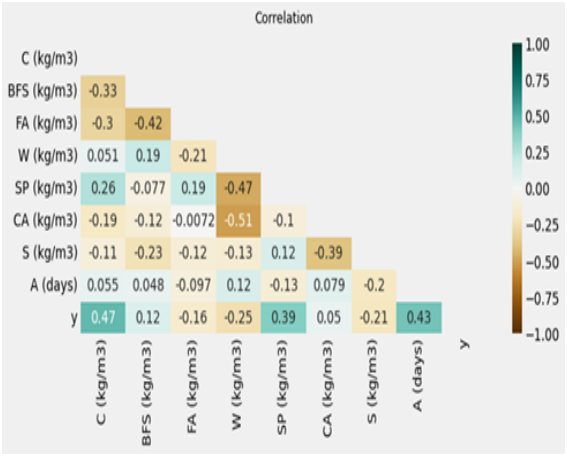


Figure 1. Heat map of correlation matrix

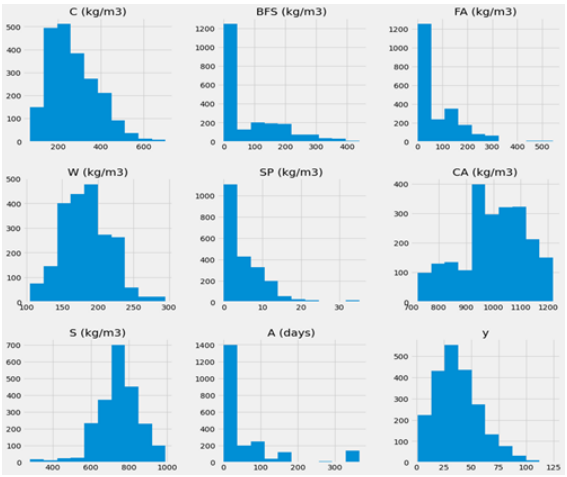


Figure 2. Histogram plot for distribution of dataset

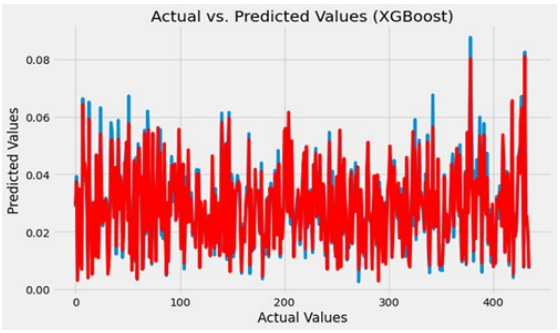


Figure 3. Actual vs Predicted values using XG Boost model

Figure 3 shows the comparison between actual and predicted compressive strength values. The result shows the ability of the algorithm to estimate actual compressive strength values, with close alignment between predicted and actual values. Table 1 shows the performance values of the proposed XG Boost model.

Table 1 Performance of the model

Model &Metrics	RMSE	R2	Data points
RF	4.80	0.93	1030
DT-Bagging	4.72	0.92	1030
MFA-ANN	4.85	0.90	1133
ANN-PCA	4.64	0.92	1030
ABN-CFNN	4.04	0.95	2171
Current Study	3.91	0.96	2171

4 Conclusion and Future Scope

The author effectively developed a robust prediction model for evaluating the compressive strength of HPC by using the XGBoost Regressor. The efficacy of predictive model was assessed using well-established measures such as the root mean RMSE and R2 score. The findings of this study invariably demonstrated the superiority of the XGBoost Regressor model over conventional statistical approaches.

5 References

[1] Aıtcin, P. C. (2003). The durability characteristics of high performance concrete: a review. Cement and concrete composites, 25(4-5), 409-420.

[2] Duan, J., Asteris, P. G., Nguyen, H., Bui, X. N., & Moayedi, H. (2021). A novel artificial intelligence technique to predict compressive strength of recycled aggregate concrete using ICA-XGBoost model. Engineering with Computers, 37, 3329-3346.

[3] Imran, M., Khushnood, R. A., & Fawad, M. (2023). A hybrid data-driven and metaheuristic optimization approach for the compressive strength prediction of high-performance concrete. Case Studies in Construction Materials, 18, e01890.

Session 11

Sustainability in Built Environment

ID-146

Effect of Slenderness on the Design of FRP reinforced Concrete Columns

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Abstract

Fibre-reinforced polymer (FRP) bars can be a promising sustainable alternative to steel due to their low life-cycle cost and potentially low environmental impact as a reinforcement. This paper investigates the behaviour of FRP-reinforced concrete (FRP-RC) columns with varying slenderness ratios. The reduction in moment capacity, axial load capacity and load-moment interaction diagrams of FRP-RC columns with the increase in slenderness are studied in comparison to steel-reinforced concrete (steel-RC) columns. The study shows that guidelines and design standards such as Eurocode 2 for steel-RC pertaining to the simplified design of slender columns, slenderness limit and minimum reinforcement ratio need to be revised for FRP-RC columns.

Keywords: Fibre-reinforced polymer bars, FRP-reinforced concrete columns, slender columns

1 Introduction

In this study, the behaviour of FRP-RC columns is examined along with the consideration of geometric non-linearity arising out of the slenderness ratio (λ). To examine the behaviour of the FRP-RC column in comparison with the concrete steel-RC column, a numerical method was implemented in Matlab (R2022b) for second-order analysis of reinforced concrete columns with a rectangular column cross-section of 300 x 300 mm with corner reinforcement.

2 Load-moment interaction

Due to the linear elastic behaviour of FRP bars the portion of the FRP-RC load-moment interaction diagram below the balance point will lead to a brittle-tension failure and it is undesirable to design a section in this region. Generally, the balance point is observed for low reinforcement ratios (ρ) such as 1% as seen in Figure 1 however, it can even appear for higher reinforcement ratios, as the concrete compressive strength (f_c) increases or the ultimate tensile strain (ε_{TFRP}) of the FRP bar reduces. Hence to avoid brittle-tension failure a minimum reinforcement ratio based on all the affecting parameters shall be ascertained such as concrete compressive strength, modulus of elasticity of FRP bar, ultimate strain of FRP bar and axial force in the column. For steel-RC columns with a steel yield strength (f_y) of 500 MPa, a balance point is observed for all values of the reinforcement ratio which signifies that its appearance in the load-moment interaction curve is not affected by the reinforcement ratio. For steel-RC columns, the balance point occurs generally at the “knee” bend of the load-moment interaction curve and normally this is at the location of maximum moment capacity. However, for FRP-RC columns balance point does not occur at the “knee” bend of the load-moment interaction curve and the location of the balance point is not the location of maximum moment capacity, as seen in Figure 1. The position of the balance point would be of importance in estimating the curvature for the design of long columns using approximate

design methods based on the column curvature such as the nominal curvature method in Eurocode 2 [1]. In such methods for steel-RC, the curvature of the column at the maximum moment capacity or at the balance point is used to estimate the column curvature at the level of design load.

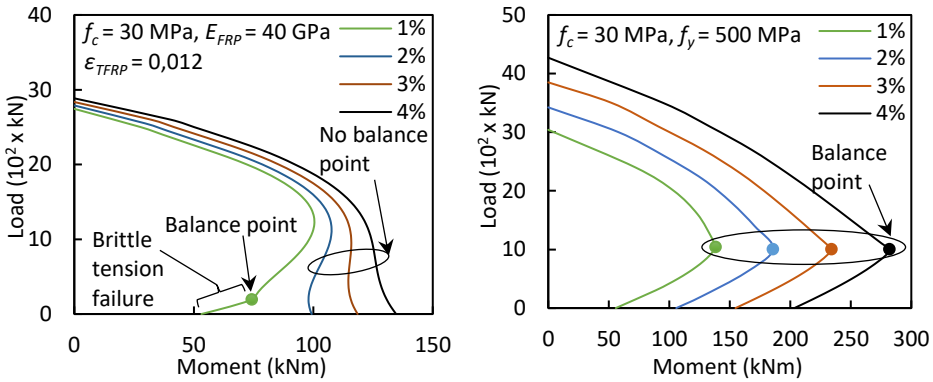


Figure 1. Load-moment interaction curves for (a) FRP-RC and (b) steel-RC columns with λ = 0 (no second-order effects)

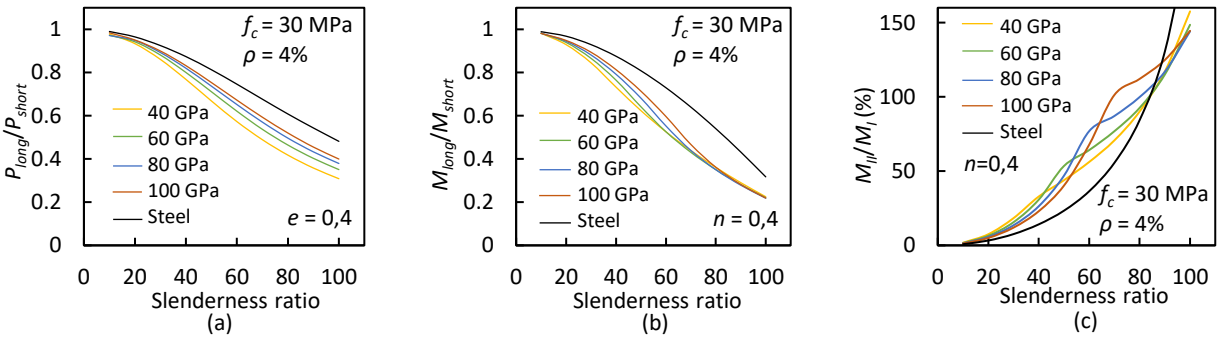


Figure 2. (a) Load capacity reduction, (b) moment capacity reduction and (c) increase in M_{II}/M_I due to an increase in λ for varying modulus of elasticity of FRP bar

3 Capacity reduction for slender columns

FRP-RC columns are more susceptible to capacity reduction in terms of load capacity (P_{long}) at constant eccentricity ratio (e) and moment capacity (M_{long}) at constant axial force ratio (n) as the slenderness ratio (λ) increases with respect to the cross-sectional load capacity (P_{short}) and moment capacity (M_{short}) as shown in Figure 2. This would affect the nominal stiffness estimation of FRP-RC columns for simplified methods of design of long columns such as the nominal stiffness method. Also, the rise of second-order moments (M_{II}/M_I) with respect to first-order moment (M_I) is faster in FRP-RC columns as compared to steel-RC columns indicating a lower value of slenderness limit compared to steel-RC columns. The existing equations for slenderness limit in steel-RC column design standards need to be revised for FRP-RC columns.

4 Conclusions

The paper shows that the characteristics of the load-moment interaction curve of the FRP-RC column are different in comparison to the steel-RC column such as the appearance and location of the balance point for both short and slender columns. The estimation of nominal curvature and nominal stiffness for approximate design methods of long columns, slenderness limit and minimum reinforcement in Eurocode 2 need to be revised for FRP-RC columns.

ID-176

Disruptive Change in Mineral Building Materials - High-Performance Prefabricated Elements Made of UHPC for Circular Buildings

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Abstract

Concrete (NPC) is the most commonly used building material worldwide, which has great development potential in the form of UHPC. With the help of high-performance prefabricated elements, significant advantages can be achieved in relation to the classic in-situ concrete construction in terms of resource and energy efficiency as well as in terms of recyclability and durability. This report uses specific application examples to show the savings that can be achieved in manufacturing phase A. When used appropriately for the material, high-performance precast elements made of UHPC can save up to 85% in resources (R) and up to 65% in energy (GWP = CO2e = E) achieve. The implementation of high-performance prefabricated parts in our new buildings enables significant changes in buildings, both in terms of emissions consumption and urban mining potential. The disruptive change in the construction industry requires consistent choose, want, venture and repeat from those involved. In this regard, we are all called upon to make a contribution together.

Keywords: Include a list of not more than 10 keywords, for example: post-tensioning; anchors; slabs; walls; high-rise buildings.

1 Introduction

Building has always represented the fight against erosion, which has been countered by constant technological developments over the course of building history, with the result that ever more energy-intensive construction methods have become established across all materials. In the 21st century we are at the crossroads of counteracting these energy-intensive construction methods with new technological developments. Resource and energy efficiency as well as the conversion of the linear economy into the circular economy are in the foreground in almost all specialist areas of constructive building research. It is undisputed that the future path to a reasonably climate-neutral circular economy by 2040 will involve far-reaching transformations in buildings, industry and production.

If one looks at the emissions of a building or a component over the life cycle phases, one can assume that approx. 55% of the total energy in the production phase (phase A1-A5) is mainly emitted as embodied energy (PENRT). The embodied energy of building materials is determined by the choice of material, the choice of structure and the manufacturing process of the building materials, the design process of which is referred to as creative potential for climate-friendly constructions. New developments in the material sector, which have increasingly resulted from the material concrete since the turn of the millennium, include glass-fiber concrete, ultra-high-performance (UHPC) concrete, gradient-concrete and carbon-concrete and have the common goal of improving the properties of the material on the one hand through its ecological balance sheet and on the other hand through adjustments to the required application conditions to improve.

The building material reinforced concrete or UHPC is an anisotropic material that can be used both as a beam and as a plate with optimization options for

the inner and outer structure. Optimization means a consistently high utilization of the material properties across the building material, which means that in addition to resource efficiency ΔR, high energy efficiency ΔE of the design can also be achieved.

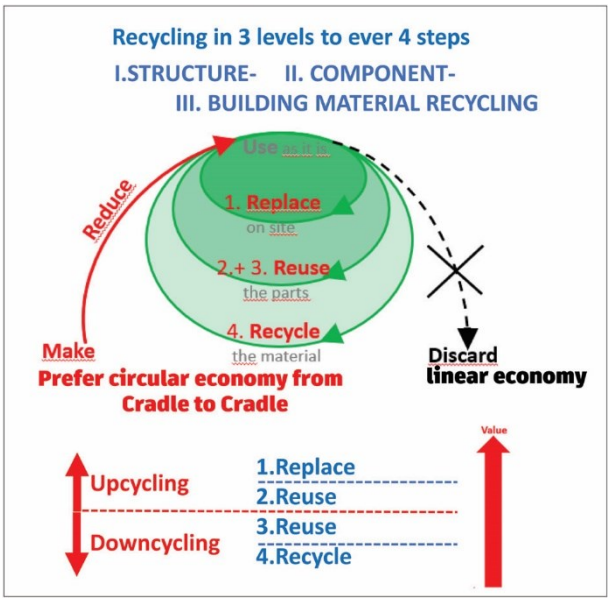


Figure 1. Circular economy for high-performance precast elements

However, the preferred choice of material for the shell construction is largely determined by the circular economy of the construction. The aim of future construction should be that once energy has been introduced into the system in the form of embodied energy, it should remain in the system for as long as possible. Therefore, replace is the form of recycling to strive for. However, in order to be able to maintain the constructions in as many cycles as possible (from cradle to cradle), it depends on how the building components are dismantling at the end of a life cycle and mantling in new cycles permit. Due to their durability and prefabrication, high-performance prefabricated elements offer the ideal conditions for circular economy. Dismantling is possible for all high-performance prefabricated elements listed in this article. As shown in Figure 1, recycling basically takes place in three levels, each with 4 steps. The highest level in the recycling of buildings, building components and building materials is replace, followed by reuse. Upcycling takes place in each case.

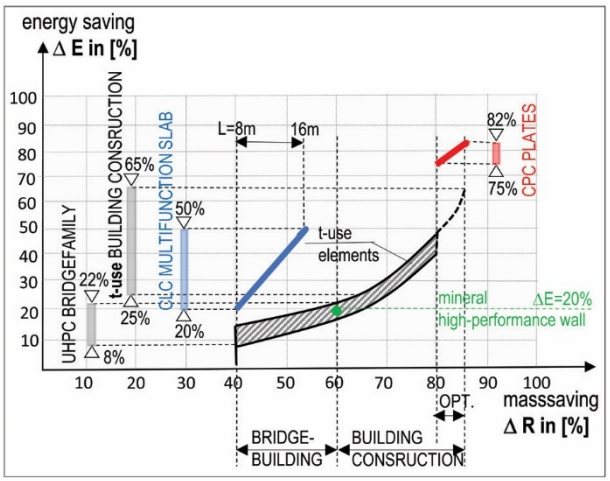


Figure 2. Relationship between recource savings ΔR [%] and energy savings ΔE [%] of high-performance precast elements compared to in-situ concrete solutions

Figure 2 summarizes various applications of the high-performance precast elements in connection with possible mass savings ΔR and energy savings ΔE compared to conventional in-situ concrete solutions. For high-performance precast UHPC building materials (e.g. t-use), the mass savings range is ΔR = 60 - 85% and the associated energy savings are ΔE = 20 – 65 %. Further mass savings of ΔR = 80-85% are only possible through further optimization of the outer structure, e.g. through integrated openings in places where stress utilization is low. For the high-performance prefabricated element of the CLC multifunctional slab, the savings compared to a classic reinforced concrete flat slab are, depending on the span (preferred application range L= 8 to 16 m), in resources at ΔR = 40 – 55 % and in gray energy at ΔE = 20 - 50 %. With the high-performance lightweight concrete wall, the savings in resources are ΔR= 60% and in energy ΔE = 20 %.

ID-191

Mapping structural engineering strategies for sustainable development

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Abstract

In 2015 many countries signed the Paris agreement. These countries agreed that global warming should be limited to 2 degrees, preferably 1,5 degrees Celsius, to avoid inevitable, catastrophic, and hard to control consequences. It is evident that a change of behaviour is needed across the whole of society to limit CO2 emissions and get us anywhere near the set target of 1, 5 degrees Celsius.

Considering current trends in the Netherlands with regards to sustainability, there is a strong desire at Delft University of Technology to incorporate sustainable structural design strategies in the civil and structural engineering curriculum. Based on literature study and own experiences in practice, a coherent approach was developed, that can help students and practitioners to increase sustainability in their projects. The approach consists of a roadmap with 4 key strategies: increase lifespan of existing structures by reusing them, increase lifespan of existing structural elements by reusing them, design future proof and with a long-life span, and optimise the design for environmental impact. The key points from every strategy are depicted in the figure below. In the paper the strategies are explained and illustrated with examples.

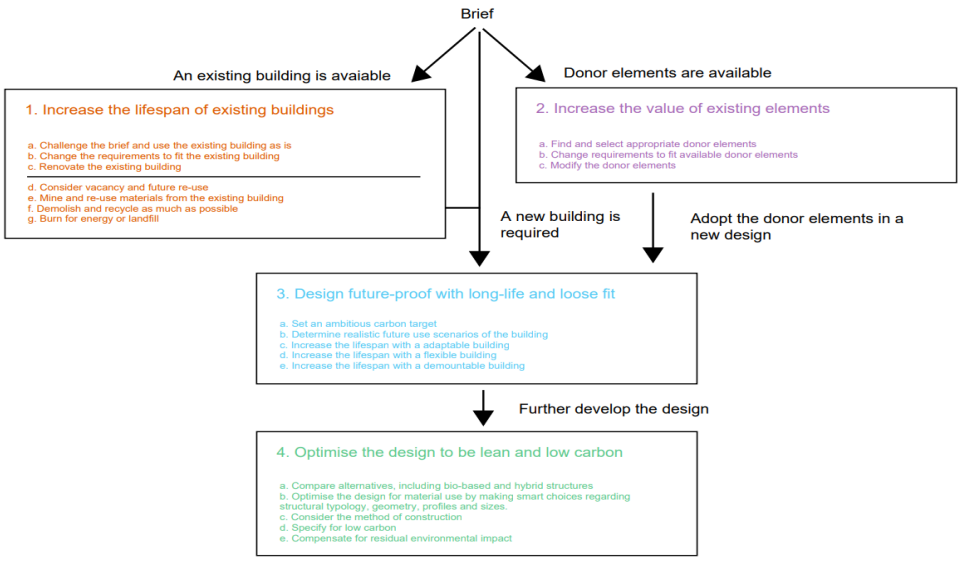


Figure: key points from the main strategies

The challenge for the structural engineer is to come up with a sustainable design. This can start as early when challenging the client brief . Subsequently, a clear hierarchy of strategies can be adopted in the design process.

Most sustainable is not using new materials at all, by considering to what extent existing buildings, existing elements or renewable elements are available. Irrespective of the use of existing or new materials, it is important to set the limits for the allowable environmental impact of the design, and to consider realistic use and change scenarios. This enables a future-proof building with the “long life, loose fit” strategy.

Finally, within the constraints set by these previous steps, the final step is to create a lean structure with efficient material use and a sustainable specification, adopting bio based materials were reasonably possible.

Keywords: sustainable structural design, environmental impact, carbon footprint

ID-203

Mechanical Behavior and Load-Bearing Capacity of Components Made from Sustainable Lime-Paper Material

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Abstract

The efforts of the national states to significantly reduce co2 emissions will have a major impact on the construction industry. In particular, production of gypsum, which is mainly obtained by flue gas desulfurization, will decrease. A replacement of gypsum by sustainable lime-paper, mainly produced from secondary raw materials, is considered for various applications. In this paper, the mechanical properties of components feasible with lime paper are investigated and compared with the requirements of the construction elements.

Keywords: lime-paper, secondary raw materials, replacement materials, sustainability, strength

1 Sustainable building material limepaper made

Gypsum is an essential finishing material, mostly as plasterboards. In Germany, more than 50% is FGD gypsum, a cheap by-product during the flue gas desulfurization at coal-fired power plants. Due to the German cut of coal-fired plants, around 5 million tons of gypsum will be missing from 2038. It is urgent to replace the loss of FGD gypsum by alternative products with similar mechanical properties. The main criteria are based on the requirements as a component for interior applications, in which gypsum and plasterboards are currently used. Mineral building materials are mixtures of binders, fillers and additives. The composition of a sustainable interior building material that can serve as plaster alternative should maximize secondary or recycle raw materials and minimize primary raw materials.

2 Test specimens, panels and bricks

Various mixtures were produced in different compositions varying the percentage of each component. Specimen (prism) of 4 cm x 4 cm x 16 cm were produced manually. 14 days after production, the bending strength (3-pointbending) and compressive strength were tested.

The test results show a similar picture across the different mixtures. With a specific weight of app. 750 kg/m3, the test specimens are considerably lighter than gypsum.

Regardless of the mixture, the test specimens have a compressive strength of between 0 N/mm2 and 1.0 N/mm2. The bending strength is between 0 und

0,3 N/mm2. Mixtures with sand 0/2 as filler (mixture D-F) deliver very poor strength. Generally, the increase of binders does not necessarily increase the strength.

Generally, the compressive strength is improved by the addition of very small, powdered additives. The use of mineral grinding residues has a positive effect and increases the degree of sustainability.

For further production and investigation of plates and bricks, mixture A with 100 g of shredded newspaper, 600 g of water, 300 g of limestone powder, and 250 g of lime was used

Experimental matrix													
Specifications in grams	Mixture A	Mixture B	Mixture C	Mixture D	Mixture E	Mixture F	Mixture G	Mixture H	Mixture I	Mixture J	Mixture K	Mixture L	Mixture M
Paper	100	100	100	100	100	100	100	100	100	100	100	100	100
Water	600	600	600	467	600	600	600	600	600	600	600	600	600
Limestone-flour	300	250	200	67	150		350	400	500	600			
Abrasive glass particles											300	250	200
Silica sand		50	100									50	100
Sand 0/2				67	150	300							
Air hardening lime	250	250	250	133	300	250	200	150	100		250	250	250
Total Weight	1250	1250	1250	834	1300	1250	1250	1250	1300	1300	1250	1250	1250
Dry weight	650	650	650	367	700	650	650	650	700	700	650	650	650

Overview of results													
Results after 14 days	**Mixture A**	**Mixture B**	**Mixture C**	**Mixture D**	**Mixture E**	**Mixture F**	**Mixture G**	**Mixture H**	**Mixture I**	**Mixture J**	**Mixture K**	**Mixture L**	**Mixture M**
Average bulk density	787 kg/m³	759 kg/m³	788 kg/m³	640 kg/m³	799 kg/m³	773 kg/m³	748 kg/m³	780 kg/m³	782 kg/m³	913 kg/m³	847 kg/m³	792 kg/m³	792 kg/m³
Average compressive strength of the prisms	0,83 N/mm²	0,99 N/mm²	0,95 N/mm²	0,46 N/mm²	0,03 N/mm²	0,44 N/mm²	0,58 N/mm²	0,60 N/mm²	0,73 N/mm²	0,93 N/mm²	0,99 N/mm²	0,63 N/mm²	0,67 N/mm²
Average bending strength of the prisms	0,30 N/mm²	0,34 N/mm²	0,31 N/mm²	0,00 N/mm²	0,00 N/mm²	0,00 N/mm²	0,02 N/mm²	0,15 N/mm²	0,14 N/mm²	0,05 N/mm²	0,33 N/mm²	0,23 N/mm²	0,26 N/mm²

Table 1. Matrix and Testing results of Compression and Bending Testing of lime-paper mixtures



Figure 1. Lime-paper specimen

In interior construction, panel-shaped building elements are the most cost- and time-efficient way to clad rooms. The lime-paperboard panels are manufactured by hand. An uncovered board is manufactured and, after drying, glued into the cardboard cover. The cardboard material is taken from the industrial production of gypsum boards. The thickness of the board is 12.5 mm, which is comparable to gypsum board.



Figure 2. Lime-paper plasterboard

According to DIN 4103 the bending testing was performed and delivered fracture loads between 120 and 220 N with deformations in the range of 50 mmm to 70 mm. Use as monolithic component in brick format

In a student project, the suitability of the investigated material lime board as a building bricks was examined at the example of standard bricks 240 mm x 115 mm x 71 mm.

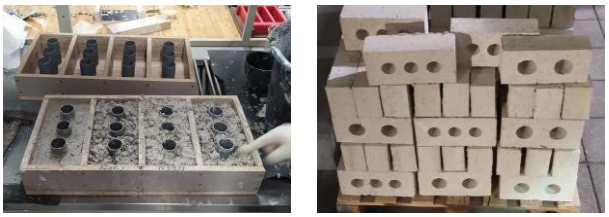


Figure 3. Lime-Paper bricks at production

For the bearing capacity test of masonry, RILEM test specimens were built and tested according to DIN EN 1015 and resulted in strength values of about 1 N/mm², which is at the lower end of the usual masonry strength characteristics, which end between 0.9 N/mm2 and ~15 N/mm2

Finally, the student group build an arch of 3 m span, 0.75 m with and 60 cm rise.

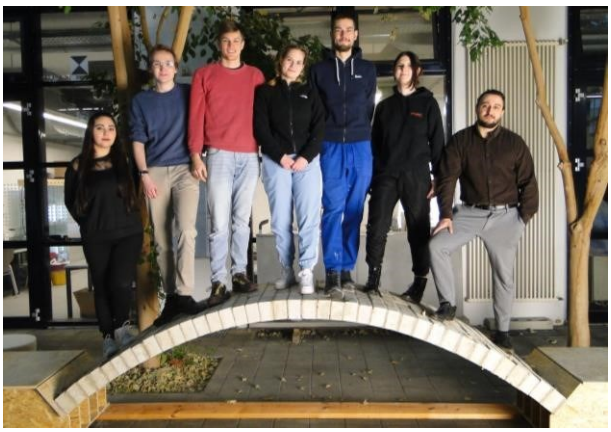


Figure 4. Lime-paper arch

3 Conclusions

Lime paper is a lightweight (750 kg(m3)) material that can potentially be used for various interior elements. Various tests have shown a certain strength, which needs to be further increased to compete with gypsum elements.

ID-205

Replacement of Gypsum Plasterboard With Sustainable Secondary Raw Material Composition

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Abstract

Climate change and the efforts of states to significantly reduce CO2 emissions require considerable efforts in the construction industry. Interior components in particular offer the potential to test new building materials. Gypsum is an essential finishing material, especially in the form of plasterboard. Due to the German cut of coal-fired plants, around 5 million tons of gypsum will be missing from 2038. It is therefore urgent to replace the loss of FGD gypsum by alternative products with similar mechanical properties, that can be produced at similar cost and in an adequate volume worldwide. In addition, however, these building materials must also be compostable, non-toxic and meet sustainability criteria. The paper describes approaches for substitute

Keywords: lime-paper, secondary raw materials, replacement materials, sustainability, gypsum, plasterboard.

1 Introduction

Climate change and the efforts of states to significantly reduce CO2 emissions require considerable efforts in the construction industry.

Interior components in particular offer the potential to test new building materials due to the low requirements for building law, statics and building physics.

Gypsum is an essential finishing material, especially in the form of plasterboard.

More than 50% of the gypsum available on the German market is FGD gypsum.

Due to the German cut of coal-fired plants, around 5 million tons of gypsum will be missing from 2038.

It is therefore urgent to replace the loss of FGD gypsum by alternative products. In addition, however, these building materials must also meet sustainability criteria. This is a major and responsible task in the construction industry.

2 Gypsum production and Alternatives

Gypsum as a raw material is extracted by mining as gypsum rock, but today it also frequently occurs as a by-product of various large-scale chemical processes, the flue gas desulfurization process.

Up to 7 million metric tons of FGD gypsum, that is 55% of the total gypsum amount, are produced each year in German lignite and hard coal-fired power plants. With the energy turnaround, the available quantity of FGD gypsum will decrease in perspective.

There are efforts to replace gypsum. However, this is currently proving difficult, as no suitable recycled gypsum substitute products exist to date.

In addition to efforts to increase the recycling rate of gypsum, the development of alternative

building materials for interior finishing plays a prominent role in countering the foreseeable shortage of gypsum.

The main criteria are based on the requirements for interior components, such as non-toxic, recyclable, easy to work with, in which gypsum is currently also predominantly used, e.g. as plasterboard or gypsum filler, and on overall compatibility. For this purpose, studies were made.

Experimental matrix													
Specifications in grams	**Mixture A**	**Mixture B**	**Mixture C**	**Mixture D**	**Mixture E**	**Mixture F**	**Mixture G**	**Mixture H**	**Mixture I**	**Mixture J**	**Mixture K**	**Mixture L**	**Mixture M**
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Water	600	600	600	467	600	600	600	600	600	600	600	600	600
Limestone-flour	300	250	200	67	150		350	400	500	600			
Abrasive glass particles											300	250	200
Silica sand		50	100									50	100
Sand 0/2				67	150	300							
Air hardening lime	250	250	250	133	300	250	200	150	100		250	250	250
Total Weight	1250	1250	1250	834	1300	1250	1250	1250	1300	1300	1250	1250	1250
Dry weight	650	650	650	367	700	650	650	650	700	700	650	650	650

Overview of results													
Results after 14 days	**Mixture A**	**Mixture B**	**Mixture C**	**Mixture D**	**Mixture E**	**Mixture F**	**Mixture G**	**Mixture H**	**Mixture I**	**Mixture J**	**Mixture K**	**Mixture L**	**Mixture M**
Average bulk density	787 kg/m³	759 kg/m³	788 kg/m³	640 kg/m³	799 kg/m³	773 kg/m³	748 kg/m³	780 kg/m³	782 kg/m³	913 kg/m³	847 kg/m³	792 kg/m³	792 kg/m³
Average compressive strength of the prisms	0,83 N/mm²	0,99 N/mm²	0,95 N/mm²	0,46 N/mm²	0,03 N/mm²	0,44 N/mm²	0,58 N/mm²	0,60 N/mm²	0,73 N/mm²	0,93 N/mm²	0,99 N/mm²	0,63 N/mm²	0,67 N/mm²
Average bending strength of the prisms	0,30 N/mm²	0,34 N/mm²	0,31 N/mm²	0,00 N/mm²	0,00 N/mm²	0,00 N/mm²	0,02 N/mm²	0,15 N/mm²	0,14 N/mm²	0,05 N/mm²	0,33 N/mm²	0,23 N/mm²	0,26 N/mm²

Table 2. Matrix of mixtures for lime-paper compositions and Testing results of Compression and Bending Testing



Figure 4. Shredded newspaper and Lime-paper pulp



Figure 5. Lime-paper specimen

3 Testing results

Regardless of the mixture, the test specimens have a compressive strength of between 0 N/mm2 and 1.0 N/mm2. The bending strength is between 0 und 0,3 N/mm2. Generally, the increase of binders does not necessarily increase the strength. Mixture J without lime delivers surprisingly high strength.

The thermal insulating behavior seems to be significant due to the lightness, but requires more precise measurements.

Preliminary fire tests have shown that the test specimens are non-flammable and can withstand temperatures in the range of up to 700 °C. Further investigations into fire behavior are planned.

Based on the standard mixture A the A1-A3 GWP-CO2- equivalence was calculated with app 650 kg CO2 eq./t. Considering the lightweight of lime-paper materials of app. 750 kg / m3 compared to the weight of gypsum of app. 2300 kg /m3 the GWP-CO2 equivalence can be expressed for lime-paper material with app. 480 kg/m3 compared to gypsum cardboard with app. 350 kg /m3.

4 Conclusions

A big advantage of lime-paper lies in the use of only natural materials and the non-toxic nature of the individual substances. Lime-paper is compostable and decomposes into limestone, cellulose and mineral fillers.

Investigations into the application in components were also carried out by the authors and are published.

A complete composability and final use as lime fertilizer for forests is given. Thermal insulation behavior and fire behavior are promising and require further investigation.

ID-207

Sustainability by Integration of Existing Structures into new Infrastructures

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Keywords: Sustainability in structural engineering, underground structures, existing structures, fire protection

One of the solutions for sustainable development of transport infrastructure is upgrading the old transport system or – in case a substantial enlargement of capacity is needed – by integrating existing transportation structures into new transportation structures with higher capacity. However, the upgrading and/or integration of existing structures goes along with demanding engineering tasks:

- Reassessment of the existing structure
- Actual integration (e.g. connection design and wholistic assessment)
- Fire protection

In many cases deviations from codes and regulations become necessary. Therefore, project-related approvals which allow to go beyond the scope of current codes and regulations are required. This often necessitates laboratory testing. Therefor it seems promising to work towards an expansion of testing capacities and the establishment of further testing facilities to be prepared for future needs.

Using three case studies, the present paper reports on the experiences from an infrastructure project in Germany. The planning and construction task is characterised by the integration of existing structures into a newly built tunnel and underground station on a vast scale.

Case Study 1: Reassessment

A finite element analysis of the monolithic structure of the underground station predicted excessive cracking of the existing structure at the intersection of the western exterior wall with the bottom slab (Fig. 1 (a), (b)). Unfortunately, the excessive cracking was predicted to extend to the inaccessible outer surface of this intersection. Thus, neither an inspection nor the preventive application of an exterior crack-bridging waterproofing was feasible.

As a first approach, it was proposed to consider the surface reinforcement as an *envelope layer* (Fig. 1 (b)). This near surface layer of comparatively small-diameter bars should form an enveloping layer around the highly reinforced tension chord with its large rebar diameters. This envelope layer is then considered as an independent tension chord with comparatively small crack widths due to the smaller rebar diameters.

Because this approach partially transgresses the regulations, a consultant was asked for an expertise. In summary, it can be stated that a crack width of up to 0.3 mm is acceptable if continuous seepage can be effectively prevented. As a solution, it is planned to apply a sealing in the form of crack bandages or concrete to the interior surface. Depending on the solution to be chosen, laboratory tests may be necessary.

Case study 2: Integration

In contrast to *reassessment*, the term *integration* is to be understood to include design tasks regarding the static/structural design of connections between new and existing structures as well as the design of the overall structural system which consists of new and existing components.

For the described project, it became clear during preparatory excavation works and further detailed investigations, that solutions beyond the scope of the current building code rules must be found:

On the one hand, the narrow spacing of the as-built reinforcement–especially in joint areas–must be accounted for. In the existing structure, rebar laps with barely existing to none distance between adjacent laps have been identified.

On the other hand, considerable internal concrete deficiencies within the structure were found. Here, solutions for the rehabilitation of these deficiencies and/or theoretical models for the shear force transmission in these zones must be developed.

As a third issue, the fatigue strength of welded joints, which will be necessary for connecting the reinforcement of newly erected parts to the existing structure, must be verified. However, according to the current code regulations, only flash butt welding is permissible for welded joints in case of tension fatigue loading. However, this is not applicable in this specific project due to the in-situ geometry and rebar arrangement. For this reason, laboratory tests on welded joints specimens and a project-related approval becomes necessary. To validate the test results, additional specimens are produced under in situ conditions (Fig. 1 (c)).

Case study 3: Fire Protection

Parts of the existing structure which will be integrated as a tunnel deck in the later structure, are not equipped with an additional layer of welded mesh fabric reinforcement, as it was required by the guideline applicable at the time of construction of the tunnel. Therefore, strengthening for fire protection was necessary. This was achieved by installation of additional welded mesh fabric reinforcement into a layer of shotcrete.

However, as the applicable guideline does not provide any regulations regarding structural strengthening for fire protection with the help of shotcrete, large-scale fire tests had to be conducted. Altogether six large-scale fire tests were carried out with a temperature-time profile according to the design fire curve (Fig. 1 (d)–(f)). These fire tests showed that excessive heating of the load-bearing reinforcement can be prevented by applying a shotcrete layer containing PP fibres.

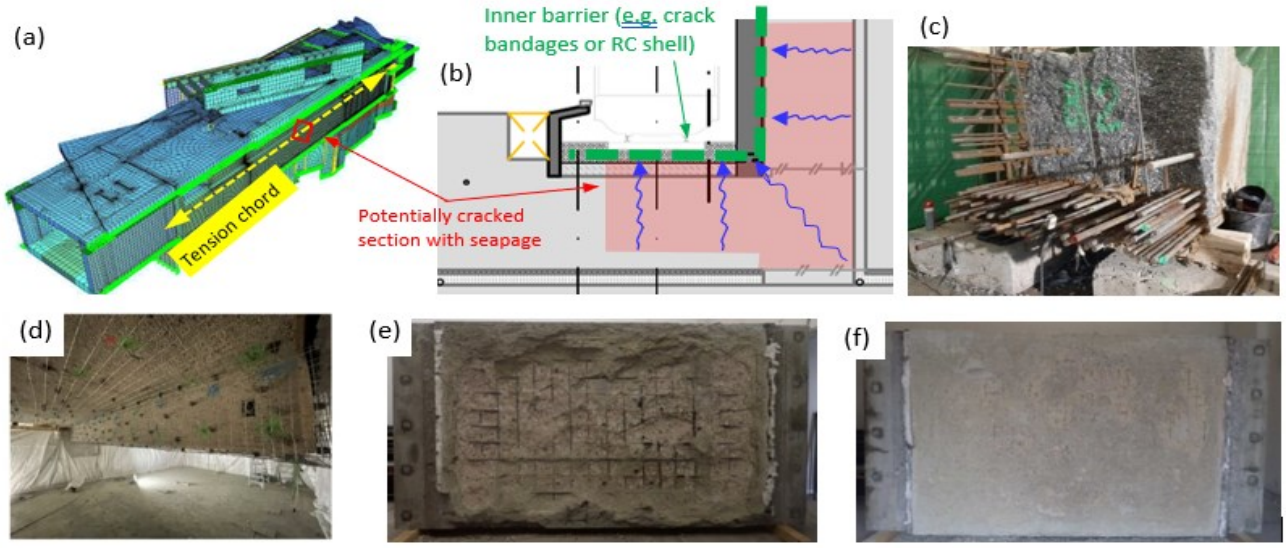


Figure 1. (a) FE-model, (b) cracked tension chord with sealing, (c) preparation of specimen under in-situ-conditions for fatigue testing of butt joint welding, (d) fire protection: additional N94-reinforcement ready for shotcrete-strengthening, (d)–(e) specimen after fire testing without (d) and with (e) PP-fibres

Session-12

Heritage Structures

ID-358

Bridges as Built Heritage: Preservation, Reimagination, Transformation

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Abstract

From ancient civilizations to thriving industrial cities, mobility infrastructure provides safe crossings and promotes economic vitality within both urban and rural communities. Bridges provide rituals of movement connecting users to key parts of our collective cultural identity. Built heritage is a form of placemaking – and the preservation of built heritage creates both environmental and social value.

Dissing+Weitling presents three unique projects to illustrate how cities can balance infrastructure and public safety demands with cultural heritage. Scotland's Queensferry Crossing, Canada's Samuel De Champlain Replacement Bridge, and Switzerland's Zweite Hinterrheinbrücke provide examples of how bridge architecture can reinforce cultural heritage while adapting to modern safety and user needs for safe crossing – whether through ensemble, replacement, or expansion of heritage infrastructure.

Keywords: built heritage; cultural heritage; replacement bridge; ensemble bridges; stakeholder engagement; transformation; train infrastructure; pedestrian bridge; cultural identity

1 Bridges as Built Heritage

Mobility infrastructure is built to last: with intended lifespans of centuries rather than decades, it is an inevitability of bridge design to consider how local communities will not only functionally benefit but also find cultural relevance and pride within their routine crossings.

Where local planning authorities must balance competing demands to accommodate increased traffic volume, public safety, and environmental impact – mobility architecture can provide a complementary pathway to socially sustainable value creation. By incorporating cultural heritage considerations into the evaluation of a project's stakeholders, function, and form, infrastructure development can be seen as a placemaking effort.

Dissing+Weitling presents three unique cases to demonstrate how infrastructure development can create social value through the lens of cultural heritage. Each project exemplifies how considerations of built heritage can widen the scope of a project's community relevance beyond economic vitality and assurance of public safety. These cases attempt to answer the question: how can mobility architecture reinforce cultural heritage while providing safe crossing?

2 Queensferry Crossing

Queensferry Crossing is both an innovative stand-alone bridge and a carefully planned cultural heritage development. Completed in 2017, the bridge crosses the River Forth (locally Firth of Forth) to connect Edinburgh to the County of Fife.

For all its landmark qualities, Queensferry Crossing is first and foremost an ensemble bridge. With an alignment alongside the UNESCO World Heritage-listed 19th-century Forth Bridge and the 20th-century long-span suspension Forth Bridge – Queensferry Crossing can be viewed in direct conversation with complementary infrastructure across functions, aesthetic styles, and temporal dimensions.

Queensferry Crossing provides a case for how three distinct objectives – traffic solution, landmark architecture, and cultural heritage development – can be unified to create social value. The bridges themselves are not merely crossings – but connection points to the history of the region and they provide locals with a tangible sense of place. The addition of Queensferry Crossing can thus be seen as strengthening these cultural connections – reinforcing history and connecting past to future.

3 Samuel De Champlain

The Samuel de Champlain Bridge was a necessary and vital replacement project with an incredibly difficult time horizon – seven years from concept to completion. The Original Champlain Bridge – a steel cantilever bridge – had reached the end of its useful life after fifty years. A major expressway connecting Montreal and its suburbs, it was not an option for the original structure to be reinforced or transformed. Moreover, it was essential to local planning authorities that the connection to the originally built heritage was not severed during construction and demolition – setting the stage for a parallel replacement which provided a rich juxtaposition of the decommissioning of a local icon with the emergence of a new landmark.

Despite the inherent nature of demolishing the existing bridge, The Samuel De Champlain Bridge can still be viewed in this context as a socially sustainable development project. Both the bridge as a product and the stakeholder engagement initiatives as a process – ensured that the replacement project could respect both past and present while ensuring a safe and dynamic future.

4 Zweite Hinterrheinbrücke

Completed in 2019, Zweite Hinterrheinbrücke is a sleek 'little sister' to the historically listed 1895 Erste Hinterrheinbrücke – a half-timber truss bridge supporting the UNESCO Listed Albula and Bernina Alpine train routes. The new 200-metre crossing over two main Rhine tributaries, Zweite is an ensemble bridge alongside the original structure – providing necessary structural relief to support both a train line and a motorway – and allowing the original bridge to be transformed into a footbridge for hikers. A key priority of the bridge expression was to not compete with the Erste Hinterrheinbrücke – but rather serve as the new rail connection without de-centering the original infrastructure. The new bridge is in service of the old, rather than a replacement. The Zweite Hinterrheinbrücke is a cultural heritage driver: its role as an ensemble structure preserves the existing built heritage and cultural connections of the UNESCO-listed train lines – while simultaneously expanding the number of user groups who have access to and can benefit from the Alpine natural environment.

The visual impact of the Zweite's elegance, therefore, is an active tool used to reinforce the region's cultural heritage.

5 Cultural Heritage Drivers

Together, these three bridges provide alternative perspectives on the mechanisms for social value creation within the built environment. All three-leverage cultural heritage to deliver positive social impact – but the approaches diverge based on site context, regional planning time horizons, and user needs. Across ensemble and replacement bridges, a throughline emerges new infrastructure that can support the evolution of cultural heritage within the built environment. Whether preserving existing infrastructure by diverting traffic, supporting the transformation of existing infrastructure into a second life, or providing something completely new in the face of structural decline – safe crossings have the potential to reinforce cultural heritage and create long-term social value for communities.

ID-368

Conservation discourses in technical education, India

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Abstract

Over 13 sub climatic zones and more than 415 living languages is a testimony to India's rich and diverse natural and cultural heritage. Equally significant is the census data showing 65% of population below the age of 35 and the nations thrust towards urbanisation and infrastructure development.

While the task of technical education (Civil/ Structural Engineering, Architecture and other technical fields) in India itself is daunting, conservation discourse is a much needed but scantily addressed.

This paper highlights the need for courses and educational infrastructure promoting awareness and sensibilities towards a conservation approach to development instead of demolish and build en-masse.

Heritage, both natural and cultural deserves to be treated with care and is vulnerable to neglect and apathy. Over past decades, in its quest for a 'new India', urban and infrastructure growth has been a-sympathetic to its built & natural heritage due to lack of awareness, knowledge and trained human resource.

Indian heritage has a huge potential of contributing to the liveability index and UN's sustainable development goals. Awareness building, public mobilisation towards cultural and ecological heritage and adequately trained and skilled human resource across the country for conservation is the requirement today.

Technical education institutions sensitising of youth towards acknowledging and nurturing heritage through creation of environment for conservation learning and imparting necessary knowledge and skills need further impetus. State, Private Organisations and Corporates can provide this impetus to promote excellence in conservation discourses of technical education and to encourage and facilitate a conservation approach to urban and infrastructure development.

After elaborating on the significance of cultural as well natural heritage diversity in India, the paper outlines the challenge for conservation in a fast urbanising and an ambitious nation. It draws attention to conservation as a sustainable approach to development rather than against it. It then calls upon the need for capacity building in the sector.

The United Nations' sustainable development goals include a focus on cultural heritage and sustainable cities and communities. India's rich heritage has the potential to contribute significantly to the liveability index and the United Nations' sustainable development goals. However, achieving this requires increased awareness building, public mobilization towards cultural and ecological heritage, and adequate training and skilled human resources across the country for conservation.

Technical education institutions play a crucial role in sensitizing the youth towards acknowledging and nurturing heritage through creating an environment for conservation learning and imparting necessary knowledge and skills. However, there is a need for further impetus to promote excellence in conservation

discourses of technical education and encourage a conservation approach to urban and infrastructure development. This can be done through the support of state, private organizations, and corporates.

The Indian government has initiated several programs to promote technical education in the country. The Ministry of Education's Technical Education Quality Improvement Programme (TEQIP) aims to improve the quality of technical education in the country. The program supports capacity building initiatives for faculty and staff, including training programs in heritage conservation.

Private organizations have also taken initiatives to promote heritage conservation through technical education. The Indian National Trust for Art and Cultural Heritage (INTACH) has collaborated with several technical education institutions to promote conservation learning. The organization has launched various programs, including heritage clubs, to raise awareness and impart knowledge and skills related to heritage conservation.

Corporate entities also play a significant role in promoting heritage conservation through technical education. A report by the Confederation of Indian Industry (CII) notes the importance of corporate social responsibility (CSR) in promoting heritage conservation. The report emphasizes the need for corporates to invest in heritage conservation initiatives and promote awareness among employees and stakeholders.

The promotion of excellence in conservation discourses of technical education and the encouragement of a conservation approach to urban and infrastructure development requires the support of state, private organizations, and corporates. The collaboration of these entities can play a significant role in sensitizing the youth towards acknowledging and nurturing heritage and imparting the necessary knowledge and skills for conservation.

Keywords: urban heritage, sustainability, architectural heritage, sensitive development.

ID-403

Influence of Residual Stresses on the Mechanical Properties of Structural Steels Subjected to Laser Ablation Treatment

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Abstract

Laser cleaning, an application of laser ablation treatment, is a cutting-edge technique for the removal of contaminated and painted layers from solid surfaces. It is a non-contact process, which can be carefully controlled to minimize damage to the original substrate beneath a contaminated or corroded surface. This research investigates residual stresses and mechanical properties of nanosecond and femtosecond laser-cleaned steels by using experiments. The residual stress data were obtained by using non-destructive X-ray and neutron diffraction methods at the Australian Nuclear Science and Technology Organisation (ANSTO). X-ray diffraction was used for near-surface residual stress measurements while neutron diffraction was used to enable sub-surface residual stress analysis. Results from nanosecond lasers are presented in the paper.

Keywords: laser cleaning; femtosecond and nanosecond pulse laser; structural steel; heritage conservation; residual stress

ID-409

Improving of (Energy) Performance of Existing (Heritage) Buildings

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Abstract

For heritage buildings, energy consumption and sustainability were not always in focus or scope during time of erection. The commonly assumed life span of 25-30 years for facades is only a portion of the primary structure, and this remains true even if the service life of facades is doubled. Demolition and recycling of the whole structure and erection of a new building following the actual state of the art is usually not an option – and from point of holistic view taking into consideration grey energy does not make sense either. So special care has to be taken to combine improved energy performance and historic appearance – just adding insulation is not acceptable. Glass as a transparent material is an important element in facades, first a general overview especially on glass related questions is given, followed by examples of rehabilitation of classified historic buildings.

Keywords: listed historic buildings; glass types; façades; energy performance; safety; design.

1 Introduction

A large part of the carbon emissions come from the operation of existing buildings, for heating and cooling. At the same time, the buildings themselves store a large amount of gray energy, demolition and new construction is not an option; rather, the energy balance of existing buildings must be improved. The building envelope, in particular the facade with the windows, plays an important role here. With regard to glazing, there have been many developments in recent decades to contribute to energy savings, and the façade construction has also developed further. The above also applies to listed buildings - even if exceptions are sometimes made here with regard to the energy balance requirements.

First, the special features of glass as the most important element of facades and windows will be discussed in more detail. Examples of executed projects of listed buildings illustrate the challenges in the conflicting areas of monument protection and current requirements for safety and function.

2 Glass elements for facades

2.1 Introduction

Glass as a transparent element is also an important element in listed buildings. Historically, there was a development regarding the production technology of the basic glass as well as the finishing or processing to coated glass, safety glass, laminated glass or insulating glass units (IGU). Associated with these production methods are questions regarding several important aspects:

- Size
- Surface
- Safety
- Strength
- Solar and energy performance

In the full paper, the development and its implications for an application are considered for each of the aspects – from the perspective of historic preservation as well as the current understanding of safety and energy performance.

3 Examples of projects

3.1 GMN Nürnberg

A façade of the building complex of the Germanic National Museum in Nuremberg, which was reconstructed and rebuilt in 1953-1978 by Sep Ruf and protected as a historic monument, was to be renovated. Individual glasses are broken, the steel construction shows corrosion. A minimal retrofit is planned for the facade. The steel structure will be locally de-rusted and recoated after removal of the glass. As far as possible, the original single panes were to be kept; the use of coated panes to ensure thermal insulation in summer was not possible, so an independent sun protection was placed in front of the facade in its original state.

3.2 New National Gallery Berlin

The Neue Nationalgalerie (New National Gallery) in Berlin (**Error! Reference source not found.**) was b uilt according to the plans of Ludwig Mies van der Rohe between 1965 and 1968. After almost 50 years of use, a renovation of the listed museum building was necessary. Here, only a brief report is given on the issues related to the glass formats.

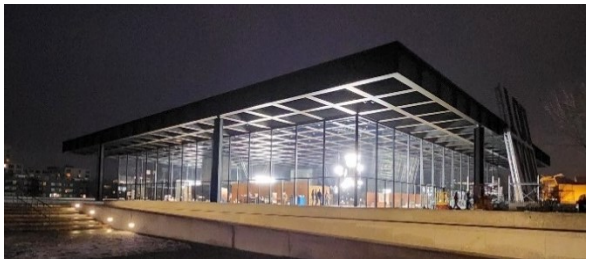


Figure 14. Overview of building

3.3 HVB-Tower Munich

The 114 m high HVB Tower was erected according to the design of the architects Walter and Bea Betz in the years 1975 - 1981. The building is a landmark of Munich, unique in construction and appearance, **Error! Reference source not found.**. T he revitalization during the last decade was accompanied by HENN architects. This revitalization included a complete demolition of all facade elements and their replacement with modern multi-layered multifunctional box window facade elements that leave the exterior appearance unchanged.



Figure 15. HVB-Tower before rehabilitation

The outer shell is formed by laminated glass with a special coating and reused aluminium elements in the parapet area. Openable windows with triple IGU are used as inner shell, allowing natural ventilation. The glass of the outer shell is a particular challenge: in order to select the most suitable coating, samples were compared under varying light and weather, **Error! Reference s ource not found.**.

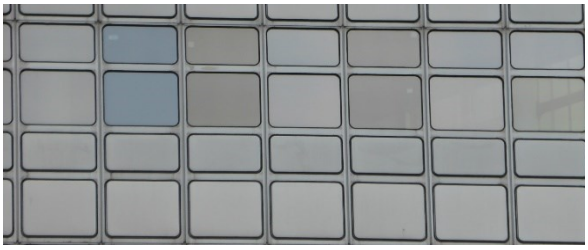


Figure 16. Different types of coating

4 Conclusions

Retrofitting and preserving listed historic landmark buildings is a challenge. With appropriate knowledge and openness to discussion, a compromise can be found that strikes the right balance between preserving history and fulfilling actual requirements in terms of safety as well as energy performance.

ID-454

Preservation of Heritage Masonry Structures: Assessing Compatibility of Consolidative Treatments on Fired Clay Bricks

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Abstract

1 Background

India is home to vast monumental brick structures, which are of great importance due to it's architectural, cultural and historic values. Heritage structures are prone to deterioration due to aging and dynamic environmental conditions. Among the various degradation mechanisms, soluble salt crystallization within the pores of substrate materials of heritage structures is found to cause the greatest damage. Restoration of matrix structure and further protection by "consolidative treatments" is one of the ways of preservation of these heritage structures.

Consolidative treatment is most preferred in restoration and preserving heritage structures, especially in cases where adhesion between the particles are also to be improved. Consolidants work by penetrating through the surface of the deteriorating substrate and attempt to restore cohesion within and further improve the physical and mechanical properties to some extent. This will increase the durability of the structure causing the deterioration rate to be reduced and hence, extending the life of the structure.

Compatibility of a consolidant with the substrate is complicated and depends on the material properties and exposure conditions. Selecting the wrong consolidant can accelerate the deterioration instead of restoration of properties.

To date, many heritage sites, especially in India, are still preserved by application of water repellant coatings and plastering which tend to alter the appearance of the structure. In this study, the effect of acrylic polymer and silane based consolidants are assessed on three types of fired clay brick samples to evaluate how well they would perform in marine conditions to reduce the rate of deterioration.

2 Materials & Methods

2.1 Materials used

The fired clay bricks used in this study were of different quality and mineral composition; one commercially available fired clay brick (F) and two types of heritage fired clay bricks H1 & H2 sourced from Nala Sopara Stupa – a heritage structure protected under the Archaeology Survey of India (ASI).

The effect of two types of consolidants: an acrylic-based polymer (methyl methacrylate – MMA), and a silane based consolidant, were evaluated on the three different types of brick samples.

2.2 Experimental Methods

To evaluate the performance of the consolidants on these bricks, the initial physical, mechanical and microstructural properties of the substrate samples were established through test methods like Helium Gas Pycnometry for evaluating density, Water Absorption, Open Porosity,

Scanning Electron Microscopy for understanding the morphological features, X-Ray Diffraction for understanding the mineralogical composition, and Compressive Strength.

These initial inherent properties were then compared to the final properties after treated and untreated samples were subjected to accelerated weathering cycles and desalination. In this artificial accelerated salt weathering, the treated and untreated samples were exposed to alternative wetting and drying cycles where damages due to salt crystallization was simulated.

The comparison of the untreated weathered samples to that of the silane and acrylic treated weathered samples was done to understand the extent of damage and conclude on whether a treatment is working effectively or not. This comprehensive analysis assesses the compatibility and feasibility of application of silane and acrylic consolidant to heritage brick structures.

3 Discussion & Conclusions

The three brick samples were of different quality and mineral composition as indicated from the XRD analysis (X-ray diffractograms as shown in *Figure 1*) and further justified by the physical and mechanical properties evaluated *(Table 1)*.

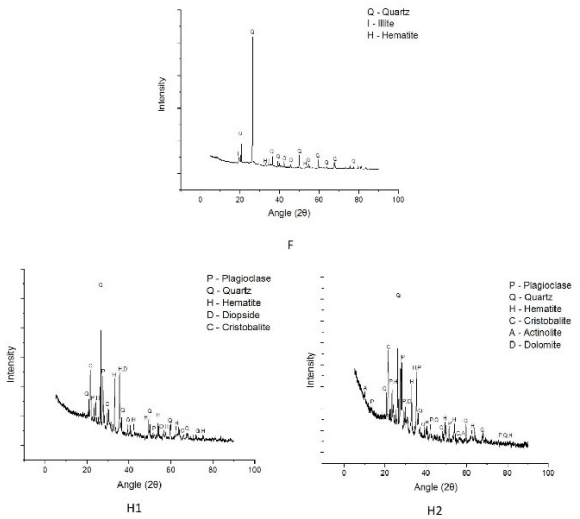


Figure 1: X-ray diffractograms of the three brick samples

Table 1: Physical and mechanical properties of the samples

Materials:	F	H1	H2
Water Absorption (%)	17.58	8.23	11.97
Density (g/cc)	2.60	2.96	2.94
Open Porosity (%)	39.29	39.01	34.63
UPV (km/s)	0.89	1.88	2.14
Compressive Strength (MPa)	1.30	4.00	14.67

During accelerated weathering cycles, the untreated sample F and the acrylic treated samples were vastly deteriorated by exfoliation and powdering, where at the end of 15 cycles, less than 30% of their initial mass was found to be retained. Treated and untreated H1 samples were able to withstand 30 days of weathering cycles, the change of mass throughout was minimal, there were no visual changes occurring with the sample during the weathering process. In both H1 and H2, the mass and UPV values were moving in similar patterns for untreated and acrylic treated samples. Sample H2 also managed to withstand the 30 days of accelerated weathering cycle but not as well as H1, since during the desalination stage, cracks began to form on the untreated and acrylic treated specimens.

Silane based consolidant was found to have high efficiency compared with acrylic-based consolidant in preserving the samples and reducing the rate of deterioration with minimal overall mass loss in all three of the samples. It is evident that there are some incompatibility issues with the acrylic based consolidant and the brick samples; more so, it appears to have less or negligible effect in preserving the bricks and reducing the rate of deterioration.

ID-658

Lime-Red Mud Binders for Repair of Heritage Structures and for CO_2 Sequestration

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Lime was one of the most prominent building materials used. The introduction of cement led to the decline in use of lime. The major reason for this change is the slow setting and strength properties of lime [1]. The current rise in concern of conserving heritage structures has led to the reintroduction of lime in construction sector. Use of cement for the repair of lime based heritage structures has been observed to be more damaging [2]. The further damage can be attributed to the low porosity, dense and higher strength of cement than ancient materials [2]. The major disadvantage associated with lime is its slow setting that can be avoided with the use of mineral admixtures, particularly industrial waste materials. Air lime sets by the process of carbonation and can mineralise decent amount of CO_2. Any potential waste material that can capture CO_2 or support lime in carbonation can be used to make a binder. In the present study an industrial by-product red mud is used a replacement material for lime. This will reduce the environmental impact caused by red mud and can further lead to the development of a new sustainable material. As an alternative to steel and wood, aluminium is quickly expanding as a sector of the economy. Red mud is a potentially dangerous by-product generated during production of aluminium. Red mud leftovers are created in amounts ranging from 1 to 2 tonnes for every ton of aluminium produced [3]. India produces roughly 4.71 million tonnes of red mud annually, or 6.25% of the world's total production [4]. Currently most of the red mud is dumped into mud lakes, nearby water bodies or directly into the sea with the aid of pipelines. When dumped in open yard, it can pollute soil and groundwater both by penetrating the ground and also contaminate nearby rivers and ecosystems [5].

1 Materials

The materials used in the study are red mud and lime. The specific gravity of lime and red mud are 2.37 and 3.14 respectively. Red mud obtained was in lump form, which was pulverised and particle size distribution was noted. Crushed sand of three different size ranges was used in equal proportions as fine aggregate. The size ranges are; 2mm passing and 1mm retaining, 1mm passing and 0.5mm retaining and 0.5mm passing and 90 µm retaining.

2 Experimental programme

The current work focuses on replacing lime with red mud in mortars at replacement levels of 10-50% designated as RM10 to RM50. Physio-mechanical properties were done on all the different mortars developed.

3 Results and Discussions

3.1 Workability assessment using flow tests

It was observed that water requirement of the mortar for a flow of 180-190 mm decreases with increment of red mud proportion. Addition of red

mud evidently increased the workability of lime binders.

3.2 Setting rate

It was observed that lime mortar specimens (RM0) were in plastic state till 3 days after casting. The specimens could be demoulded only after 3 days. However, with addition of 10% red mud, setting time was observed to reduce drastically. With the addition of red mud, the specimens could be easily demoulded in a day.

3.3 Compressive strength

Figure 1 illustrates the compressive strength results of the various binders developed in lab. The red mud replaced mortars were tested after 3, 7, 14 and 28 days of air curing. It is imperative to note that the 28 day strength of RM0 is lower than 7, 14 and 28 days strength of red mud replaced binders. The red mud replaced mortars were observed to achieve the 28 day strength of RM0 at 3 days alone. The strength values are found to be more for lime with 30% replacement of red mud. The higher early strength can be attributed to the high alkaline nature of red mud that initiates reaction. The combined action of carbonation and pozzolanic reaction can also be the reason for higher strength.

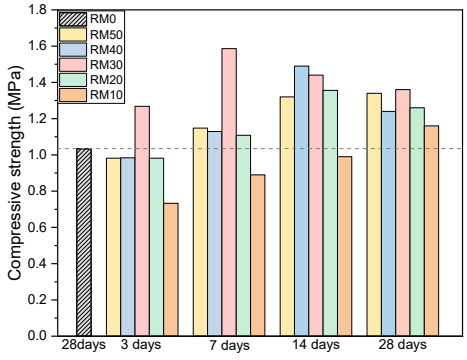


Figure 1: Compressive strength development of various mortars for different curing ages

3.4 Ultrasonic Pulse Velocity results

Figure 5 shows the UPV results of various binders at 3, 7, 14 and 28 days. The results indeed show that the mortars are extremely porous. The 90 day UPV of RM0 is similar to UPV of red mud based binders after 14 days of curing. The reduction in UPV at the age of 28 days can be owed to the higher porosity of the specimens.

3.5 Water Absorption Test

Water absorption of lime-red mud mortars for different mix proportions were conducted after 7 and 14 days of curing. The water absorbed was measured after 1, 2, 4 and 24 hours of partial immersion. The water absorption variation in different specimens is observed to be marginal. Even though the increase is marginal, the rise of water absorption with red mud addition can be due to the porous nature of specimens as reported in previous researches [12,14].

4 Thermogravimetric analysis - CO_2 sequestered

RM30 was chosen as it had the highest strength compared to all other binders. The result indicates that 100g of RM30 can mineralise 8g of CO_2 in 7 days of exposure. Similarly Figure 7(b) depicts the TGA and DTG curves of RM0 samples after 28 days of air curing. The CO_2 sequestered is estimated to be 12.3% through tangential method analysis.

5 Conclusions

The present study majored on finding a compatible mortar for the repair of heritage structures. Red mud was chosen as an alternative material for replacing lime partially in lime-based binders. Various combinations of lime-red mud were developed and tested for its properties. It was observed that red mud acted as set accelerator and reduced the setting time of lime drastically. The early age strength of red mud added binders was also promising. The surface shrinkage was reduced completely with addition of red mud. 30% replacement of red mud with lime gave optimum results of setting and strength gain. Water absorption was measured to be on a higher side which can be attributed to the porous nature of the system. The porous nature of the developed binder ensures breathability while being used as a repair material in heritage structures. Finally, the CO_2 sequestered was found to be relatively similar to that of the lime mortars without other additives. Therefore, further research is suggested to understand the reaction

mechanisms and durability of the developed mortars as well.

6 References

[1] H. Hwang, Y. Kwon, S. Hong, S. Kang, Comparative study of effects of natural organic additives and cellulose ether on properties of lime-clay mortars, J. Build. Eng. 48 (2022) 103972.

[2] A. Menon, Cement , Concrete and Conservation, Asian Conf. Ecstasy Concr. Proc. of W (2010).

[3] A. Collazo, D. Fern, M. Izquierdo, Evaluation of red mud as surface treatment for carbon steel prior painting, 52 (2005) 351–358. https://doi.org/10.1016/j.porgcoat.2004.06.008.

[4] Li Wang, Ning Sun, Honghu Tang and Wei Sun, A Review on Comprehensive Utilization of Red Mud, (2019).

[5] S. Rout, S.K. Das, Utility of red mud as an embankment material, (2021).

[6] I. 4031-11 (1988): M. of physical tests for Hydraulic, P. 11: D. of density [CED 2: C. Cement, A. Concrete], , (1988).

[7] P. 4: G. IS 2720-4 (1985): Methods of test for soils, size analysis [CED 43: S. and F. Engineering] , (1985).

[8] P. IS 6932-8 (1973): Method of test for building limes, V.D. of workability [CED 4: B. Limes, and G. Products] , (1973).

[9] A.C. 1403 – 00, Standard Test Method for Rate of Water Absorption of Masonry Mortars 1, (n.d.) 5–7.

[10] I. 2250 (1981): C. of P. for P. and U. Of, M.M. [CED 13: B.C. Practices, V. and A.F. including Painting, (1981).

[11] I. 13311-1 (1992): M. of N. testing Of, P. 1: U. pulse velocity [CED 2: C. Concret, A. Concrete], (1992).

[12] D. Dodoo-arhin, R.A. Nuamah, B. Agyei-tu, Awaso Bauxite Red Mud-Cement Based Composites : Characterisation for Pavement Applications Case Studies in

Session 13

Sustainability in Transportation Structures

ID-148

Sustainable Development Requires Risky Decisions - Problematic 300 Ton Overweight Transport Passing a Bridge

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Abstract

Oversize and over-weighed load passages over bridges are one of the research issues related to sustainable development that engineering and scientific teams around the world have to deal with . The article presents the scope of activities that enabled the passage of an oversized vehicle with a total weight of over 300 tonnes over a reinforced concrete slab. The bridge load capacity is 30 tonnes. In order to assess the capacity of the bridge, detailed visual inspection, inventory, tests during a load test, field and laboratory tests of concrete, location and inventory of reinforcement, static and strength calculations were carried out. Unfortunately, the tests done during the passage of an oversize vehicle on the bridge showed that the actual weight of the set were greater than originally declared. Fortunately, it turned out that there were still some reserves in the structure load-bearing capacity and the over-weighted vehicle entered the bridge without any damage.

Keywords: reinforced concrete bridge; overweight transport; FEM; GPR; load testing.

1 Introduction

One of the research issues related to sustainable development that engineering and scientific teams around the world have to deal with are oversize load passages over bridges. Many of them are several and sometimes even several dozen times heavier than the estimated usable load capacity of the bridge on which they intend to pass. The lack of archival documentation approval of an overweight vehicle passage is quite complicated. Therefore, the aim of the paper is to present a representative methodology for assessing the load-bearing capacity of a bridge to allow the passage of an oversize vehicle.

2 Current state of the bridge

The bridge is located in Poland. It is a two-span continuous reinforced concrete slab with a total length of 13,1 m (**Error! Reference source not found.**).

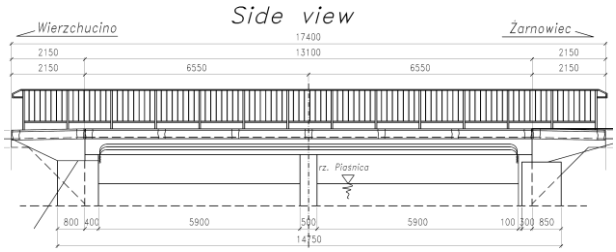


Figure 17. Side view

The load capacity of the structure was determined to be 30 tonnes (300 kN). However, there was a lack of any data on the calculations made. Therefore, the condition and load-bearing capacity of the bridge is to be determined on the basis of a detailed visual inspection, test loading and testing.

A detailed inspection of the bridge did not reveal severe cracking. Scratches or delamination would indicate a significant reduction of the load carrying capacity, namely suggest that the structure had been overloaded.

The main reason of the proof loading was to check the behaviour of the bridge. Different loading schemes were applied to induce a condition corresponding to the declared load capacity of the bridge in the individual elements of the structure (span, pillar, abutment). (**Error! Reference source not found.**).



Figure 18. Test load setting inducing a minimum bending moment over the intermediate support

Static test results confirmed the elastic behaviour of the bridge, as intended. Experimental analysis confirmed the ability of the structure to carry loads even higher than 30 tonnes.

The main aim of the materials identification was to check whether severe degradation processes in concrete have begun. Identification of the amount and distribution of the reinforcement in the slab were conducted as well. In consequence, the following actions were undertaken: concrete specimens chemical compositiontesting, concrete strength determination , concrete reinforcement scanning.

3 Static and strength analyses

The main purpose of the computational analyzes was to determine whether it is possible to safely drive an oversize vehicle through the structure in its current state.

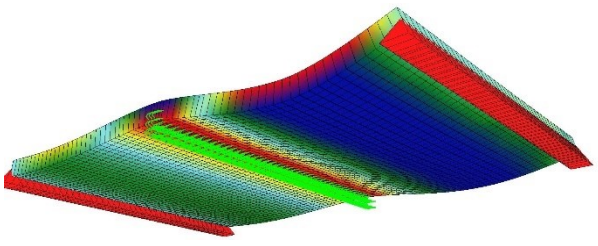


Figure 19. Visualisations of the deformation of the FEM model used for the calculations

The results of the static calculations showed that all the internal forces in the bridge during the oversize passage are lower than the values generated by the standard design loads or the testing load.

4 Oversize crossing

As recommended, bridge surveys were carried out during the passage. These included settlement measurements of the supports and technical monitoring of the span vertical displacement.

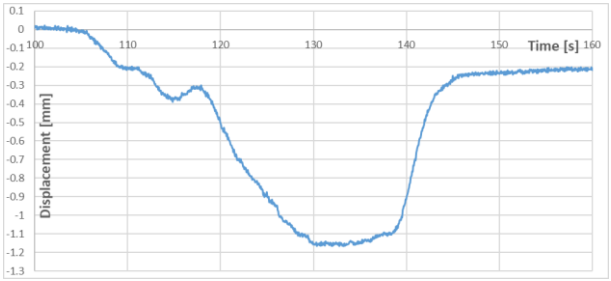


Figure 20. Graph of the change in displacement in the middle of the span from the oversized crossing

It turned out that the recorded displacement values at the u1 point were about 25% higher than those obtained from the numerical simulations.

5 Conclusions

The article succinctly outlines the extent of the work that was required to allow passage of an oversize vehicle with a declared total mass of 300 tonnes through over a 40-year old bridge, whose declared load capacity was 30 tonnes. Unfortunately, the tests carried out indicated that the actual impact of the transport on the structure may have been up to 25% greater than predicted in calculations. These unique results indicate possible inaccuracies in the assessment of the weight of the load transported by the oversize vehicle and trailer. In the case of analogous extremely risky passages, it seems that it necessary to measure the axle loads of the convoy before allowing them to enter traffic. In this case, it was possible to deliver new power station generator to the plant and provide local consumers with access to electricity. The test results analysis suggests that the bridge almost reached its limit load capacity. As no new damage of the bridge was observed after the passage, it is however likely that this did not happen due to material strength reserves and additional bonding between the sloping concrete and the slab, which were not included in the FEM simulation

ID- 245

Sustainable Design and Construction of Bridge – Case Study of Design of Arch Bridge in Nepal using Multi-Criteria Decision Analysis

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Abstract

The importance of sustainability in transport infrastructure continues to gain momentum. Policymakers and planners play a vital role in integrating sustainability into transport infrastructure, so sustainability assessment should begin with decision-making. This paper highlights the use of the Multi-criteria Decision Analysis (MCDA) technique: Analytical Hierarchy Process (AHP) to compare bridge design options in terms of sustainability. AHP can be a user-friendly assessment tool in developing countries where incorporating sustainability isn't prioritized yet. The project "Design and Build of Bridges along Narayanghat-Mugling Highway" in Nepal is selected as the case study. Using AHP, a monolithic concrete arch bridge was compared with a two simply supported spans of prestressed concrete bridge. Criteria such as economic, environment, construction ease and maintenance were incorporated in the AHP. The results of AHP show that the Arch bridge is sustainable design option.

Keywords: Analytical Hierarchy Process (AHP); Multi-criteria Decision Analysis (MCDA); Sustainable design; Arch Bridge; Transport Infrastructure.

1 Introduction

Traditionally in developing countries, economics and functionality are prioritized over sustainability in the design and planning. Sustainable development awareness has led to a change in policy. But the pressing question still remains- "How to compare and select sustainable infrastructure design option?" Decision makers are in search of tools and techniques to assess sustainability in various life stages of infrastructure projects [2].To address the demand of policymakers for a versatile and easy-to-understand sustainability assessment tool, in this research, AHP was used to compare a concrete Arch Bridge of span 60 m with side spans of 15 m (Option A) was compared with a PSC box girder bridge with a span arrangement of 2×45 m with a pier at the centre (Option B) in terms of sustainability. The criteria used for AHP are economic, environment, construction ease and maintenance. The objectives of this research are: to perform AHP between the bridge design options in terms sustainability; and, to highlight how AHP can be used by decision-makers to incorporate sustainability.

2 Bridge design option

The drawing of bridge design options are shown in figure 1 and 2.

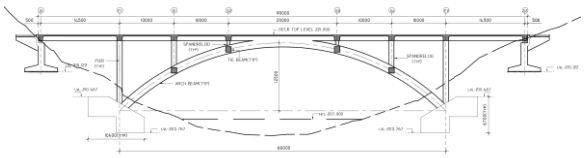


Figure 21. General Arrangement Drawings of Arch Bridge (Option A)

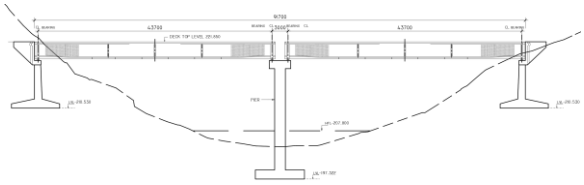


Figure 22. General Arrangement Drawings of PSC Box Girder (Option B)

3 Sustainability Assessment tool- MCDA

MCDA is family of methods which evaluates multiple conflicting options to determine the best alternative on the basis of selected criteria. Out of the multiple available MCDA methods, the AHP method is well established, easy to understand and versatile [4]. Therefore, the AHP method is selected for this paper. The criteria used for AHP are economic, environment, construction ease and maintenance.

3.1 AHP methodology

The first step is to define the problem statement. As per, the problem statement, criteria and the alternatives the hierarchy is defined. To select the desirable alternative, every element in the hierarchy must be compared with each other. Pairwise comparisons are issued to determine the relative importance of elements with respect to each other. To quantify the pairwise comparisons, the 1-9 Saaty scale is used [4]. The next step is to create the pairwise comparison matrix. Pairwise comparison matrix is a symmetric matrix where the score of an element a_{ij} symbolizes the importance of the element on the row (i) over the element on column (j). Pairwise comparison matrix is formed as given in Equation (1)

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \quad (1)$$

Such that $[a_{ij}] > 0$

Then, geometric mean method is used to calculate the weightage/priority vector with respect to each other. Due to it's practicality the AHP allows for slightly non-consistent pairwise comparisons [7]. Therefore, consistency ratio (CR) of each pairwise comparison matrix is to be calculated. The comparison matrix is to be only considered if the CR is less than 10% [7]. To calculate CR and consistency index (CI) equation (2) and (3) are used.

$$CI = (\lambda_{max} - n)/(n-1) \quad (2)$$

$$CR = CI/RCI \quad (3)$$

Finally, after consistency check, the final priority is calculated by summing the product of the criteria weight and the contribution of the alternative, with respect to that criteria.

3.2 AHP Results

As per the results of the AHP, Option A with a priority value of 0.64 is the better sustainable design option over Option B with a priority value of 0.36

4 Conclusion

The calculations and results shown in this paper show that the AHP technique can be used by decision-makers in the infrastructure sector. Further research on this topic should focus on selecting the correct and diverse set of criteria for AHP that suit the project requirement. With the flexibility of AHP in selecting criteria such research would help the decision-makers arrive at more nuanced decisions.

ID-280

Sustainable Bridges – Past and Future Reflections on a European Project 2003 - 2007

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Abstract

Twenty years ago, in 2003, a European project was started to increase the sustainability of existing railway bridges. This paper summarises what was achieved and looks ahead. Nine Working Packages were organized: (1) Background material; (2) Guidance by stakeholders; (3) Condition Assessment and Inspection Guidelines; (4) Loads, Capacity and Resistance Guidelines; (5) Monitoring Guidelines; (6) Repair and Strengthening Guidelines; (7) Demonstration with Field testing of Bridges; (8) Demonstration on Monitoring on Bridges; and (9) Training and Dissemination

Some of the main results (from 4 Guidelines and 47 Background documents) are highlighted and some experiences, conclusions and thoughts about the future are given. Hidden strengths and weaknesses are discussed, analyses and codes for assessment can be improved, new monitoring and strengthening methods are available and life length can be prolonged.

Keywords: Bridges, Management, Assessment, Modelling, Monitoring, Testing, Codes, Load-carrying capacity, Strengthening, Life-length



Figure 23. Three types of existing railway bridges being studied: Masonry Arches, Steel Beams supported by Reinforced Concrete Arches and a Steel Truss carried by a Steel Arch.

Results

The work wasn't limited to a specific bridge type or material but aimed to be of universal applicability, see examples in Figure 1. Background reports and four guidelines were published, see Table 1. The four guidelines covered the following items:

- Inspection & Condition Analysis (ICA)
- Load & Resistance Assessment (LRA)
- Monitoring (MON)
- Repair & Strengthening (STR)

Sustainable Bridges Background Reports

WP 1 - Start up and Classification
1.2 European Railway Bridge Demography, 15 pp.
1.3 European Railway Bridge Problems, 18 pp.
1.4 European Railway Research, 44 pp.

WP 3 - Inspection and Condition Assessments
3.2 Inventory on condition assessment methods, 63 pp.
3.3 Condition Assessment Procedures, 79 pp.
3.4 Steel bridges. Stress measurements, 94 pp.
3.5 Combination of radar data of different polarisation, 48 pp.
3.6 Scanning system for concrete surfaces, 23 pp.
3.7 Impact-echo system for crack depth measurement, 29 pp.
3.8 Radar tomography system, 51 pp.
3.9 Corrosion detection, 35 pp.
3.10 Lab test results on the effect of steel bar corrosion, 137 pp.
3.11 Nonlinear FEM model, reinforced concrete, 90 pp.
3.12 LIBS (Laser-Induced Breakdown Spectroscopy), 34 pp.
3.14 Cross hole tomography, 58 pp.
3.16 NDT Toolbox, 53 pp.
3.17 Demonstration of measurements, 27 pp.

WP 4 - Loads, Capacity and Resistance
4.3 Loads and dynamic effects, 150 pp.
4.4 Safety and probabilistic modelling, 328 pp.
4.5 N-L analysis and remaining fatigue life of RC bridges, 192 pp
4.6 Improved assessment. static & fatigue res. old steel railway bridges, 218 pp.
4.7 Masonry arch bridges, 277 pp.

WP 5 - Monitoring
5.1 Monitoring instrumentation techniques, 135 pp.
5.3 Prototype – crack sensor sheet - optical fibres, 78 pp.
5.4 Prototype – fibre optic grating sensor, 42 pp.
5.5 Prototype - MEMS, 47 pp.
5.6 Prototype – shaker for vibration tests, 70 pp.
5.7 Prototype – wireless communication network, 58 pp.
5.8 Prototype – smart data processing, 58 pp.
5.9 Prototype – TOF Fiber optic sensor, 18 pp.

WP 6 - Repair and Strengthening
6.2 Repair and Strengthening of Railway Bridges – Literature and Research Report – Extended Summary, 807 pp.
6.3 Field tests, 181 pp.
6.4 Method statement guideline, 74 pp.

WP 7 - Field Testing of Bridges
7.2 Riveted steel bridge, France, 73 pp.
7.3 Concrete bridge, Sweden, 406 pp.
7.4 Masonry bridge, Poland, 113 pp.

WP 8 - Demonstration of Bridge Monitoring
8.2 Demonstration of bridge monitoring, 129 pp.

WP 9 - Dissemination
9.2 Sustainable Bridges – Assessment for Future Traffic Demands and Longer Lives, Overall Project Guide, 28 pp.
9.3 Sustainable Bridges – Assessment for Future Demands and Longer Lives, Conference Proceedings, Wroclaw 2007, 492 pp.

Guidelines

Inspection & Condition Assessm, of Railway Bridges (ICA), 259 pp.
Load & Resistance Assessments of Railway Bridges (LRA), 428 pp
Monitoring of Railway Bridges (MON), 93+125 pp.
Repair and Strengthening of Railway Bridges (STR), 137 pp.

https://ltu.diva-portal.org/smash/

- *Table 9. Overview of Publications (Web Address: https://ltu.diva-portal.org/smash/. Search for "Sustainable Bridges Background Document X.X" or Title).*

ID-536

Research on Concrete Box Girder Bridge Widening Based on Spatial Grid Model

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Abstract

In this paper, based on a practical project, the spatial grid model is used to analyze the stress of the widened bridge. By comparing the stress changes, it is concluded that the shrinkage and creep of the new bridge will affect the stress of the whole structure after two bridges are connected. At the same time, the foundation settlement of the new bridge will generate additional stress at the connecting deck of the two bridges. Therefore, when the bridge is widened, certain measures should be taken to reduce the shrinkage and creep of the new bridge and the settlement of the foundation, so as to reduce the influence on the structure and ensure the safety of the widened bridge.

Keywords: Bridge widening; Spatial grid model; Shrinkage and creep effect; Foundation settlement

1 Introduction

With the increasing traffic flow,many bridges built in the past can no longer meet the traffic needs.In order to make full use of the old bridges and give full play to their economic value,bridges need to be widened to improve its bearing capacity.Therefore,in order to obtain more accurate stress state of the bridge, spatial grid model is adopted in this article.Combining a practical project,main factors that affect the stress of the structure after bridge widening are analyzed, including shrinkage and creep effect , foundation settlement and temperature effect.

2 Project overview

This project is a three-span prestressed concrete continuous bridge. The span arrangement of the bridge is (28+40+28) m. The width of the bridge after widening is 20.5m.The cross section after widening is shown in Fig. 1.

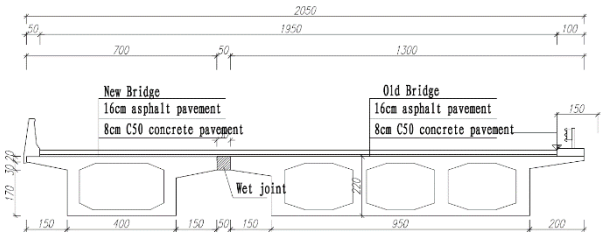


Figure 1. Cross section after widening

3 Spatial grid model

By establishing a spatial grid model to analyze the bridge, the stress changes of each position of the bridge after widening can be obtained. The spatial grid model of the widened bridge is shown in Fig.2.

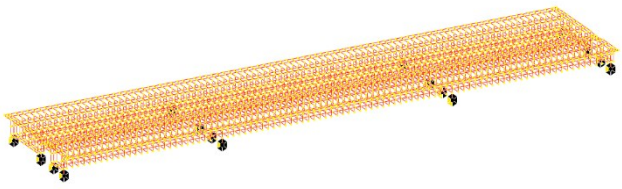


Figure 2. Spatial grid model of the widened bridge

4 Analysis of influencing factors

4.1 Shrinkage and creep effect

Due to the shrinkage and creep of the new bridge, the old bridge presents an eccentric compression state in the longitudinal direction and the new bridge presents an eccentric tension state. The deformation of both bridges before and after shrinkage and creep is shown in Fig.3. Therefore, the compressive stress of the old bridge webs increases, and the change rate of the stress near the joint is the largest, while that far away is the smallest. The compressive stress of the new bridge webs is decreased.

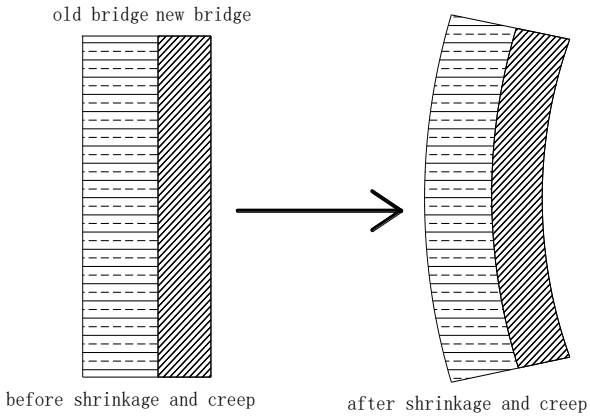


Figure 3.Integral deformation of bridge after shrinkage and creep

4.2 Foundation settlement

When the new bridge is built, the foundation settlement will occur under the action of self-weight and live load. The deformation of the deck between the two bridges will be restrained as shown in Fig.4.

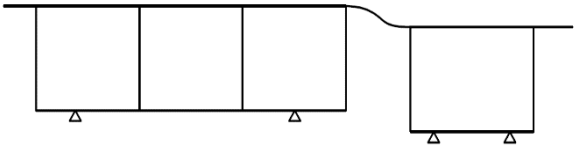


Figure 4:Foundation settlement deformation of the bridge

It is necessary to calculate the settlement that can be met by the bridge deck. When the old bridge deck can not meet the bearing capacity requirements, it needs to be reinforced to bear the additional internal stress .

4.3 Temperature effect

When the bridge is widened, the old and new bridges are connected through the bridge deck, and the deformation under the temperature effect will also be transferred, so the transverse additional stress will occur when the deformation is restrained.Under the effect of temperature, the stress on the flange plate before widening is uniformly distributed in the longitudinal direction. After widening, the stress of the bridge deck at the pier position increases more obviously, because of the vertical displacement limitation at the pier location.

5 Conclusions

The stress state of the widened bridge can be calculated and analyzed accurately by spatial grid model. After two bridges are connected, the bridge is in an eccentric stress state due to the shrinkage and creep of the new bridge. The normal stress of the old bridge webs increases, while the new bridge webs decreases. The shrinkage and creep of the new bridge will have a great impact on the overall structure. At the same time, the foundation settlement of the new bridge will produce additional stress on the connecting bridge deck, which has the greatest impact at the pier position. The additional stress has a linear relationship with the foundation settlement. Therefore, certain measures need to be taken to reduce shrinkage and creep and foundation settlement when the bridge is widened, and the bearing capacity of the bridge deck needs to be checked to ensure the safety of the bridge.

6 References

[1] Liu C, Xu D. Application of Space Frame Lattice Model in a Box-Girder Bridge. IABSE Symposium Report. 2009, 96(11): 148-157.

[2] Bing T. Research on mechanical performance and reliability of joined-width concrete bridge structure. Hunan University, 2018 (in Chinese)

ID-547

Adoption of Stainless Steel in Bridge Construction for Safety and Sustainability

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Abstract

Stainless steel, an iron alloy with chromium, is corrosion-resistant with low maintenance requirements. It has good strength, toughness, and fatigue properties. Stainless steel can be fabricated using a range of engineering techniques and are fully recyclable at end-of-life. The high ductility of stainless steel is a useful property where resistance to seismic loading is required.

The high strength with low maintenance effort makes Stainless Steel an attractive candidate for the material of construction for Bridges. There is increasing awareness that whole life cost, not just initial cost, should be considered when selecting materials. Experience shows that using a corrosion-resistant material in order to avoid future maintenance, downtime, and replacement can be a sustainable cost-effective solution, even though the initial material costs are higher.

Keywords: stainless steel bridges; sustainable construction; life cycle costing of bridges.

1 Introduction

Structural Steel has been one of the preferred materials for construction of bridges for a long time. The low weight to strength ratio of steel together with its ease of fabrication is the main plus point. Steel is also recyclable allowing it to be reused. Normal Carbon Steel is affected by corrosion when exposed to the atmosphere. The durability of steel bridge is achieved by suitable coating with paints or galvanising to inhibit corrosion. The resources used for periodic painting during the long life of a bridge results in the whole life expenditure on the bridge much higher than the initial construction cost.

Stainless steel, an iron alloy with chromium, is corrosion resistant. Stainless steel bridges do not need any painting. Although the initial cost of construction with stainless steel will be higher, the bridges will have a longer service life and can be fully recycled at the end of service life. This would lead to an overall lesser whole life cost.

2 Sustainable Construction

The urgent necessity of reversal of over exploitation of earth's resources and the associated consequences has now been accepted globally. The resulting global warming is caused by increasing concentrations of greenhouse gases (GHG). The realisation has led the international community to voluntarily take up reduction of GHG

emission and follow the path of sustainable development, which is defined as development that meets present needs without compromising the ability of future generations to meet their own needs.

For bridge engineers, it translates to adopting efficient materials of lesser quantity so as to minimise the associated embodied energy to build a durable structure without compromising on safety and functionality. At the end of long service life, it should be recyclable and reusable.

3 Corrosion of Steel

Corrosion is the degradation of materials' properties due to interactions with their environments. It is estimated that globally more than 3% of GDP is wasted every year due to corrosion. On average two tonne of CO_2 is emitted while producing one tonne of Steel. One has to add the CO_2 emission associated with the production of the energy used in steelmaking. It has been estimated that the CO_2 emissions associated with the steelmaking required to replace corroded steel is between 3 to 5% of the total. This is a significant amount and calls for measures to prevent it. Thus even though the negative implications of the monetary cost of corrosion are undeniable, the environmental impact of corrosion as estimated by the carbon dioxide emissions associated with the manufacturing processes required to replace corroded goods and infrastructure is also significant.

4 Stainless Steel for Bridge Construction

Although Stainless Steel has been around for more than a hundred years, it has not been widely used in bridge construction until recent years. This Iron-Chromium alloy is corrosion resistant. When exposed to atmosphere, stainless steel like carbon steel forms an oxide layer on the exposed surface. The difference is that while the oxide layer on carbon steel is porous allowing the rusting process to continue through the depth, the thin chromium rich oxide layer on stainless steel is extremely adherent and passive. It inhibits further progress of oxide formation. The film is also self-repairing in the sense that in case it gets damaged, it forms within a few minutes.

The main advantages of adopting stainless steel for bridge construction are:

High strength stainless steel enables lightweight bridge design without compromising on strength or safety. There are many grades of stainless steel available to suit specific needs.

Stainless steel enables attractive designs that seamlessly blend in with the environments.

Stainless steel exhibits high ductility and toughness. It can be employed in extremely cold atmosphere.

Stainless steel is corrosion resistant. From harsh cold climates to coastal areas, bridges need to withstand all types of weather and other corrosive elements. De-icing salts used in cold and icy conditions, salty air in coastal areas and pollutants such as sulphur dioxide pose significant threats to the long-term integrity of bridges. Stainless steel stands up to salty air and pollutants without the need for a protective coating.

Stainless steel is 100% recyclable at the end of its long service life and thus satisfies one of major yardsticks of sustainable construction material. More than half of all the stainless steel materials that are in use today have been sourced from scrap materials.

In view of above it does qualify as a true Green Material for sustainable bridge construction.

The high initial cost of a stainless steel bridge gets offset to a large extent by lesser amount of material usage, elimination of periodic painting, requirement of less frequent inspection and repair compared to carbon steel bridge. It has been found that Life Cycle Cost (LCC) of stainless steel bridges is lesser on many occasions.

Designers should consider stainless steel as a possible material of construction at the feasibility/ conceptual design stage of a bridge and it is expected that stainless steel will become the final choice for a large number of bridges.

ID-681

Underground Metro: A Solution for Sustainability

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Abstract

Time is not far when this world will have to find place on other planets to surmount the difficulty of shortage of land on the Earth. Metro has been going underground at many places. Taking a cue from Paris and London, the city appears so neat, when the metro is all put underground, especially in the main city. India is moving very much in the same direction. And underground metro provides effective means of sustainability in many ways. The masses can be transported in urban areas without cluttering the ground level roads. Being underground, the pollution levels are reduced to minimum. Tunnel and many times platforms and OT ducts are made in precast concrete, thereby reducing the quantum of site produced concrete and reduce environmental pollution. Construction of various structures of UG Metro is carried out in a specialized manner. The following paras explain broadly adopted construction methods of each of these.

Keywords: Underground, Sustainability, Precast concrete, Construction,

1 Underground Metro Station

A typical underground metro station has a main station body of about 20m width and 250m length. Figure 1 depicts a typical station footprint. Figure 2 shows an inside view of concourse & platform levels (with a large opening at the concourse level in the present case).

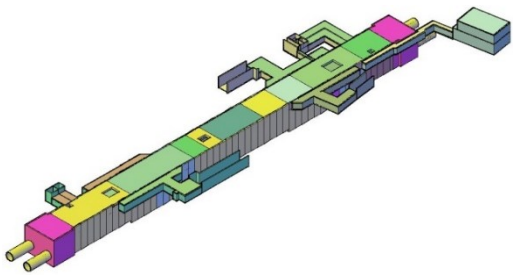


Figure 1. Typical Station Footprint



Figure 2. Inside View of Station

2 Top-down & Bottom up Methods of Construction

In top down method the roof is constructed first and lower levels later. Figure 3 depicts the construction of diaphragm walls for top down construction.



Figure 3 Diaphragm Wall Construction

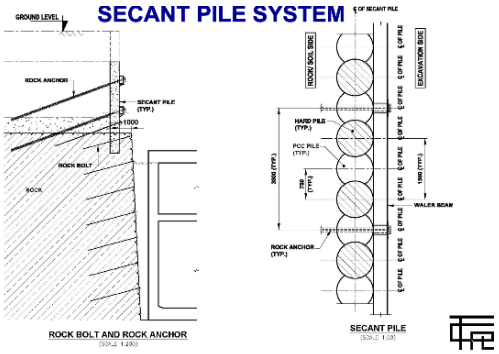


Figure 4: Secant Pile System for Bottom-up Construction

Figure 4 depicts Secant pile with lateral bracing system associated with bottom up construction.

3 Launching of Tunnel Boring Machine (TBM)

The end wall of the station launching retrieval area is constructed and TBM is required to penetrate through it to move. A Soft Eye comprising Glass Fiber reinforcement or Carbon Fiber reinforcement is incorporated as shown in figure 5.



Figure 5. TBM Penetration of Launching/ Retrieval Shaft End Wall

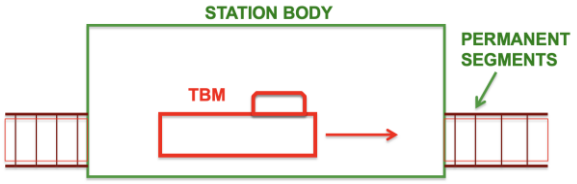


Figure 6. Drag Through TBM

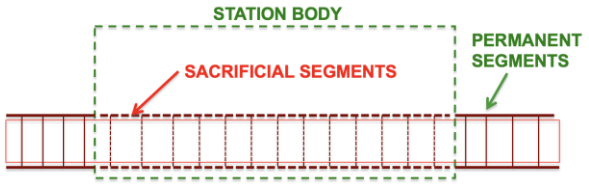


Figure:7- Bored Through TBM

Drive Through (Bore through) and Drag Through are used in specific cases. See figure 6 for drag through. See figure 7 for drive through.

4 Manufacturing of Tunnel Precast Segments

There is a different art attached to manufacturing & handling of tunnel segments. Figures 8 & 9 depict method casting in a steel mould and that of stacking them.



Figure: 8- Casting of Tunnel Segments



Figure: 9-Stacking of Tunnel Segments

Session 14

Case Studies in Sustainable Materials,

Technology and Practices

ID-118

Construction of the Multi-span Cable Stayed Bridge at Ambhora, near Nagpur, Maharashtra

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Abstract

The multi-span cable stayed bridge over river Wainganga near Ambhora, Maharashtra, has an overall length of 705m and deck width of 15.25m to accommodate 2 lanes of vehicular traffic and 3m+3m footpath for pedestrians. The structural arrangement of the bridge comprises 2 modules, with Module 1 of 420m and Module 2 of 280m length with span arrangements of 70m+140m+140m+70m and 70m+140m+70m respectively. The superstructure is cable stayed with RCC deck with an RCC pylon height of 30m above deck level. The pylon P3 at the center of the bridge is also proposed with Viewing Gallery 40m above deck level which is structurally independent from the main bridge. This paper discusses the construction aspects of the bridge along with the details of a special travelling formwork (form-traveller) used to enable the cantilever construction of the spans over deep waters. The Module 1 of the bridge is constructed by cantilever method for pylon P2 and anchored span method for pylon P1 and P3. The Module 2 of the bridge is constructed entirely on staging. This is one of the very few cable-stayed bridges in India where all 3 methods of construction of a cable stayed superstructure are adopted in the same bridge.

Keywords: Cable stayed bridge, Multi-span, Cantilever construction, Travelling Formwork, Form-traveller

1 Introduction

A high-level multispan cable stayed bridge across the Wainganaga river. A five-span cable stayed bridge with pylons spaced at 140m was proposed at the location.

A sky gallery was proposed to be built above the central pylon with staircase and elevator access. For that purpose, wide footpaths of 3m on either side of the carriageway were proposed thus taking the total carriage way width to 15.25m.

2 General arrangement and Geometry

The cable stayed portion of the bridge is 700m long which is divided into 5 equal spans of 140m each

(see Figure 1). The bed profile varies in such a way that the waters are shallow between the Nagpur side abutment (A1) and the first pylon (P1), and for a portion of about 300m towards the Bhandara side abutment (A2).

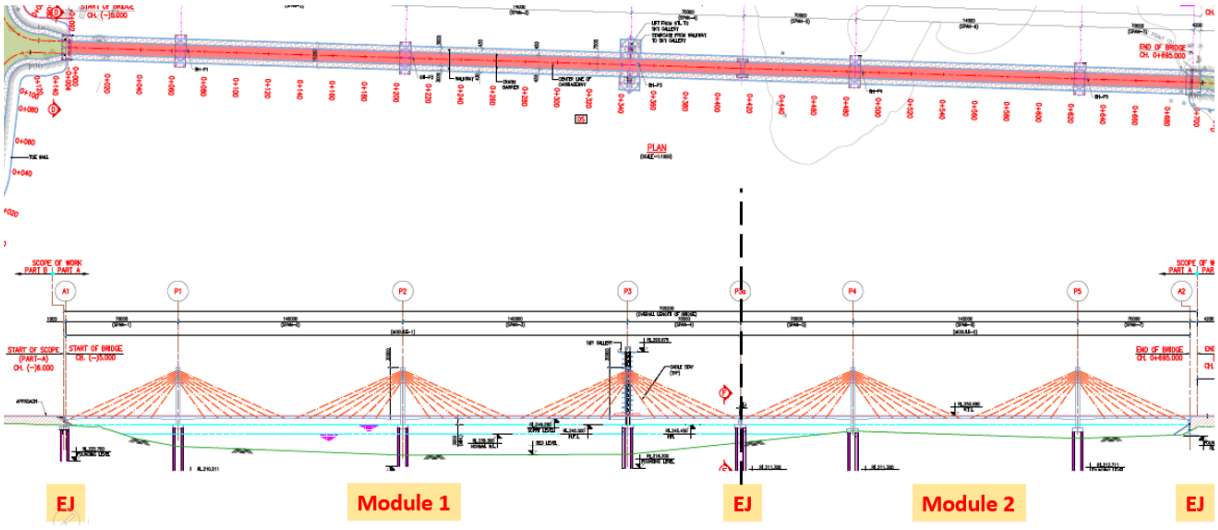


Fig 1: General Arrangement of bridge

The bridge superstructure is structurally separated into two modules, Module 1 and Module 2. Module 1 is a 3-span continuous cable stayed system with a total span of 420m from A1 to P3a (P3a is an intermediate pier between Pylons P2 and P3). Module 2, therefore, is a 2-span continuous system of 280m length between P3a and A2. The superstructure consists of a 7.5m wide 2 lane carriage way with 3m wide footpaths on either side. The deck spans between RCC cross girders spaced at 4m in longitudinal direction.

3 CONSTRUCTION METHODOLOGY

Module 1 and Module 2 are separated by expansion joint at pier P3a and the superstructure of Module 2 is entirely cast on staging as a parallel activity to the construction of Module 1.

The staging for module 2 is removed after the cables are stressed as per predetermined sequence.

The superstructure of Module 1 on either side of Pylon P2 is constructed by balanced cantilever method. Two specially designed travelling formworks (form-travellers) were mounted on pier-head segment on each side of the pylon P2. The pier head segments themselves are cast on a truss resting on the pile cap. After the pier head segments are cast, temporary stay cables are used to support this segment before the staging is moved and the form-traveller is erected. For pylons P1 and P3, the superstructure on A1 side of the pylon P1 and P3A side of Pylon P3 (i.e., the shallow water side) are cast on the staging. These span acts as anchored spans for the cantilever construction of superstructure for pylon P1 and pylon P3 on Pylon P2 side

For cantilever construction, the segment length varies from 5.7m to 8.5m. RCC longitudinal and cross girders are first cast on the form-traveller, and the stay cables are stressed. Temporary supports from cross girders support the deck slab staging. Once the deck slab is concreted and is hardened stage 2 stressing of cables is carried out.

After completion of casting of all the segments of cantilever construction, a gap of 4.6m remains between the superstructures of P1 & P2 and P2 & P3 and the form-travellers are by then de-launched from the bridge decks. These stitch segments are cast by providing separate steel girder frames

hanging from both the free ends of girders on either side of the segment.

4 Form-traveller – Design and Testing

For each construction cycle, the form-traveller is pushed by a set of hydraulic jacks that are abutted to the rail beam which is in turn bolted to the deck of the bridge. The form-traveller is designed to be lowered before movement to steer clear of stay cable anchorages in the girders. Raising and lowering is carried out by another set of synchronized hydraulic jacks placed under the C-frame above deck and at rear roller support of the truss.

Rear end of the form-traveller is butted up against the soffit of the bridge deck. Since the center of gravity of the form-traveller is further from the hinge connection towards the cantilever portion, the rear end reaction is always upwards.

The arrangement of dual shaft rear support makes the operation easier and leads to compact sizes of rollers.

The connection between C-frame and the main truss is designed as a specially designed hinge joint that allows the truss to rotate about this hinge in the longitudinal direction. The concrete load on main truss is transferred to the bridge through the c-frame on whose lower arm the main truss rests. In the current design, this connection is deliberately hinged to allow rotation of the joint in longitudinal direction.

After fabrication, the form-traveller is assembled and tested with the following key performance areas to study:

a. Stability and behaviour at 1.25 times the design load

b. Measurement of deflection during loading and unloading

c. Calibration of deflection behaviour of the form-traveller under a given load

d. Trail operation of raising, lowering, and pushing of the form-traveller.

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ID-178

First Time Use of LRB for Seismic Isolation of a Major Bridge in India - A case study

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Abstract

This paper presents first time application of Lead Rubber Bearings (LRB) in one of the Bridges in India, presently under construction and located in high seismic zone (Zone IV). LRB is adopted as a Seismic Isolation device for reduction of seismic demand. LRBs have found wide application worldwide because of their simplicity and combined Isolation-energy dissipation function in a single unit. Its components include a lead core and a laminated rubber bearing. In addition to withstanding a strong horizontal and vertical load, the lead core also has the ability to absorb energy through plastic deformation via hysteretic damping. LRB enhances flexibility of the structure and thereby the natural time period of structure defers with the natural time period of ground motion. LRB being the most viable option in high seismic zone, it was decided to use it in one of the projects, namely the viaduct approach spans of the 4-lane bridge over river Ganga at Patna, Bihar (Parallel to the Existing Mahatma Gandhi Setu). The project is being executed on EPC contract Mode.

Keywords: Lead rubber bearing (LRB), Seismic Isolation, stiffness, system analysis, lead plug, hysteresis damping, time period, energy dissipation, Euro codes.

1 Introduction

Lead Rubber Bearing (LRB) is being used as a seismic isolation device in Viaduct of Mahatma Gandhi Setu for the first time in India. Key features of Viaduct are as follows:

The approach Viaduct to the main bridge has a length of 1565,1 metres. The span arrangement comprises of several modules of spans, ranging from 2 span modules (2 x 33,3m), 3 span module (3x33,3m) and a few 4-span module of similar span range. The structural scheme of 18m wide deck superstructure comprise of five numbers pretensioned girders with in-situ RCC deck slab and diaphragms. Continuity is established through deck slab only within a module. Each span is supported on eight nos. LRBs. The deck structure is resting on pier cap with single pier (with pile foundation). Soil strata in the area is such that loose filled-up soil is encountered up to 15m depth from ground level. To cater for large forces arising due to high seismic forces and poor soil conditions, LRBs have been resorted to in this project. This paper gives salient technical details of the LRBs used in this project.

2 Background

Seismic isolation is a response modification technique that reduces the effects of earthquake on bridges and other structures. It is a combination of period shift and added energy dissipation that must be considered jointly in order to fully utilise the benefits of isolation.

LRB is composed of a laminated rubber bearing with a cylindrical lead plug inserted in its

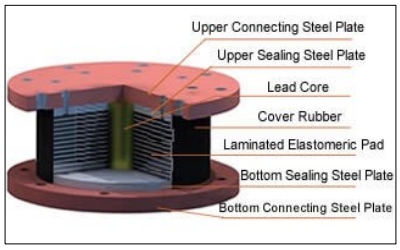


Figure 1. Component of LRB

centre(**Fig. 1**). Lead plug is introduced to increase damping by hysteretic shear deformation of the lead.

3 Application of LRB in MG Setu Project

3.1 Design of LRB

LRBs used in Viaduct of MG SETU have been designed, manufactured and tested in accordance with European standards, ISO and IS code.

3.2 Hysteresis loop

The hysteresis loop is formed by plotting the lateral force acting on the LRB against its corresponding shear deformation. The area inside the hysteresis loop represents the energy dissipated by the bearing during the earthquake.

3.3 System analysis

As per EN:15129, two sets of system have been performed. One with Upper Bound design properties (UBDP) and other with Lower Bound design properties (LBDP). It was found that seismic displacement is critical with LBDP, whereas base shear is critical with UBDP.

3.4 Inspection, maintenance and corrosion protection

An appropriate inspection and maintenance manual has been prepared for LRBs used in Viaduct. As per manual, LRBs are maintenance-free during their design life, apart from regular inspections, cleaning, and renewal of corrosion protection as appropriate.

3.5 Testing protocols

LRBs are tested in accordance with EN: 15129 and ISO standards. Full scale testing and prototype testing have been performed on LRBs used in Viaduct. The test results are based on characteristic strength, displacement, post elastic stiffness, energy dissipated per cycle, damping ratio, visual observations, effective stress and strength of steel laminate. Tests were performed as per codal procedure (on LRB to be used in Viaduct) and results were found satisfactory.

3.6 Comparison of carbon footprint

Table 1 shows a comparison of carbon footprint amongst LRB, Elastomeric and metallic bearing.

Table 1: Quantities/Equivalent of pile, pile cap and pier in a typical 3 span continuous module

Option	Module With	Concrete (m^3)	Untensioned steel (MT)	GWP* (Carbon footprint) $kgCO_{2e}$ per sq.m of deck area
1	Lead rubber bearing	1091	82	224 (64%)
2	Metallic bearing	1511	117	311 (89%)
3	Elastomeric bearing	1689	150	350 (100%)

GWP*: Global warming potential values

Assumed Values of carbon footprint: Concrete: @ 350 $kgCO_{2e}/m^3$, Steel: @ 260 $kgCO_{2e}$/ton

4 Conclusions

Use of LRB for dissipation of earthquake energy and for isolation is an effective method for mitigating seismic risk. This project has proved that use of LRB has not only helped in improving the seismic performance of structure, but also helped to optimise the design and assisted in achieving sustainable development. As per **Table 1,** carbon footprint of a typical module with LRB is only 64% and that with metallic bearing is 89% when compared with Elastomeric bearing. All-inclusive, LRBs are reliable and effective solution for mitigating the adverse effects of earthquakes and the same have been successfully validated with the help of full scale and prototype testing on LRB which are used in Viaduct.

ID-246

Double-Decker - Nagpur Metro Flyover with Spine & Wing Superstructure

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Abstract

The rapid urbanisation demands the development of National highways (NH) & Metro corridors. However, the space available for the transportation structures is only the existing road width, which becomes a deadlock for executing agencies. The Nagpur Metro rail development & NH flyover work along the demanding Wardha road happened to follow suit. The 3.4Km stretch of NH & Metro alignment coincided between Ajni and Airport Road. The challenge became an opportunity to construct a double-decker, however, with various riders such as aesthetics, a stringent schedule, and overall economy. The stretch also included three stations and one obligatory span, which resulted in a Link Bridge for passenger movement and extended pier caps. The multilevel structural arrangement resulted in the optimisation of land use, materials, and other precious resources. The successful implementation of a double-decker became a trend-setter for upcoming projects.

Keywords: Double-decker; Metro; Flyover; Spine and Wing; Combined Pier; Link Bridge; Aesthetics.

1 Introduction

The National Highways Authority of India (NHAI) proposed an elevated corridor of 3.4km on NH-6 passing through Nagpur city, wherein the alignment coincided with the metro alignment proposed by Maharashtra Metro Rail Corporation Ltd. (MAHA-METRO) between the Airport Road and Ajni. The double-decker with metro alignment on top of the flyover is conceptualised in consultation with all the stakeholders.

The combined alignment eliminated land acquisition requirements. The Metro alignment comprises a viaduct with two tracks and three stations. The NHAI flyover comprises 4-lane divided carriageways for most of its length and a part of 6-lanes to accommodate traffic from a merging flyover connecting Manish Nagar. The consultant proposed a scheme with a spine and wing superstructure for the flyover that allowed a single combined pier for the metro and flyover.

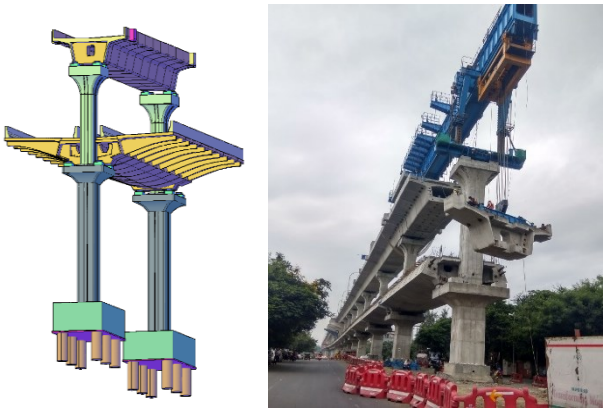


Figure 24. Double-decker arrangement

2 Double-Decker – Planning

The double decker is planned within available land width by keeping constant median widths. The Metro superstructure have Box girder, whereas the NHAI flyover is provided with Spine & Wing type of superstructure. The deck width of 19.6m for 4-Lane traffic is achieved by single cell spine of 6.50m with

6.55m long wing segments. For 6-Lane the deck width is 26.6m with twin cell spine of 8.5m width and 9.05m long wings. The standard spans of 28m

2m.

3 Double-Decker – Design Aspects

The double-decker required to satisfy both the standard provisions of Indian road congress (IRC) and Indian Railway Standards (IRS) for combined substructure and foundation. The double-decker pier size must satisfy deflection criteria as per UIC-776-3 (Deformations) section-7. The crack width criteria of IRS become more stringent as it accounts for live load effects. The Pile cap design is governed by corner pile punching requirements of both the codes.

The spine and wing superstructure is analysed using MIDAS civil software, 3D FEM – plate modelling is used for transverse design. The critical checks of spine & wing joint for indirect support & interfacial shear behaviour are carried out.

4 Double-Decker – Critical Structures

The double decker corridor comprises of three stations within 3.40 km length. The free passenger movement at concourse level had been obstructed, hence the Link Bridge structure with both side cantilevers is provided on single pier.

The alignment has obligatory span of a 40.5m crossing nalla, hence, to keep the harmony of concrete structures extended pier cap at both the levels is provided. The Metro span is reduced to 37m and NHAI span reduced to 34.83m to use existing superstructure forms.

5 Construction Aspects

The double decker launching girder (DDLG) is used to erect both level segments. The weight of each segment ranges from 45MT to 63MT. At first each spine segment has been transported to the site by trucks, lifted and held in position by DDLG. After lifting of all segments for one span, all the segments are dry matched and checked for the geometric accuracy. Then the segments are separated, and epoxy glue is applied on the face. Temporary pre-stress is applied at each segment joint by means of tension bars. After all segments are glued, then permanent pre-stress is applied, and spine is released from LG on to the temporary

are adopted for most of the stretch. The substructure consists bottom Piers of size 2m to 3m x 2.5m and upper piers of size of 1.5m x

stool. After completion of flyover spine girder launching, metro box segments will be lifted from the front cantilever and the segments will be brought inside from the space between two front legs of L.G. The earlier steps will be repeated.

Launching & erection of wings could have been simpler without pier protruding through superstructure. The special launching system had been prepared for wing erection. Wings are erected by cantilever frames supported on spine.



There are transverse stiches between adjoining wings and longitudinal stitch between wing and spine. After these stitches are done, cross pre-stressing is carried out. Other finishing works were taken up subsequently.

Figure 25. Completed Double-decker

6 Conclusions

The overall evolution of double-decker for the Nagpur Metro Flyover provided several insights to carry forward. The proper selection of structural form enables greater savings of precious resources. The superstructures with spine and wing helped reduce the footprint of the substructure, which provides more width for the at-grade road. The use of such options enhances the aesthetics of the structure and the outlook of the locality itself. The double-decker viaducts will be the next trend.

ID-263

Study of A Monumental Stair Susceptible to Excessive Vibrations Due to Human Movements

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Abstract

Excessive vibrations of monumental stairs can become a major serviceability issue as users may feel uncomfortable or unsafe. It is, therefore, important for structural engineers to be able to predict the behavior of these systems as accurately as possible. Inaccuracies in the response prediction can result in a structure with excessive vibrations or great unnecessary costs in terms of material consumption, particularly steel, which is against one of the main goals of sustainability in construction. To evaluate the accuracy of response prediction using a Finite Element computer analysis, this paper presents a study of a monumental stair susceptible to excessive vibrations due to human movements. A series of tests including a modal test and walk tests by an individual were conducted. The subject's applied footfall forces were subsequently measured in a laboratory environment using a mock stair. A computer model of the structure was created and modified to have dynamic properties close to those found from the measurements. Different criteria were used to evaluate the computer model and its accuracy and relevance to the measurements. These included the stair's natural frequencies, Modal Assurance Criterion (MAC), and Frequency Response Function (FRF). The stair responses due to the ascent and descent at its first sub-harmonic of fundamental frequency were computed and compared with those from the measurement. Conclusions were made in regards to the computer modeling of the structure and its effectiveness in walk response prediction.

ID-266

Designing World's Tallest Statue for Wind: Statue of Unity

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Abstract

A tall statue is a confluence of iconic symbolism as well as challenging structural engineering aspects. The Statue of Unity (SOU) is an iconic symbol of the 'Iron Man of India', Sardar Vallabhai Patel, located on a river island called "Sadhu Bet", in the state of Gujarat, India. SOU is presently the tallest statue in the world, with a height of 182 m. Considering the height of the statue, its specific geometry and specific location posed the greatest challenges as the use of Building codes is not reliable for such unconventional geometries. Wind tunnel studies were carried out to understand the effects of local topography, to derive wind-induced loads for the design of structural and cladding systems, and to assess pedestrian wind comfort at the site of the statue.

Keywords: Statue of Unity (SOU), Topographical study, High-Frequency Force Balance (HFFB), Cladding wind loads, Pedestrian Level Comfort, International standards.

1 Background

The geometry of The Statue of Unity is complex. It is slender most at the base, which goes against the norms of what other tall statues have followed. The walking poses also opened up a gap of 6.4m between the two feet which then had to be tested to withstand wind velocity. The statue's complex geometry and location on an island with unusual terrain conditions and the associated technical complexities necessitated wind tunnel testing for accurate estimation of wind loads. For non-conventional buildings like statues, most building codes including IS875 [1} recommend wind tunnel tests.

Studies were carried out to understand the effects of local topography, to derive wind-induced loads for the design of structural and cladding systems, and to assess pedestrian wind comfort at the site of the statue.

Topographical model studies ensure that the effect on the wind flows around the study site is captured accurately in the presence of mountains and statues.

The mean speed and turbulence intensity at the SOU site measured using a 1:1500 scale model is matched for 1:300 model scale. Figures 1 and 2 shows a comparison of the mean wind speed normalised by respective gradient height wind speeds and turbulence intensities respectively for 173m height for both the large- and small-scale wind tunnel test. Remaining mismatches were accounted by velocity scaling factors. The topographic study and the subsequent wind simulation for the 1:300 model ensure that the effects of the far-field topography are captured.

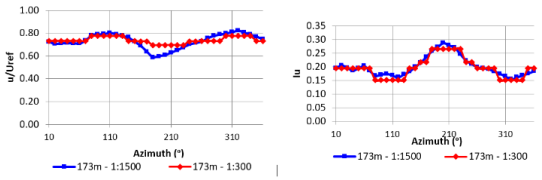


Figure 1: Normalized Mean Wind Speed (u/Uref) and Turbulence Intensity (Iu) Vs. Wind Directions (°)

For the safe design of the structure the lateral wind loads and moments on the structural system of the statue. The horizontal accelerations of the upper part of the statue are required to ensure that the sensations of motion by occupants do not exceed normal guidelines for comfort. Considering the complexity of geometry High Frequency Force Balance Technique was employed using a 1:300 scale model. Statue being an important structure, a 50-year return period 3-second gust wind speed of 39 m/s at a height of 10 m in open terrain along with k1 factor of 1.06 was used. This speed is specified in IS:875, (Part 3), for Gujarat. The application of k1 factor gives a 100-year target wind speed of 41.3 m/s. The base moments shears and torsion for the statue is shown in Figure 3. The drag coefficient calculated for each direction is also plotted in Figure 4. SOU will be open for visitors and there are observation decks at the top of the statue which requires the prediction of acceleration as well. The acceleration were within the acceptable limits.

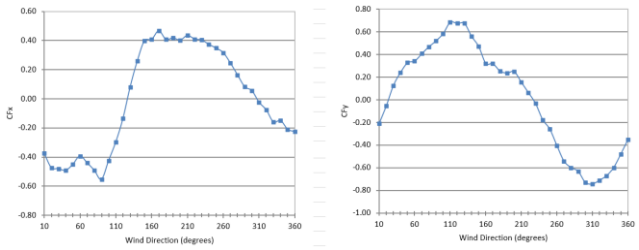


Figure 4. Mean aerodynamic drag coefficients

For the safe design of the cladding the local wind pressures that act on the exterior envelope of the structure was measured by instrumenting the 1:300 scale model with pressure taps at critical locations, as explained by Irwin [4]. The wind speed used for the cladding study was the same as used for the structural loads. The peak cladding loads were determined by adding the exterior pressures with the estimated interior pressure, where applicable. The internal pressures were based on the assumption that there would not be any internal compartmentalisation between the external skin and interior core of the building.

The range of negative pressures for the statue varied from -1.5kPa to -4kPa. The positive pressures varied from +1.5kPa to +2.5kPa. For the podium, the range of negative pressures was from -1.0kPa to -3.0kPa and of positive pressures was from +1.0kPa to +3.0kPa.

For this study, the mean and gust wind speeds at a full-scale height of approximately 1.5 m was measured using Irwin sensors for 36 equally incremented wind directions for pedestrian comfort and safety. The combined effect of mean and gust speeds can be quantified by a Gust Equivalent Mean (GEM) speed, which is the greater of either the mean speed, or the gust speed divided by 1.85, a gust factor typically used for wind comfort. This wind speed predicted for each test location on the model is compared to the RWDI wind criteria to determine pedestrian comfort, while the gust speed is used for the wind safety evaluation.

2 Conclusions

The Statue of Unity is an iconic structure with very complex geometry and is located in complex terrain conditions. Hence the statue can be affected by the wind in unpredictable ways. All factors which influence the wind loading and wind comfort like, the local topography near the statue determines the wind flow upwind of the site was addressed. Wind tunnel testing was carried out on a scaled model of the statue to determine the wind loads on the statue for the proper design of the structural and cladding system. In addition to this, the statue being an iconic tourist location, the comfort of the visitors while in the vicinity of the statue should be ensured which was confirmed by Pedestrian level wind comfort study.

ID-332

488 University Avenue - Toronto: Redefining possible in the vertical expansion of buildings

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Abstract

488 University Avenue condominium is a unique, first-ever designed and constructed 55-story tower, where 37 stories of residential units were added above an existing 18-story office building. This was made possible by an innovative structural solution assisted by extensive wind tunnel testing and the implementation of a tuned sloshing damper (TSD) system to achieve the required strength and serviceability performance targets.

In this paper, a detailed description of the structural solution implemented for this building is first presented. Then, the wind tunnel testing considered for the evaluation of the wind performance of the building is discussed with a particular focus on the assessment of wind-induced motions and their acceptability for occupant comfort. Lastly, the implementation and the as-built performance verification of the TSD are demonstrated using full-scale measurement data obtained from a long-term structural monitoring program.

Keywords: vertical expansion; high-rise buildings; wind tunnel testing; motion comfort, tuned sloshing damper, serviceability performance; structural monitoring.

1 Introduction

488 University Avenue condominium is located in the downtown area of Toronto and is a unique, first-ever designed and constructed 55-story building, where 37 stories of residential units were added above an existing 18-story office building The developer's vision for this project was to create a state-of-the-art mixed-use development by fully renovating the existing office building in a sustainable manner. The renovation plan included the expansion of the underground parking from two levels to six levels and the addition of 37 floors of residential condominiums above the existing office building while keeping it fully operational throughout the entire construction period. 488 University Avenue is the most daring vertical expansion of an existing high-rise building which was made possible by an innovative structural solution assisted by extensive wind tunnel testing and the implementation of a TSD system to achieve the required strength and serviceability performance targets.

2 Structural solution

The structural solution included two 800 mm thick load-bearing concrete walls located at the center of

the existing office building and 24 new "sister" columns with diagonal braces to form a braced tubular exoskeleton structure wrapping around the existing building structure. The braced tubular exoskeleton structure was an inventive solution to support the additional 37-story tower gravity and lateral loads as well as to avoid the overstressing of the existing building structure.

3 Wind performance assessment

Wind performance evaluation was an important component of the structural design for this unique, first-ever designed and constructed high-rise building. Detailed wind tunnel testing and multiple rounds of analysis were conducted to confirm the required strength and serviceability performance targets were achieved. Nine iterations of stiffness, mass, and supplemental damping optimization were conducted until a motion mitigation solution was found where the improvement of torsional velocities was achieved through torsional stiffness increase while the reduction of sway accelerations was made possible through the implementation of a cost-effective supplemental damping system in the form of a tuned sloshing damper (TSD).

4 TSD Implementation

The design of the TSD system was based on the findings from the structural dynamic optimization exercise and consists of two bi-directionally tuned, stacked tanks.

As the tower construction progressed, three rounds of frequency measurements were conducted at Levels 27, 42, and 52 to measure the as-built frequencies of the partially completed building.

These measurements were then compared to a structural model of the tower at an equivalent stage of construction completion to determine how the building frequencies were trending. The observed trend was then used as a basis to determine whether any adjustments in the tanks' footprint dimensions would be required to ensure the TSD stays within the design tuning range of -10% to +25% of the original nominal frequencies.

A final round of frequency measurements was conducted at Level 56 when the structure was complete and building fit-out was underway. The purpose of these measurements was to establish the final as-built structural frequencies, which enabled the final tuning and commissioning of the TSD system.

Following the commissioning of the TSD, a long-term monitoring system was installed to confirm the TSD system was functioning as intended. The monitoring system installed consisted of four ultrasonic wave probes to measure the wave heights within each tank in the X and Y directions, as well as two accelerometers to measure building motions. The wave probes were installed through holes cored through the tank end walls, while the accelerometers were installed on mounting brackets bolted on the structural shear walls of the upper-level mechanical room of the building.

Data collected through simultaneous monitoring of the building accelerations and the TSD wave heights were used as a basis to verify the performance of the TSD system.

The measured building acceleration and wave height spectra were compared to those that were theoretically predicted during the design stage. The results of this comparative analysis showed excellent agreement, indicating that the TSD system is functioning as expected.

5 Conclusions

A unique and innovative structural solution first ever implemented in the vertical expansion of an existing high-rise building is presented. A detailed description of a structural solution which was assisted by extensive wind tunnel testing and the implementation of a tri-purpose TSD system is provided. The implementation of the TSD system and its as-built performance verification are demonstrated using full-scale measurement data obtained from a long-term structural monitoring program. The theoretically predicted and measured spectra are in excellent agreement, indicating that the TSD system is functioning as expected.

Session 15

Analysis, Research and Standardisation

ID-186

Research on creep and shrinkage effects of steel-concrete-Ultra-High Performance Concrete (UHPC) composite structure under different construction methods

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Abstract

This paper mainly calculates and analyses the shrinkage and creep effects of steel-concrete-UHPC composite slabs under two different construction methods (cantilever construction and full framing construction). Firstly, the solid finite element method is used to simulate the shrinkage and creep effects of the composite structure. Then, the stress and deformation of each component in the composite slabs under the two working conditions are compared and analysed. Finally, the influence of construction methods on the shrinkage and creep performance of the steel-concrete-UHPC composite structure is revealed and summarized.

Keywords: Steel-concrete-UHPC composite structure; Cantilever construction; Full framing construction; Shrinkage and creep effects.

1 Introduction

The shrinkage and creep of concrete and UHPC have a great influence on the mechanical performance of composite bridges. The difference of mechanical performance of UHPC and concrete results in different shrinkage and creep effects on the composite bridges. In previous time, many scholars have conducted a study about the shrinkage and creep effects of concrete. However, it is rare to consider the effects of UHPC and concrete in the meantime. In order to reflect the influence of shrinkage and creep of concrete and UHPC, a finite element model is built based on practical bridge. The analysis of shrinkage and creep effects of composite slabs will provide a reference for the design of composite bridges in the future.

2 Methods

The shrinkage and creep effects of concrete has been studied for a long time[1]. The shrinkage effects are similar to cooling effects. In the finite analysis, the shrinkage and creep effects of concrete are considered based on the existing guidelines[2]. In terms of UHPC, the study about UHPC is rare as a new material. Similarly, the shrinkage and creep effects are considered based on the requirements of latest guidelines[3]. In order to reveal the mechanical performance accurately, a three-dimensional finite model is built to analyse the stress and strain distribution of the composite slabs. In the finite analysis, two types of construction methods are calculated and analysed. One is the cantilever construction. The other is the support construction.

3 Discussion and results

The stress distribution of each component of the composite slab during different construction stages is shown in the **Error! Reference source not found.~Error! Reference source not found.**.

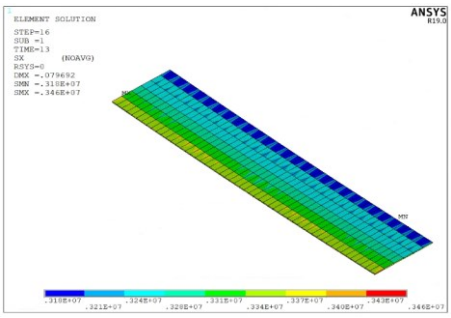


Figure 26Transverse stress of UHPC layer under cantilever construction

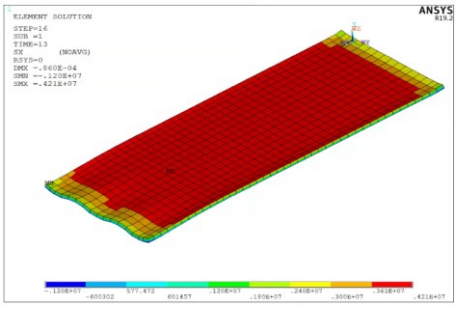


Figure 27Transverse stress of UHPC layer under support construction

(1) cantilever construction: after pouring and curing of UHPC, the stress gradually increases with age. And the steel-concrete composite section has a higher rigidity. The joint connection makes the shrinkage deformation of UHPC obviously limited, so the maximum transverse stress of UHPC layer reaches 3.4MPa.

(2) support construction: the stress state of the UHPC layer in the early stage is mainly related to its own shrinkage and creep. And the concrete restrains the deformation of UHPC layer. The maximum tensile force at the top of UHPC layer is 4.21MPa. After the system conversion, the tensile stress of UHPC layer increases to 4.51MPa under the action of self-weight.

4 Conclusion

The stress of every component of the composite slab is shown in the **Error! Reference source not found.**.

Table 10 Calculation results of transverse stress of composite slabs

Specimens	Steel ribs (MPa)	Steel plate (MPa)	Concrete (MPa)	UHPC (MPa)
Cantilever construction specimen	34.9	-19.8	-0.52	3.4
Full support construction specimen	-5.03	-8.64	0.39	4.5

Through the calculation and analysis of the steel-concrete-UHPC composite bridge deck, it can be seen that,

(1) The shrinkage and creep of materials is a long-term effect, and the shrinkage and creep parameters of concrete and UHPC materials are quite different;

(2) Compared with the full support composite slab, the transverse stress of the bottom steel plate and steel ribs is higher for cantilever construction composite slab. And the concrete and UHPC layer has lower transverse stress;

(3) In order to give full play to the excellent performance of UHPC, a part of the effects of shrinkage and creep can be eliminated by high-temperature steam curing, improving the performance of composite slabs.

5 References

[1] Wang Longfei.2021. Comprehensive Simulation on Shrinkage and Creep Effects of Concrete in Bridges during Time-varying Process. *Journal of Highway and Transportation Research and Development, 38(02), 54-61. (in Chinese)*

[2] Ministry of Transport of the People's Republic of China. 2018. *Specifications for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTG 3362-2018) Beijing: China Communication Press. (in Chinese)*

[3] Ministry of Transport of the People's Republic of China. *Specification for application of Ultra high-performance concrete for highway bridges and culverts (draft) (in Chinese)*

ID-199

Butt-Jointed Reinforcement Bars in The Longitudinal Joints of Tunnel Segments: Experimental Investigation

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Abstract

A tunnel lining built with a TBM (tunnel boring machine) consists of a large number of segments interacting via joints, that are commonly decisive for the design of the segment. In order to overcome this limitation, the Institute of Structural Engineering at TU Wien developed a novel reinforcement concept to enhance the longitudinal joint in terms of the ultimate load.

This paper presents the results of an experimental campaign on large scale test specimens investigating the load-bearing behavior of load transfer zones under compression with butt-jointed longitudinal reinforcement bars. The focus is on the effects of using a minimum transverse reinforcement on the load-bearing capacity of the segments. Based on the satisfactory results, it can be stated that the TU Wien reinforcement concept has a great potential for improving the performance of highly stressed tunnel segments.

Keywords: segmental tunnel lining, precast tunnel segments, joint reinforcement, resource-efficient structure

1 Introduction and idea

Building the load-bearing tunnel structure with a segmental lining has gained growing relevance within recent decades and is now an internationally established and frequently used construction method. The load-bearing capacity of the longitudinal joint is typically the decisive factor when designing tunnel segment rings. This is due to the reduced cross-section of the segment in the longitudinal joint, accounting for installation and durability requirements.

In order to improve the performance of the longitudinal joint, the Institute of Structural Engineering at TU Wien developed a novel reinforcement concept. With this approach, the longitudinal joint is no longer the weakest link in the segment ring. The new reinforcement concept is covered by a patent application [1, 2]. National patent phases have begun in Europe, the United States, Canada, and China.

According to the new concept, additional reinforcement bars, as indicated in Figure **Error! Reference source not found.**a, are positioned precisely adjacent to the contact surface of the longitudinal joints. The load-bearing capacity can be improved by increasing the number of reinforcing bars according to the specifications of the individual project.

Typically, compressive normal forces dominate the whole tunnel ring, which guarantee the durability of the longitudinal reinforcing bars of the TU Wien reinforcement concept. Bending moments caused by asymmetric load cases occurring at a longitudinal joint may result in a gap between two tunnel segments. To avoid reinforcement oxidation, the joint reinforcement bars must be positioned in the predicted compression zone.

The proof of concept of the innovative reinforcement concept has already been done in 2019. In this paper, first results of a new extensive experimental campaign are presented and

compared with the results of the 2019 tests TU Wien design approach.

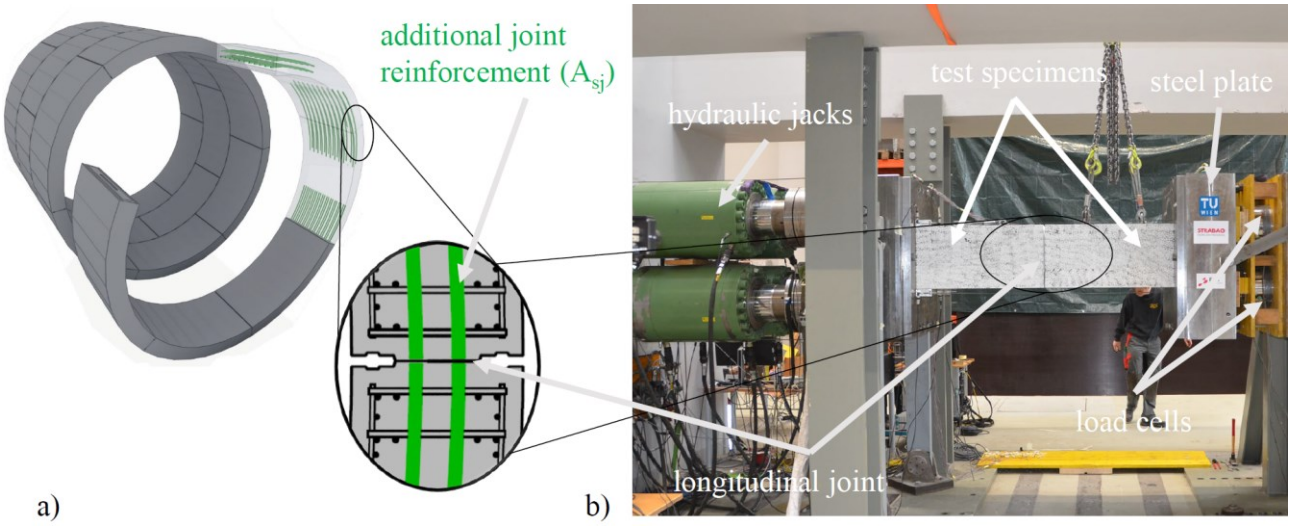


Figure 28. TU Wien reinforcement concept: a) overview of the tunnel structure (taken and adapted from [3]); b) installed specimens in the testing rig

2 Experiments

Large-scale tests have been carried out at the Institute of Structural Engineering to collect further data about the performance of the TU Wien reinforcement concept (shown in Figure **Error! R eference source not found.**b). The main purpose of the experiments done in 2023 is to investigate the behavior of the TU Wien reinforcement concept applied to tunnel segments using a lower limit of transverse reinforcement ratio in direction of the load distribution.

In total eight compression tests (two of each specimen type) are presented in this paper. The experiments are still ongoing and further results will be presented in the future.

3 Conclusion

Based on the experimental campaign presented in this paper the following conclusions can be drawn:

- The full activation of the joint reinforcement using the minimum allowed transverse reinforcement ratio according to current design codes was demonstrated.
- The increase of the load-bearing capacity of the longitudinal joint by approx. 44% and 35%, respectively, could be achieved with the presented experimental investigations.

The results provide further important data for a successful application of the TU Wien reinforcement concept in the near future.

[1.] Kollegger J., Proksch-Weilguni C., Wolfger H., and Decker M. Tübbing aus bewehrtem Beton. AT patent application A 50433/2019, submitted at 14th May 2019.

[2.] Kollegger J., Proksch-Weilguni C., Wolfger H., and Decker M. Reinforced concrete tubbing. PCT patent application PCT/AT2020/060030, submitted at 4th February 2020.

[3.] Proksch-Weilguni C., Decker M., and Kollegger J., *Longitudinal joint design for eco-efficient tunnel structures*, in *fib International Congress 2022*. fib, 2022.

ID-222

Bridge Cables – Non-Desctructive Testing

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Abstract

When constructing bridges with large spans, there is virtually no alternative to the use of high-strength tension members. As a rule, full-locked coil ropes are used here, although the use of parallel strand systems is becoming increasingly widespread. Both types of tension members are regulated in EN 1993-1-11. The corresponding protection targets are:

- sufficient safety of the bridge in ultimate limit states
- sufficient safety in use in permanent design situations
- sufficient durability and low maintenance requirements

The required robustness and sustainability are particularly sought after in the use of tension members in bridge structures, since the tension members can either not be replaced at all or only at great expense. The tension members are therefore one of the main components that essentially determine the service life of a bridge structure.

Damage to the tension members used is manifested in particular by wire breaks, which can have various causes.

In order to ensure a consistent level of safety here, regular inspections are essential. Since visual inspections can, by their very nature, only detect surface damage, magnetic inductive testing is an option here, taking into account the technical and economic feasibility. The principle of magnetic inductive testing has been known for many decades and has been used in the past for testing tension members, especially in ropeway construction and in the testing of mining ropes. An application to bridge structures is a recent development.

On the basis of an interlaboratory test involving the two test centers DMT and ROTEC, various rope tension members (three full-locked coil ropes and two parallel strand systems), which had previously been artificially provided with discontinuities, were tested non-destructively. The number and location of the discontinuities were known neither to the research center nor to the participating test centers.

Different testing methods were applied for different parts of the rope. The free length of the rope was tested using magnetic inductive methods, while the parts of the rope close to the end connections were examined using ultrasonic tests.

Magnetic inductive rope testing is a flux leakage method. When passing through the testing device, the tension member is magnetized until magnetic saturation is reached. Damages in the rope cause magnetic inhomogeneity. Those disruptions in the magnetic field can be picked up and converted into a digital signal using sensors. The test signal measured in this way can then be used to draw conclusions about possible defects in the rope. Different testing devices using various sensors and magnetization units were used at variable speeds. **Error! Reference source not found.** shows an exemplary comparison of the test signal and e valuation of the two test centers for the same rope. The defects that were identified as such by both test centers are marked in green.

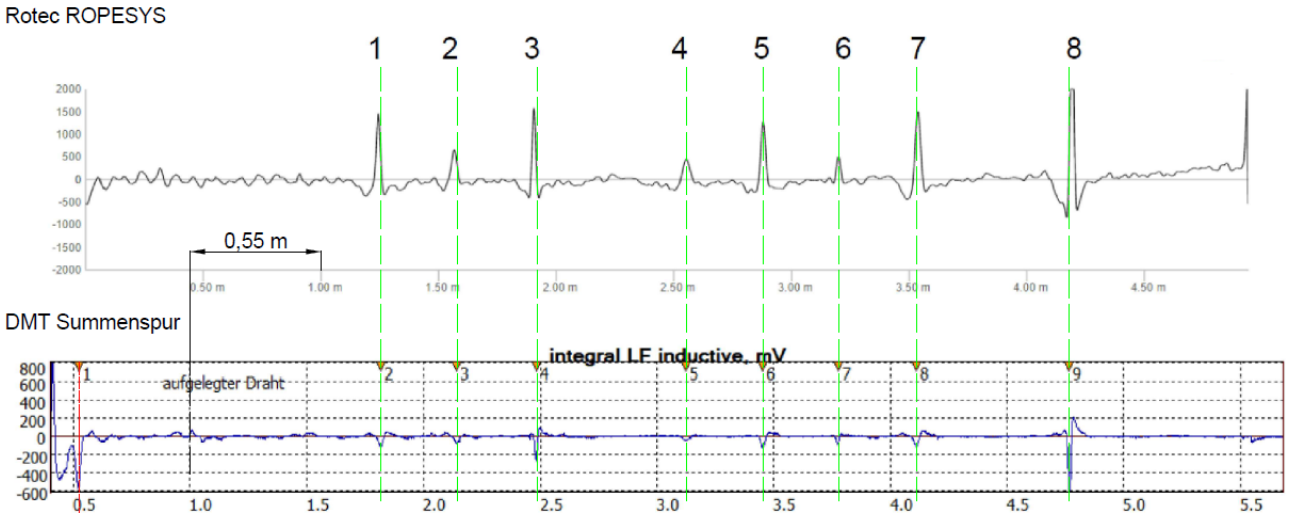


Figure 29. Evaluation of testing signals for full-locked coil rope (∅110 mm) by the ROTEC and DMT test centers

The ultrasonic tests in the area of the end connections were carried out using the impulse echo technique.

The magnetic inductive tests were carried out at the KIT in Karlsruhe; as shown in **Error! Reference source not found.**, the ultrasonic tests took place subsequently on the BASt premises.



Figure 30. Magnetic inductive tests carried out by test centers ROTEC (left) and DMT (right): KIT

Based on the results of the tests, recommendations for an extension of the RI-ERH-ING were developed. The recommendations are not conclusive, as a final evaluation of the performance of the test sites was not possible without knowledge of the discontinuities introduced into the specimens.

However, the German Federal Highway Research Institute (BASt) has provided information on the accuracy of most of the test results. According to this information, flaws in ropes with a diameter of up to 110 mm could be identified with an accuracy of approximately 86%, missing only minor flaws. The accuracy for the rope with the greatest diameter of 130 mm was lower, varying from 50 to 63 % depending on the test center.

The results of the research project show that the MIT method has the potential to improve the safety and reliability of bridge cables, contributing to the longevity and sustainability of transportation infrastructure.

With regard to the detection of imperfections, especially those where there is no complete material separation, there is still a need for development in the examination of bridge cables. The same applies to the only rudimentary possibilities for automated signal processing or detection of imperfections.

ID-236

Seismic performance of rigid-frame suspension composite bridges

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Abstract

Rigid-frame suspension composite bridges can improve the problem of continuous mid-span deflection of traditional long-span continuous rigid-frame bridges. In this paper, a rigid-frame suspension composite bridge with a span combination of (70+130+80) meters was selected as the case study. The elastoplastic three-dimensional dynamic finite element model of the bridge was built by OpenSees software. Nonlinear time history analysis and fragility analysis were carried out. The results show that the dynamic characteristics of the rigid frame suspension bridge are similar to those of rigid frame bridge. The rise-span ratio affects the displacement at the top of tower, the bending moments at the bottom of tower and at the top of pier in the transverse direction. The results of fragility analysis show that the bridge tower remains elastic under earthquakes.

Keywords: seismic performance; rigid-frame suspension composite bridges; rise-span ratio; fragility analysis

1. Introduction

The structural feature of rigid-frame bridges is that the main beam is rigidly connected to the bridge piers. Its most obvious advantage is that the pier and beam can work together to resist external forces. Compared to bridges with smaller spans, the response of large-span continuous rigid-frame bridges to earthquakes is more significant, and their seismic analysis is more complex. Based on existing research results, it is concluded that vertical seismic effects have a relatively small impact on internal forces of the structure. In seismic response, the control section of high-pier and large-span continuous rigid-frame bridges is located at the bottom of the pier, the root of the main beam, and the mid-span. [1]

Suspension bridges, due to their strong crossing ability, long structural period, and small response, have gradually become the preferred bridge type in high-intensity earthquake areas. According to the literature, some suspension bridges with small spans in Japan have suffered local damage due to earthquake action. For example, one of the main towers of the Atakawa Bridge with a main span of 90m was fractured in the Kanto earthquake, and the upper chord of the Gosho Bridge's stiffening girder was bent and the anchorage moved 20cm in the Fukuoka earthquake.

The bridge type studied in this article is a combination of rigid-frame and suspension bridge systems. It combines the advantages of large rigidity of rigid-frame bridges and strong crossing ability of suspension bridges, which makes the middle part of the bridge beam more flexible. However, since this bridge type is proposed for the first time, its seismic performance needs to be studied.

2. Extended Abstract

The bridge studied in this article is a combination of rigid-frame and suspension bridge systems, with a span combination of 70m+130m+80m. The elastoplastic three-dimensional dynamic finite element model of the bridge was built by OpenSees software. Due to the good geological conditions of the bridge

site, the interaction between piles and soil is ignored in this study and the pier are fixed at the bottom. To obtain the seismic response of the bridge with different rise-span ratio, the study employed 20 far-field earthquake ground motions from the Pacific Earthquake Engineering Research (PEER) strong motion database for nonlinear time history analysis. In order to study the damage state of rigid suspension composite system bridge under earthquake, the vulnerability of rigid suspension composite system bridge is compared with that of rigid bridge. The findings are summarized as follows: (1)Under seismic excitation, the bridge tower of the rigid-frame suspension composite system is less susceptible to damage because the inertia force of the main beam is primarily borne by the bridge piers.(2)Under seismic excitation, due to the lower height and greater flexibility of the main beam in the rigid-frame suspension composite system, the seismic inertia force on the superstructure is smaller, making it less susceptible to damage compared to a continuous rigid frame bridge. To improve the seismic performance of the rigid-frame cable-stayed system, the size of the tower section can be reduced by changing its cross-section and shape to reduce the seismic inertia force of the structure.

ID-250

Numerical Modeling of Rigid Frame Suspension Composite Bridge

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Abstract

Large span continuous rigid frame bridges often suffer continuous deflection of the middle span in the service. In this paper, the rigid frame-suspension composite bridge is proposed in which main cables and hangers are adopted to support part of the beam weight at mid-span. A 70+130+80m-span bridge was selected as the case study and its finite element model was built using the software of Midas. In comparison with continuous rigid frame bridge, the rigid frame suspension composite bridge suffers significantly lower creep deflection. As the tensile force of hanger rod increases, the upper deflection value increases. The results obtained have certain reference value for the design of such composite bridges.

Keyword: rigid frame suspension composite bridge; numerical modeling; the mid-span deflection of main beam

1 Introduction

With the continuous development of bridge construction in China, the proportion of large-span continuous rigid frame bridges is gradually increasing. However, many pre-stressed continuous rigid frame bridges have appeared with mid-span sagging problems that affect the normal use and structural durability.For example, the auxiliary channel bridge of the Humen Bridge with a main span of 270m was completed in 1997. In 2003, the mid-span deflection value had accumulated to 22.2cm, which exceeded the reserved 10cm pre-arch value during construction.

This article proposes a combined system of continuous rigid frame and suspension bridge, which can fully utilize the stiffness of rigid frame bridge and the large-span crossing capacity of suspension bridge . The main cable is used to support the secondary dead and live loads and alleviate the mid-span deflection problem. The numerical finite element analysis method is used in this paper to study this type of bridge . The research results can provide references for similar engineering projects.

2 Extended Abstract

This paper studies a rigid-frame suspension composite bridge with a span combination of 70m+130m+80m. Unlike conventional ground anchor suspension bridges, the construction process of this bridge is more similar to that of a self-anchored suspension bridge. That is, a continuous rigid-frame bridge was formed, and then the main cable and hangers are installed. The finite element method was used to study the rigid frame-suspension composite bridge in the different construction stage. The effects of different bridge types and hanger cable force . on the. bridge . were studied. The following conclusions were drawn:(1) After the middle span of the rigid frame-suspension composite bridge is closed, the cables and hangers are installed, which causes an increase in mid-span deflection of the main girder. This effectively solves the problem of long-term deflection.(2) A comparison between the rigid frame-suspension composite bridge and the rigid frame bridge shows that the middle span cable and hanger greatly reduces the mid-span deflection of the structure under the dead load, making the structure more uniformly stressed.

ID-616

In-Plane Behavior of Strengthened Unreinforced Masonry Infill Walls: Experimental and Numerical Study

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Abstract

Masonry walls are often regarded as non-load-bearing components in most steel or concrete-framed buildings. However, it effectively increases the total system's strength and stiffness when subjected to horizontal forces since it is a heterogeneous construction. It is standard practice not to include the infill walls in the numerical models used for practical structural analysis and design purposes when building such structural systems against seismic activities because these parts are not load-bearing. By doing this, their contribution to the frame's stiffness and strength and its interaction with the load-bearing components (i.e., the beams, columns, and walls) are entirely disregarded. The interaction of the frame and infill between the interfaces between the surrounding structure and the infill walls, which increases the stiffness of the entire frame, is typically the only way that infill walls are considered. Masonry infill walls can significantly impact the structural performance of RC frames during seismic actions from the current published experimental and computational data. However, over the past several years, many researchers have become interested in the recent poor performance of Unreinforced Masonry Infill Walls (MIW) during in-plane seismic stress. Experimental tests examining different factors influencing the behaviour of MIW, including using Textile Reinforced Concrete (TRC) as a reinforcing material, were carried out. This paper will discuss the experiment using reversed quasi-static cyclic sinusoidal displacement-controlled loading on the masonry infill wall and explains the outstanding ductility capability of masonry infills in Reinforced Concrete (RC) frames, as seen during cyclic experimental testing on wall specimens. The study's primary aim was to describe how the rectangular brick infill panels on RC frames behave during earthquakes.

A half-scale one-story single-bay MIW specimen is created to examine its seismic performance. The specimen spans 2300 mm and has a total height of 1500 mm. The dimensions of the foundation beam section are 350 mm 250 mm, the beam section is 250 mm 140 mm, and the frame column is 200 mm 140 mm. The concrete cover is 200 mm thick in the foundation beam and has a 10 mm thickness in the beam and columns. The foundation's rings and the hoops in the beam and column are separated by 170 mm and 120 mm, respectively. Burnt red clay bricks make up the infill wall; the major bricks are 200 mm by 110 mm by 80 mm. The compressive strength of concrete is tested using three 150 mm cubes. A concrete prism's converted average compressive strength is around 25.6 MPa, whereas the average compressive strength of a concrete cube is 38.2 MPa with a standard variation of 4.3 MPa. The compressive strength of masonry is tested using three masonry prisms, and the average strength is 2.57 MPa with a standard variation of 0.22 MPa. Two vertical jacks apply a steady axial load of 100 kN to the frame columns. Low-friction rollers are used in the vertical jack's top portion to enable the

jacks to retain the same horizontal displacement as the specimen while being loaded. On top of the specimen, a force transmission device (load cell) is installed. The horizontal hydraulic servo actuator is coupled to the force transmission device to apply the cyclic displacement load. A preload precedes the test. The frame columns are first subjected to a continuous vertical force of 50 kN on each column. The specimen is next subjected to a cyclic horizontal displacement with an amplitude of 0.5 mm to determine whether the loading devices are correctly attached, and the acquisition tools are operating as intended.

In this work, the RC frame reinforced with FRCM was modelled using the well-known FEM programme ABAQUS. Concrete masonry units (CMU) and RC frame members were simulated using solid components. Expanded brick units (EBUs) are CMUs that have had their dimensions boosted by the mortar joint's half thickness in horizontal and vertical directions to link the separate CMUs and allow them to interact with one another. The reduced micro-model, albeit employing larger brick units, offered the necessary precision and is regarded as a more computing-efficient modelling technique than a complete micro-modelling approach where mortar joints and the brick units are modelled independently. Bricks and concrete were modelled using an 8-noded three-dimensional element with reduced integration (C3D8R). The bending impact of the rebars was not considered in this modelling; hence the stirrups were modelled as rectangular structures without bending performance. The reinforcement was modelled using B31, a 3-dimensional beam with a linear (first-degree) function. The concrete served as the master surface, while the brick served as the slave surface, with the relationship between them being characterised by a tie element. The brick and the RC frame were both modelled as solid parts. It is important to remember that the bricks were created as a simplified micro model, necessitating separate construction of each. Concrete and rebar interaction was simulated using the embedded area. Also, to replicate the strong foundation RC-beam plate used at the bottom of the frame in the experiment, all the nodes at the bases of both columns were restricted using coupling constraints to prevent translation and represented as a fixed connection.

The results regarding in-plane force-displacement responses, damage evolution and energy dissipation capacity will be presented. Ultimately, the experimental tests were simulated in the software ABAQUS through a simplified modelling approach and validated against the experimental results. The topmost corner mortar joint near the tie columns was first where horizontal fractures were noticed during the early loading phase. Concrete that had been crushed and spalled was honoured at the column's bottom opposite corner. The first fractures were noticed during the first cycle in the positive direction of loading, at a top displacement of around 6 mm; only the infill experienced two diagonals, stepped cracks. The opposite diagonal of the infill panel had the same behaviour during the load reversal, with two stepped fractures appearing. In infill wall the top portion of the masonry system displayed some stress formation, and cracks have formed in the wall's mortar joints. The maximum load-carrying capacity and the maximum deformation values are almost congruent. However, regarding the importance of the maximum lateral displacement, the numerical analysis values are always more significant than those obtained in the experimental results. Compared to the experimental results, Abaqus generally over-predicts the specimens' maximum lateral displacement and loading bearing capacity by a full range of 5%. Overall, Abaqus simulated results are in good comparison with experimental ones.

Keywords: Masonry Infill Walls; Quasi-Static; Textile Reinforced Concrete (TRC); Numerical Simulation; Force-Displacement Responses.

Session 16

Special Session: Existing Bridges - Our Vital Responsibility in BIM Environment

ID-546

Digital Bridge Schwindegg: Ab Initio Bridge Monitoring for A Sustainable Lifecycle Management

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Keywords: Bridge Construction; Sensors; Structural Health Monitoring; Lifecycle management; Digital Twin; Data Model; Degradation of Bridges

1 Introduction

In most countries of the world, bridge structures suffer from ageing issues, which is accompanied by deterioration of the structure's condition. If the condition of the structure becomes unacceptable, the structure must either be repaired, restricted in its use, or replaced. To extend the service life, manual testing, non-destructive testing, or Structural Health Monitoring (SHM) methods are often used. One of the latter is emergency monitoring. In this case, the bridge is kept in operation until it is rebuilt or repaired. Another approach is to use sensor measurements to detect changes in the condition of the bridge. This requires data over a long-time horizon. Therefore, a monitoring system was designed for the new construction of the Isen Bridge in Schwindegg (Germany). The bridge structure is a single-span frame structure with prestressed prefabricated beams and in-situ concrete supplement. The clear span is approx. 19,8 m.

2 Conception of the Digital Bridge

This type of bridge is widespread in Germany in terms of its construction and the materials used. It is therefore ideally suited as a real laboratory. The aim of the project is to record as many different sensory data as possible over as long a period as possible. Based on this, a feasibility study was carried out. For this, existing SHM methods were used, and the sensor planning was adapted to the bridge. As a first method, the stiffness of the frame corner is analysed. Furthermore, among other things, this spring stiffness has an influence on the distribution of the bending moment over the frame. In addition, e.g., the time-dependent losses of the pretension play a role. These two approaches provide feedback on the assumptions made in the static calculations regarding the construction method. The interaction with the bored piles and thus the foundation is investigated by measuring strain at the bored pile heads. In addition, the load assumptions of the standards regarding the daily and seasonal temperature influences are to be checked. Likewise, the vehicle crossings will be logged to generate a real traffic load model of the bridge. In addition to the engineering models, methods of data transmission and the boundary conditions for setting up a measurement system will also be investigated.

The sensor concept was derived from the key areas to be investigated in the feasibility study. A distinction is made between sensors that are accessible for maintenance and inaccessible sensors. The latter were embedded in the structure as strain sensors and temperature sensors. Installation positions were the precast beams, the bored pile heads, and the frame corner. In addition, temperature sensors were installed in the in-situ concrete carriageway slab and the abutment. The earth pressure sensors in the backfill area of the abutment are also inaccessible. As accessible sensors, different types of sensors for strain

measurement are attached to the webs of the precast beams on the underside of the bridge. Furthermore, inclinometers and accelerometers were mounted at points determined by engineering. The use of a water level measuring system completes the measuring equipment installed on the underside of the bridge. A weather station was also attached to the technical block. To obtain meaningful results from the sensors, e.g., using machine learning methods, sampling rates were specified in the measurement concept.

3 Sustainability of a Digital Bridge

The transfer of the measured data to the digital model is depicted in a data model (Figure 1). The advantages of the industry 4.0 Asset Administration Shell BBox as a holistic platform for creating digital twins beyond data storage are presented. This enables the real bridge and its twin to communicate.

Finally, the possibilities are shown how SHM can be used to make bridge structures more sustainable. The newly proposed climate limit state is used as an assessment standard. It is shown that SHM has a positive influence both on the potential impact on the service life of a structure and on the design of more sustainable bridge designs.

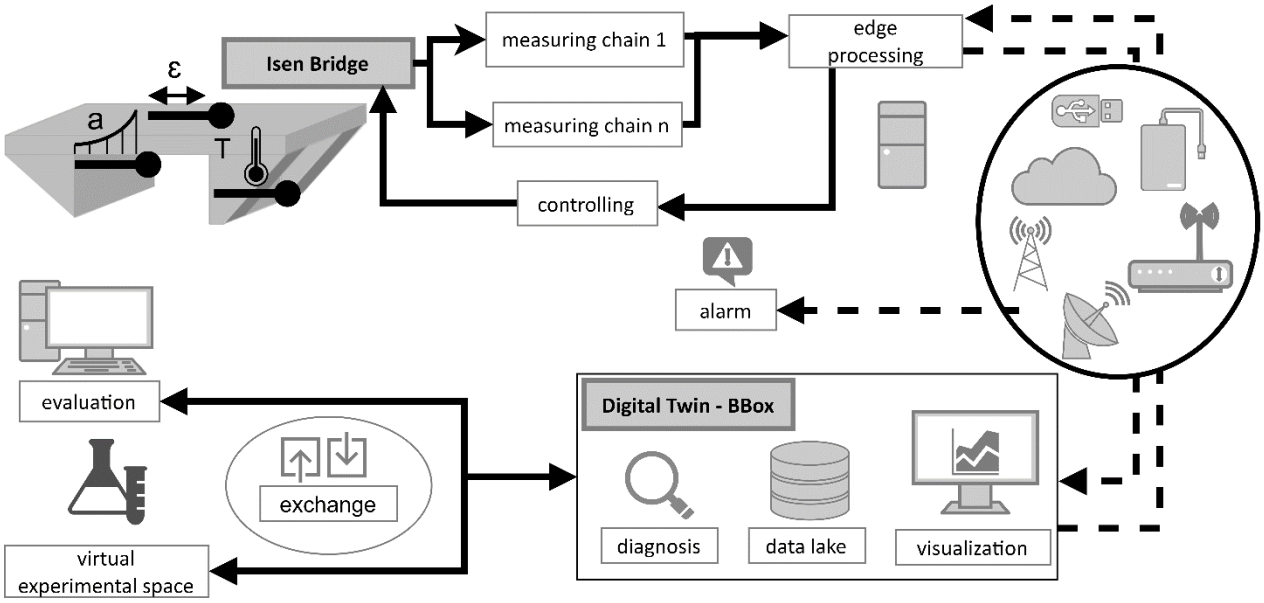


Figure 1. Path of the measured data: From the real bridge to its digital twin

ID-225

Digitalization of Bridge Inventory Via Automated Generation of BIM Models

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Abstract

The construction of building information modeling (BIM) models for infrastructure is becoming increasingly prevalent, as it facilitates current asset management practices. Existing bridges are particularly challenging to model due to their complex geometry and missing information. Given the recent advancements in 3D surveying and artificial intelligence, new possibilities emerge for the generation of BIM models. This paper presents a novel, modular framework for an automated construction of as-is bridge BIM models from point clouds of existing bridges. Bridge element datasets were provided to train neural network. Trained neural network can identify bridge elements, which are further processed using geometric algorithms into surface and solid bridge elements. This result can be additionally enriched with information from existing databases. The final BIM models are exported in the standardized, open Industry Foundation Classes (IFC) format.

Keywords: bridge inventory; point cloud; artificial intelligence (AI); deep learning (DL); building information modeling (BIM); digital twin (DT); Industry Foundation Classes (IFC).

1 Introduction

New construction projects have to be planned and built using digital building models since 2021. The benefit of the digitalization in asset operation phase can be fully exploited only when BIM models are available for the majority of the existing assets. The manual digitalization process can be costly or only feasible up to a limited extent. In addition, BIM models derived from 2D plans and asset databases often represent the as-planned and not the desired as-is state. The recent advancement of surveying technology and artificial intelligence have opened new digitalization possibilities. This paper presents a modular approach for an automated generation of as-is bridge BIM models from point clouds. It is divided into learning and application parts, which together consist of nine processing procedures. Learning part contains training dataset preparation and neural network training. Application part includes the use of trained neural network and geometric algorithms on new bridge point clouds.

2 Learning part

Procedure 1: Generation of bridge models as training data.

3D bridge models with element semantics are constructed by combining typical bridge elements.

Procedure 2: Conversion of bridge models into bridge point clouds.

Generated bridge models are virtually scanned and derived into point clouds with semantics of each scanned point. Virtual scanning simulation was designed to mimic the output of real LiDAR scans.

Procedure 3: Addition of the manually annotated real bridge point clouds to the training data.

Further training data is acquired by manually annotating real bridge point clouds, to ensure that distinct structural features are not overlooked.

Procedure 4a: Point cloud pre-processing for the learning part.

Virtually scanned and real annotated bridge point clouds are processed for neural network training.

Procedure 5a: Neural network training.

Neural network learns from annotated point cloud dataset to recognize bridge elements in new data.

3 Application part

Procedure 4b: Point cloud pre-processing for the application part.

Point clouds are unstructured, large data with varying resolution and accuracy. Pre-processing steps are performed to improve the data quality.

Procedure 5b: Neural network segmentation.

Trained neural network works on pre-processed real-world bridge scans to determine the most probable class for each point of the point cloud.

Procedure 6: Point cloud post-processing.

The results of AI-based segmentation are checked for their plausibility and corrected as necessary.

Procedure 7: Methods for deriving surface and solid models.

Segmented point clusters of bridge elements are transformed into triangulated surface meshes as well as solid models, which are more suitable for BIM model representation than points, by using a set of geometric reconstruction algorithms and the established bridge property knowledge base.

Procedure 8: Semantic enrichment and geometry adjustment.

Bridge element geometric representations are enriched with data from SIB-Bauwerke, which is a German road structure database. Bridge element geometries obtained from scans are corrected with this data and the bridge property knowledge base.

Procedure 9: IFC file generation.

An IFC-Writer-Script has been implemented to convert the bridge geometric representation and linked semantic information into an IFC file. The IFC element hierarchy corresponding to bridges is established and additional information (in the form of IfcPropertySets) is linked to these IFC elements.

4 Conclusion

This work addresses the needs of bridge owners to have up-to-date bridge asset data. The final result are as-is BIM models of existing bridges with surface and solid geometries, enriched with semantic information from databases of SIB-Bauwerke, exported in the standardized, open IFC file format. The entire processing chain of the application part from raw point cloud scan data to final BIM models was tested on several existing road bridges of the German Federal Highway Network. This demonstrates the methods' practical suitability and robustness that is needed for a future large-scale application. The findings have the ability to accelerate digital transformation in the bridge sector and improve asset management processes. A significant potential also lies in the complete digitalization of structural inspection and maintenance planning, where damage extent can be localized and visualized. Digital bridge models can be furthermore embedded into 3D terrain models, to simulate negative environmental impacts and calculate community resilience. A larger training dataset for neural networks would further increase automation levels and the robustness of results. An extended bridge property knowledge base could also help to generate more detailed bridge element geometric representation.

ID-192

Linking BrIM to BMS for bridges – concepts.

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Abstract

Bridge Information Model (BrIM) is currently replacing drawings as main deliverable in new bridge project. Several use cases for BrIM over its lifetime is identified, as well as a discussion of the use case potential. Use cases include, but are not limited to, linking Bridge Management Systems (BMS) and BrIM, handling inspection data, visualizing inspection results and damage, tracking maintenance actions and structural changes. It may also serve for the analysis of residual strength, as digital twin in structural health monitoring (conditional maintenance) and as risk-based decision-making tool for the allocation of resources.

Thus, this paper will form a basis for updates of relevant IFC classes in the BrIM data structure to facilitate seamless communication between BrIM and BMS systems. Thereby the grossly different level of detail in BrIM (individual objects), GIS (road network) and BMS (asset portfolio), the data aggregation and drill-down, and the portability of existing data collections are major concerns.

Keywords: Asset Management, Bridge, Inspection, Maintenance, digital twin, BrIM, BMS, BIM, IFC,

1 Extended abstract

The ambition of many bridge owners is that BrIM shall be used during the whole life cycle of the structure, from initial design phase, through construction, operation, and maintenance until it is removed and recycled at the end of service – a one-stop-shop for information. Operation and maintenance data is currently collected in various forms and stored in different repositories as part of a BMS. To optimize maintenance of the individual structural asset and manage the asset as portfolio of structures it is beneficial if BrIM and BMS are linked such that information can be exchanged seamlessly, also for existing structures that currently do not have a BrIM model.

The complexity of maintenance/inspection requires organized, automated, open and transparent digital processes, which should consider both structural and asset management data.

It is assumed that the BMS aims to integrate digital storage, exchange of data, cost as well as deterioration, optimization and analysis models and their interoperability with existing BIM solutions.

The vision of this work aims to form a foundation for 3D/4D/5D/6D software and hardware independent data exchange between different software technologies during life cycle and beyond, considering also monitoring, sensor equipment and damages on the structure along time axis. Open BIM technology for the interoperability from technical, semantic and organizational point of view is of main interest. Thus, the work is based on the following formulation:

BIM model should be the driver and front end and will provide a link to the BMS system. The BIM model should allow for bi-directional information flow with the BMS system (and other systems linked to the BIM) such that information is not duplicated. The aim of our TG is searching for all requests from BMS systems (in form of use cases) in order to report missing attributes within exiting Open BIM systems.

In order to prioritize the direction of the work Figure 1-1 was defined, and this paper is part of the "Identify" phase for linking BMS and BIM for bridges.

Relevant use cases for a BrIM model over its lifetime is identified, including their potential and eventual extension of IFC standard. Currently, IFC standard (widely recognized and used Open BIM standard) is used as the reference data scheme. For the future it is important to underline, that IFC is not the only possible exchange format.



Figure 1-1 Workflow.

Linking BrIM and BMS through extension of the IFC format opens up for seamless communication between the system. This will give the bridge owner the possibility to combine information stored during the design phase with data collected in the operation phase, thus, opening up for more informed and effective operations of individual structures, as well as easier comparison between structures through e.g Key Performance Indicators.

The following key extension of IFC were identified:

- Introduction of time stamp to track change on elements and information.
- Introduction of unique IDs for elements.
- A mechanism which are able to store status of elements such as initial, unchanged, modified, replaced, added and demolished entities. This could be done through a *IfcLifetime* entity type with attributes like *BirthDate* and *DeathDate*.
- Place holder for inspection and maintenance plans
- Maintenance and repair functionality including deterioration prediction, costing and optimization.
- Connection to structural assessment software.
- Definition of damage properties and damage information modelling.
- A system that handles visualisation of current status of the structure including accurate position of damage and vulnerable zones.

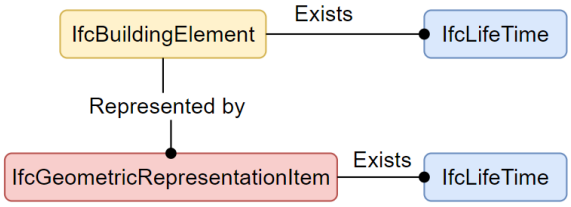


Figure 1-2 EXPRESS-G diagram Illustrating the use of the proposed IfcLifeTime entity type.

The proposed extension will work for both new structures with BrIM models and structures without BrIM models. For the latter, very simplified models can act as place holders for information and exchange with BMS, and then be expanded into more realistic models when needed.

ID-355

GABM - Empowering the Micro Bridge Inventory Owners

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Abstract

World over Bridge Management [BMS] implementation is tilted towards owners having large bridge inventories. Implementing BMS is difficult for owners with less than 100 bridges. The research resulted in evolution of a BMS called "Global Analytics for Bridge Management" [GABM] which is aimed at empowering micro bridge inventory owners fulfilling the key objectives of BMS. Sustained research to provide thousands of micro-owners in India was a herculean task. GABM allows partial integration of BMS with the Bridge Information Model [BrIM]. Integration with Short term Structural Health monitoring allows risk-free monitoring of bridges in need of rehabilitation. Freedom to choose from the various functionalities in the GABM software does not result in the user losing any technical advantages of BMS. Software development for GABM was challenging. GABM renders operational ease in all operating systems.

Keywords: Global Analytics for Bridge Management [GABM]; Bridge Information Model [BrIM]; 3D geometric model; photogrammetry model; Structural Health monitoring [SHM]; Sustainability.

Introduction

The role of Bridge Management System (BMS) is to manage and organize data related to all the bridges on the network. BMS ensure to collate data for inventory and inspections for a bridge. Bridges need continuous inspection and maintenance to ensure their structural integrity and user-safety. BMS have very efficient at data storage but are not as effective at providing analytical capabilities. Data and data analysis, are critical for BMS, for well-planned and proactive process. Global analytics for Bridge Management [GABM] is a data-driven approach that has been used to improve the safety and performance of bridges. Analysts help develop models to predict bridge failure and maintenance needs and analyse bridge performance to identify areas of improvement. GABM helps bridge owners make well-informed decisions about bridge maintenance and repair. By utilizing predictive analytics, bridge owners can identify and address potential risks. The research evolved a solution that can help to integrate innovative technologies with the focus on the key objectives of Bridge Management. GABM ensures empowering micro bridge inventory owners. GABM is internet free and has an efficient database structure, is easy to implement. GABM allows partial integration of BMS with the Bridge Information Model [BrIM] by enabling the use of a 3D geometric model and the creation of photogrammetry model for distressed elements to define the Geo-spatial location of distress. Integration with Short term Structural Health monitoring allows risk-free monitoring of bridges in need of rehabilitation. Some of the functionalities in GABM software are optional. Mandatory data collections ensure that BMS key objectives are met. Software development for GABM was challenging to ensure it is totally internet free. The innovative approach renders operational ease. The research was focused on Global reach to the analytics for bridge management, which helps bridge owners in all geographic locations understand their bridges' performance and set goals for future bridge maintenance and repair. The key improvements are:

a. Increase efficiency – Analytics helps identify potential weaknesses, and utilize

data to plan for maintenance and upgrades.

b. Improve safety – Analytics identifies potential risks and hazards.
c. Develop better bridge designs – Analytics helps bridge engineers develop more efficient and cost-effective bridge designs.
d. Monitor bridge performance – Analytics helps to monitor performance and detect changes indicating structural weakness.
e. Reduce maintenance costs – Analytics helps to understand and detect potential problems before their cost escalates.

Structural Health Monitoring (SHM) is a set of techniques used to detect and monitor the health of bridges. This allows for the rapid assessment of bridge conditions aimed for proactive management of bridge maintenance and repair. Within GABM the final and most crucial phase is ranking and prioritization. The user can select a high-risk bridge. The departmental budget and the estimated cost of repairs for the bridge are used to determine the rank of the bridge. The team determines the bridges for which remedial help is offered based on rating and priority procedure. Other bridges are added to a list of Bridges under Observation and Monitoring [BUOM] for which intervention is not offered. Short-term Structural Health Monitoring [STSHM] is used for collection of additional data for Bridges in BUOM for 3 to 4 monitoring periods, not to exceed 72 hours each, over the course of a full year. STSHM offers information regarding the performance decline seen in highly damaged bridge structure elements. In order to gauge how quickly the bridge is deteriorating, GABM records the degree of performance degradation. STSHM data is used to assess BSL and ABSL. GABM moves away from a decision-making process based solely on engineering judgement. By integrating the BMS and BrIM, the users can access comprehensive data about bridge structures, as well as up-to-date information about bridge deterioration and its geospatial location. This information can be used to plan and evaluate bridge maintenance, repairs, and upgrades. This helps proactively address any issues before they become major problems. GABM can produce one of two kinds of outcomes from digital imagery. Most of the barriers identified by various authorities as reasons why BMS should not be implemented have been removed by introduction of GABM. The global application of GABM includes all BMS, all nations, all regions, and all volumes of inventory [Micro to Macro].

GABM provides a comprehensive overview of bridge conditions and performance across multiple countries. The use of GABM has the potential to revolutionize bridge engineering and management. By leveraging data-driven analytics, bridge engineers and managers can gain insight into bridge performance, create more reliable bridge designs, and optimize bridge maintenance and repair. Additionally, analytics can help bridge managers identify safety issues, improve efficiency, and reduce costs associated with bridge maintenance and management. Ultimately, data-driven analytics can help bridge managers make informed decisions and ensure maximum safety and reliability. In conclusion, GABM offers a comprehensive and integrated approach to bridge management. It provides a comprehensive database structure and structural health monitoring system to enable bridge owners and operators to better manage the bridge assets. Additionally, the partial integration of BMS with the Bridge Information Model [BrIM] provides powerful tools to better understand and manage their bridges. GABM provides an effective and comprehensive approach to bridge management and can be used as a platform to improve bridge safety, reliability, and performance.

ID-514

An Overview of the BIM implementation on Chilean Bridges

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Abstract

In Chile the Building Information Modelling is developing since 2015. During that year, the president of Chile announced encourage of use BIM in public infrastructure with two main objectives:

1. Request of the implementation of BIM in Public contracts by term of reference, in order to standardize the request process from the Public Services.

2. The review of the project using IFC format in the municipalities for private buildings, in order to obtain the construction permission.

On that framework it was create the initiative Plan BIM, which integrate the collaboration of Academia, Public and Private Entities in order to improve the knowledge and use of BIM.

This paper provides a comprehensive overview of the developing of BIM apply on Chilean bridges, highlighting the contribution of several stakeholders. Cases of study of the implementation of BIM is presented.

The first projects linked to BIM in the area of bridges, under the supervision of the Roads Directorate, were carried out in 2018, considering a BIM implementation study in the Maipo Bridge - Route 5 South, in which the requirement for the use of BIM-compatible tools and programs arises from the construction company's own initiative to solve interferences detected during the execution of the work. The second corresponds to the implementation of BIM in the construction phase of the El Toro Bridge as an exploratory project by the Highway Administration. The main objective of carrying out observatory or exploratory projects was to visualize the benefits of this methodology in comparison to the traditional construction system through an analysis that considers ways of implementation, performance and lessons learned.

In relation to the results obtained from the pilot projects and first experiences led by the Roads Directorate, the following can be considered:

- Define beforehand a list of plans in a document to corroborate the totality of the required information.

- Define the specific objectives of the use of the BIM methodology in the project, both in its implementation stage and in the desired results.

- Respect the planning and execution phases of the project. Integration between design and construction engineers is achieved. In the same way, O&M professionals should be incorporated for project review.

- Consistent updating between the versions of the project plans and the construction and operation stages.

- Detect the critical points in the modeling of a bridge to better focus resources to solve the usual problems in this type of project. In the case of existing bridges, information on the difficulties and pathologies generated in the construction stage that can be reflected in performance indexes in the operation stage of the structure is of greater value.

From the previous point it is relevant to define the parameters or information that should be included in the model elements to be functional in the different stages. In the case of O&M, information such as repairs, inserts or project changes in construction should be considered. The implementation of BIM in advanced stages or existing works may imply the generation of incomplete models and information. BIM integration that takes place during an advanced stage of the project, the model that is developed may lack the entire structure. In the case of Maipo Bridge, this was evidenced with a model that only contemplates the deck, omitting details of the pier, piles or abutments. The above invites the generation of information gathering protocols, both at office and field level, including visual inspections, NDT and monitoring. These cases can be reviewed in the experience of the inspection of the Viña del Mar bridges, corresponding to 10 historical structures (built at the beginning of the 20th century), with limited information and deficient maintenance conditions.

Finally, to highlight the advances that AI has developed to date, in terms of the possibilities that this generates for a more robust development of the BIM methodology (automation processes) and the integration of this information in the BMS in the case of existing bridges.

Keywords: BIM; bridges; design; Public and Private Overview; Chile.

References

[1] MOP (Ministry of Public Work of Chile). “Resumen ejecutivo BIM estrategia pública 2020” (In Spanish), 2016. [Date: 4 Feb. 2018]. http://www.dgop.cl/areasdgop/semat/Documents/Resumen_Ejecutivo_Seminario_BIM.pdf

[2] MOP (Ministry of Public Work of Chile), Plan de puentes 2020-2030, ISBN 978-956-7970-59-9, Ed. Ministerio de Obras Públicas de Chile, 2022, Santiago, Chile.

[3] BIM Forum Chile. “Guía inicial para implementar BIM en las organizaciones”, (In Spanish), 2015 [on line], Santiago, Apr. 2017 [Date: 01 Jun. 2018]. Available on: http://www.bimforum.cl/descargas/

[4] Unanue, O. “Proyecto y obra, puente Maipo en Nos” (in Spanish) [Presentation slides]. 2016, Santiago, Chile.

[5] Conejeros, K., Márquez, M., Hernández, F., & Rojas, M. “Implementación de metodología BIM (Building Information Modeling) en infraestructura vial: Aplicación puente el Toro”, PROVIAL 2018, Arica, Chile.

[6] Seguel, J.L. & Seguel, C. USO BIM EN PUENTES CHILENOS Experiencia en la implementación en una oficina de puentes (in Spanish) Third International Brdige Congress Chile 2021, Valparaíso, Chile.

[7] Rojas, A., Valenzuela, M. & Peña-Fritz, A. Structural detailing of bridges, making use of the BrIM methodology (Bridge Information Modeling), through the creation of parametric models and as-build plans IABSE BIM, IABSE Congress Nanjing 2022 Bridges and Structures: Connection, Integration and Harmonisation 2022, China.

[8] Valenzuela, M., Peña-Fritz, A., Paz, A., Pinto, H, Jorquera, L. & Moraga, P. Implementation of GRDR methodology on the Quillota Bridge, Chile. A heritage review analysis. 1th IABMAS 2022, Barcelona, Spain.

ID-343

Extending the life of a historical Bridge through UHPFRC

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Abstract

Designed by Robert Maillart, the Aarebrücke Aarburg, stands as a landmark in townscape of Aarburg in Switzerland. The concrete arch bridge of 67.83 m span was built in 1912. In 1969, the original deck was replaced by a slender deck longitudinally and transversely prestressed. Chloride penetration from de-icing salt used since 1969 is endangering the prestressing of the bridge deck. Due to increased traffic loads the cantilever slabs have been protected from traffic by means of posts. Considering these conditions, a rehabilitation method is sought, capable of increasing the structural capacity of the bridge as well as providing waterproofing. A UHPFRC (Ultra High Performance Fibre Reinforced Concrete) layer is envisioned. The project has been executed as a BIM pilot for the bridge rehabilitations.

Keywords: UHPFRC, Rehabilitation, BIM, Robert Maillart.

1 Introduction

The initial design consisted of a slender concrete deck supported on a series of columns (Figure 1), a prototype of the stiffened arch bridge. Both the arch span length and the ratio span to rise (9.75) were a record for Maillart's firm at the time [1]. In 1969, the deck was replaced in favour of a wider prestressed solution and the columns were removed, whereas the original arch was preserved and strengthened by rips increasing its stiffness.

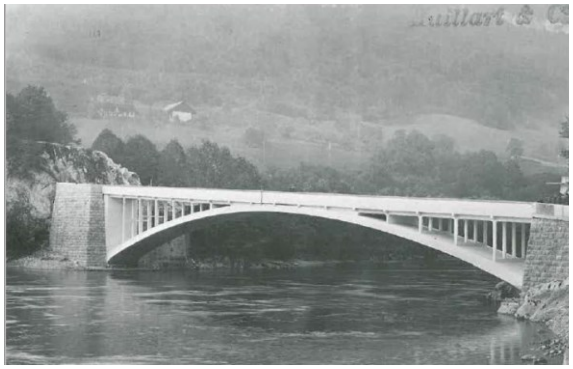


Figure 3. Original design from Robert Maillart

Being concerned of the durability of the prestressing cables, a new intervention was carried out 2022, extending the life of the historical bridge. The cantilevering sidewalks were strengthened by means of a UHPFRC layer, which also acts as a new waterproofing. Furthermore, the expansion joints and the abutment chambers were eliminated. Along with these interventions, an improvement of the bridge usage was envisioned, condensing the two lines of road traffic towards one side over the cantilever thus allowing more space for a combined sidewalk for cyclists and pedestrians on the other side. The UHPFRC layer is also used to adjust the transversal slope and simplify the drainage with a novel dewatering system on the bridge curb.

2 BIM model of existing structure

The project is the first bridge rehabilitation done in Switzerland with the support of the

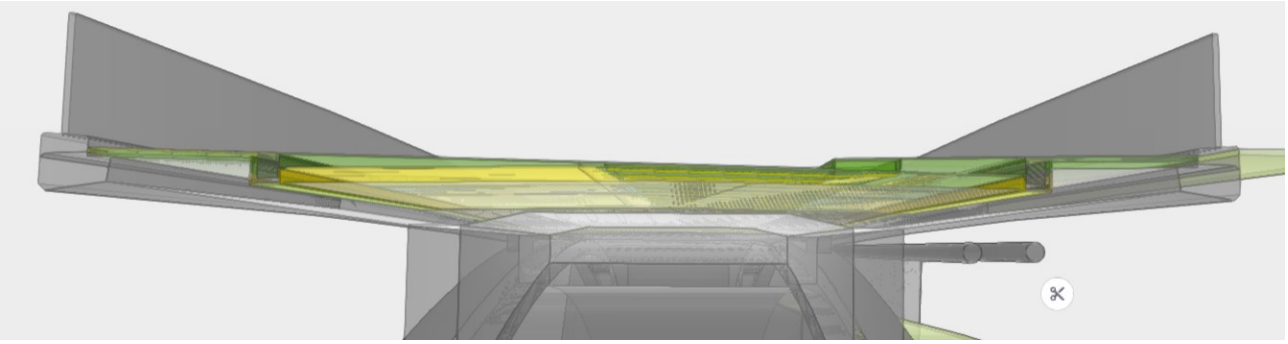


Figure 4. Cross section in geometry model, in green, new UHPFRC layer, in yellow, elements to be removed.

BIM-method. As part of the digitalisation strategy for asset management, a model is produced containing the relevant information concerning the bridge condition state and including data from the bridge management system (BMS) InfKUBA. This test project model allowed for improving the data transfer between the projects and the BMS.

The first step was to build up a reliable geometrical model of the bridge. Conversely to new structures, where all information is available from the beginning, existing structures entail a higher level of complexity and uncertainty.

The model consists of the elements, following the same logic as in the BMS. Each element includes the list of attributes, for material properties and construction year. The damages observed are included, giving an overview of the actual bridge condition in a separate damage model.

3 Structural analysis

Structural assessment is carried out for the slab on transverse direction and the longitudinal behaviour. Despite the strengthening in 1996, the cantilevers were not capable of carrying current traffic loads, determined locally by the slab thickness is only 154 mm. At the weakest section, the transverse prestress lies practically in the centre of the cross-section and contributes only 20% to the bending capacity. Since the condition of the prestressing can only be checked at great expense, the design is considering different scenarios regarding the actual contribution of the cables.

The reduced load model according to SIA 269 for existing bridges is used as a basis for decision on the necessity of strengthening measures. The target level of strengthening is recommended to be according to SIA 269 and assuming a loss of the prestress capacity if the measures are cost efficient compared with the benefits. With the strengthening considering the load models of SIA 261 for new bridges, the service life extension will not be limited from a structural aspect.

With a 40 mm layer of UHPFRC the bending capacity of the section is exceeded by 20% disregarding the existing prestressing. UHPFRC offers compressive strength up to 150 MPa, and tensile strength ranging from 8 to 15 MPa. The use of UHPFRC for bridge rehabilitation has been increasingly expanding in the past years [2], specially in Switzerland.

4 Conclusions

The existing technologies provide vital information about dimensions and condition of bridges.

With 40 mm, the UHPFRC layer provides waterproofing and sufficient strengthening for achieving the aims of the rehabilitation.

A fix deck-abutment-connection resulted in a durable bridge end.

5 References

[1] Billington DP. *Robert Maillart's bridges: the art of engineering*. Princeton University Press, 1989.

[2] Martín-Sanz H, Chatzi E, Brühwiler E. The use of Ultra High Performance Fibre Reinforced Cement-based Composites in rehabilitation projects: A review. In: *Proceedings of the 9th International Conference on Fracture Mechanics of Concrete and Concrete Structures FraMCoS-9, Berkeley, CA, USA*. 2016.

Session 17

Sustainability in Built Environment

ID-163

CROSFALL – A Knowledge Sharing Newsletter to Create a Safer Built Environment

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Abstract

Confidential Reporting on Structural Failures and Lessons Learnt (CROSFALL) is a quarterly newsletter publication. This confidential reporting system is established in India recently by the Indian Association of Structural Engineers (IAStructE) with the objective to capture and share lessons learned from various structural failures which do not otherwise get reported and do not get the attention of the public as well as structural engineers. The intent to bring out this newsletter is to have a freely available database to be used by the construction industry to improve the safety of bridges, buildings, industrial structures, and other infrastructures of national importance. The paper will highlight the salient features of this newsletter and focus on the need for the structural engineering fraternity to contribute actively to this newsletter so that structural engineers learn important lessons from others' mistakes and do not repeat them in their own design.

Keywords: CROSFALL, structural failure, confidential reporting, lessons learned, public safety

1 Introduction

The structural engineering profession has not proven itself good at learning from mistakes, which is a matter of general concern. There have unfortunately been many buildings and other infrastructure failures in India in the recent past. Some of the most notable and high profiled failures amongst them are The Lalita Park building collapse, in Delhi, 2010, Mumbai CST footbridge tragedy 2019, Ultadanga flyover collapse, in Kolkata 2013, Morbi pedestrian suspension bridge collapse, in Gujarat 2022 and under-construction Vivekananda road flyover collapse at Kolkata, 2016. While major collapses draw attention of the media and reported in electronic and print media, there are several failures and near misses, which are not reported at all. Failures may occur at any stage during the life of the structure.

One of the impediments to learning lessons from structural failure is that the full details of many failures and the outcome of forensic investigations are not made public by the authorities. Fear of blame, lawsuits, damaged business opportunities, and ruined reputations are all often cited as reasons for keeping failure cases and actual examples under the wraps, under legal non-disclosure agreements, and in insurance company files. This is a global problem and not just an India-centric issue, but some countries have found ways and means to at least generically share the lessons through more comprehensive failure dissemination methods and educational repositories. As an example, in the United Kingdom, "Structural-Safety" is an independent umbrella organisation established by The Institution of Structural Engineers (IStructE), The Institution of Civil Engineers (ICE), and the Health & Safety Executive (HSE), the UK Government body responsible for workplace health & safety. "Structural Safety" works with industry on safety matters concerned with the design, construction, and use of structures and consists of two entities: namely The Standing Committee on Structural Safety (SCOSS) & Confidential Reporting on

Structural Safety (CROSS). SCOSS was established in 1976. CROSS was established by SCOSS in 2005 to capture and share lessons learned which might not otherwise have had formal recognition.

2 Introducing CROSFALL by IAStructE

Encouraged by the success of SCOSS (Standing Committee on Structural Safety) and CROSS (Confidential Reporting on Structural Safety) in the UK and confronted with series of failures in India, which was eroding the public trust and denting the image of Structural Engineers in the society, the author was asked to set up a newsletter for confidential reporting on behalf of the Indian Association of Structural Engineers (IAStructE) in the year 2021. That was the beginning of newsletter CROSFALL, which stands for **C**onfidential **R**eporting **O**f **S**tructural **F**ailures & **L**essons **L**earnt.

The newsletter is available in public domain in IAStructE website. One can go to the link https://www.iastructe.co.in and access them. Guideline is available in the website for submission of such failure reports. How to submit a report? What type of safety issues one may report? how reports will be handled by the association? …etc. are all well explained in this website. The operating procedure adopted for CROSFALL publication, starting from receiving a report to printing and circulation, is as follows:

a) The association collects reports from firms, professional civil and structural engineers.
b) The report after deidentification is then circulated to the editorial board for review.
c) Once approved by the editorial board, the de-identified report is then sent to expert panel who reviews the report and give their views as to how others can learn from and benefit from the reported concern or occurrence.
d) These reports are then circulated widely.

3 Conclusions

At a time when the construction industry in India is growing rapidly and is under intense public scrutiny, it is more important than ever that we learn from each other's experiences and CROSFALL provides a means whereby we can all contribute towards improving quality and safety in our industry; and we can do this in a confidential, no-blame environment.

Many lessons can be learnt from Confidential Reporting on Structural Safety. The establishment of CROSFALL provides a channel for structural engineering fraternity in India to reflect on near misses, failure and even collapses. And by sharing experience we can minimise the repetition of similar situations which can no doubt improve safety in our industry and improve safety for the public.

No concern is too small to be reported and conversely nothing is too large. Small scale events are important - they can be the precursors to more major failures - and the more reports we gather the better we can understand the extent and occurrence of safety issues. Thus, everyone involved in the construction industry in India is encouraged to submit reports to CROSFALL.

However, this is but the first baby step in the development of CROSFALL newsletter in India. In the longer term, IAStructE, as the primary sponsor of CROSFALL would like to see greater involvement and support of the Clients in promoting the culture of safety in the industry.

4 References

[1] Soane A., Lessons from Confidential Reporting on Structural Safety. IABSE Conference, Geneva, Switzerland; September 2015
[2] Mike Fordyce, Colin Caprani, Development of Confidential Reporting on Structural Safety in Australasia. IABSE Conference, Christchurch; September 2020
[3] CROSFALL Newsletters – Issue No. 1, July-September 2022 published by IAStructE
[4] CROSFALL Newsletters – Issue No. 2, October-December 2022 published by IAStructE

ID-184

A Machine Learning-Based Methodology of Integrating Loading Data and Load Effect Data for Long Span Bridge Assessment

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Abstract

A number of long span bridges around the world have extensive structural health monitoring (SHM) systems installed. These bridges are complex structures under complex operational and environmental conditions, making it challenging to process and interpret the monitoring data obtained. This paper presents a machine learning (ML)-based methodology of linking bridge loading data with measured load effect data for long span bridge assessment, developed using the monitoring data obtained from the 1377 m main span Tsing Ma Bridge in Hong Kong. The proposed methodology includes supervised, unsupervised and semi-supervised learning techniques to enable and automate the identification, classification and segmentation of different live load effects. The developed methodology can assist with more realistic load rating and fatigue assessment and facilitate the operation and maintenance (O&M) of long span bridges.

Keywords: long span bridge; structural health monitoring; machine learning; traffic loading; load effect; load rating; fatigue assessment.

1 Introduction

This paper presents a machine learning-based methodology of integrating measured load effect data with bridge loading data for long span bridge assessment, developed using the monitoring data obtained from Tsing Ma Bridge. The proposed methodology includes supervised, unsupervised and semi-supervised learning techniques to enable the identification, classification and segmentation of different live load effects.

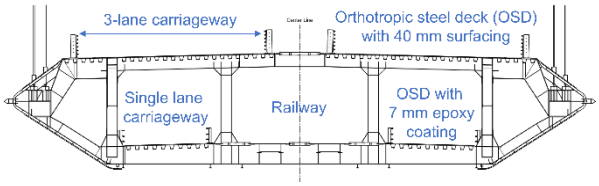


Figure 5. Tsing Ma Bridge deck section

2 Methodology and Results

The top of **Error! Reference source not found.** s hows the time history stress response data measured by sensor SS-TLS-19 (which measures longitudinal strain at orthotropic steel deck plate) throughout the whole day of 20 October 2013. The data frequency is 51.2 Hz.

The methodology involves three parts:

1. **Separation of different live load effects**: This was by using *moving average* (MA) filters with different windows (i.e., different N values in MA) and coupling with a peak removal algorithm where it is needed. In this study, N_1 *= 1 hour × 51.2 Hz = 184320* and N_2 *= 1 second × 51.2 Hz ≈ 51* were used. The stress data was separated into three load effect components, as shown in **Error! Reference source not f ound.**.

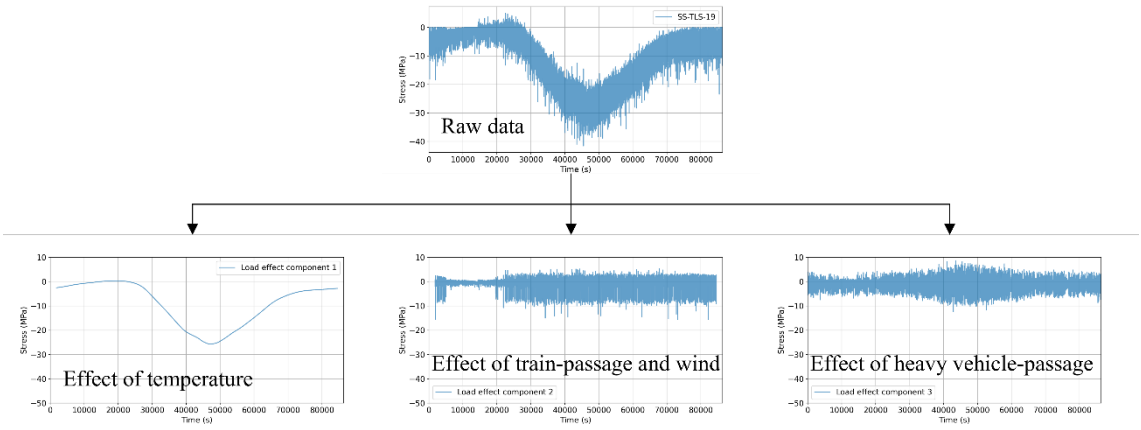


Figure 6. Separation of different live load effects

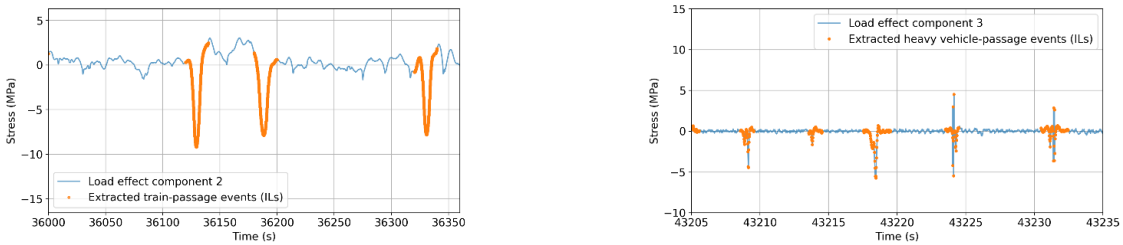


Figure 7. Extracted batches containing traffic load responses using the trained linear SVM models: (a) train-passage events; and (b) heavy vehicle-passage events

2. **Extraction of influence lines (ILs) under individual train-passage events and heavy vehicle-passage events**: This was by first dividing the stress data into non-overlapping batches and then solving a binary classification problem (with or without train / heavy vehicle) for each batch, using *Support Vector Machine (SVM)*, a supervised learning technique. See **Error! Reference source not found.** for e xample results.
3. **Clustering/classification of ILs under different types of heavy vehicles (buses and trucks)**: This was by using *Gaussian Mixture Model (GMM)*, an unsupervised learning technique, and later *Self-Training (ST)*, a semi-supervised learning technique. Domain knowledge of the configuration and loading of buses/trucks was also used. See **Error! Reference source not f ound.** for example results.

Coupled with domain knowledge and measured bridge loading data, the developed methodology can facilitate more realistic fatigue assessment and load rating, and thus provide more confident analysis results and engineering conclusions in future structural assessment of long span bridges.

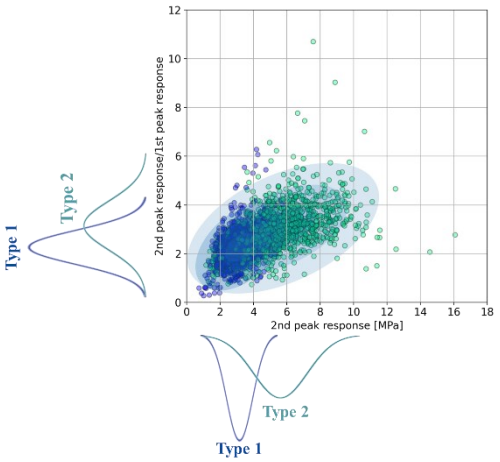


Figure 8. GMM for clustering of ILs under heavy vehicle-passage events: Type 1 is bus-like vehicle and Type 2 is truck-like vehicle

ID-253

The Second Generation of Eurocode 4

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Abstract

Work on the second generation of Eurocode 4 is nearing completion. Following the systematic review in 2014, the development of this standard has been undertaken by several project teams under the direction of the European Committee for Standardization subcommittee CEN/TC 250/SC 4, which is currently chaired by the present author. After a brief overview of the work programme that led to the second generation of Eurocode 4, this paper presents a selection of the changes that will be included.

Keywords: Include a list of not more than 10 keywords, for example: post-tensioning; anchors; slabs; walls; high-rise buildings.

1 Introduction

Eurocode 4 (EN 1994) is the European design standard for composite steel and concrete structures. The first version of Eurocode 4 was published by the Commission of European Communities (CEC) in 1985 before the European Committee for Standardization (CEN) was given the responsibility to prepare and publish the Eurocodes 4-years later. Under the direction of Technical Committee CEN/TC 250, the Eurocodes were initially published by CEN in 1992 as European pre-standards (ENV), before they were converted and published as European Standards (ENs) in 2007. Subcommittee 4 (CEN/TC 250/SC 4) was responsible for preparing the ENV and EN versions of Eurocode 4, which was published in three parts, as follows:

(i) EN 1994-1-1, Part 1-1: General rules and rules for buildings.
(ii) EN 1994-1-2, Part 1-2: General rules – Structural fire design.
(iii) EN 1994-2, Part 2: General rules and rules for bridges.

A more comprehensive review of the development of Eurocode 4 from 1970 to 2010 is presented by Johnson. In 2010 the Eurocodes replaced the former national standards within the 34 countries that are members of CEN. More recently, they have been adopted by Singapore, and it is anticipated that other countries may soon be implementing them, including Hong Kong, Macau, and Malaysia.

In response to the publication of Mandate M/515 by the European Commission in 2012, an ambitious and detailed work programme was prepared by CEN/TC 250, where specific tasks were undertaken by existing subcommittees, working groups or horizontal groups. The current structure of CEN/TC 250 is presented in **Error! Reference source not found.**.

The revision can be broadly divided into two activities:

- General revisions and maintenance of the Eurocodes following the receipt of comments from the industry through a “systematic review” undertaken by national standards bodies (NSBs).
- Technical enhancements of the Eurocodes within the scope of Mandate M/515

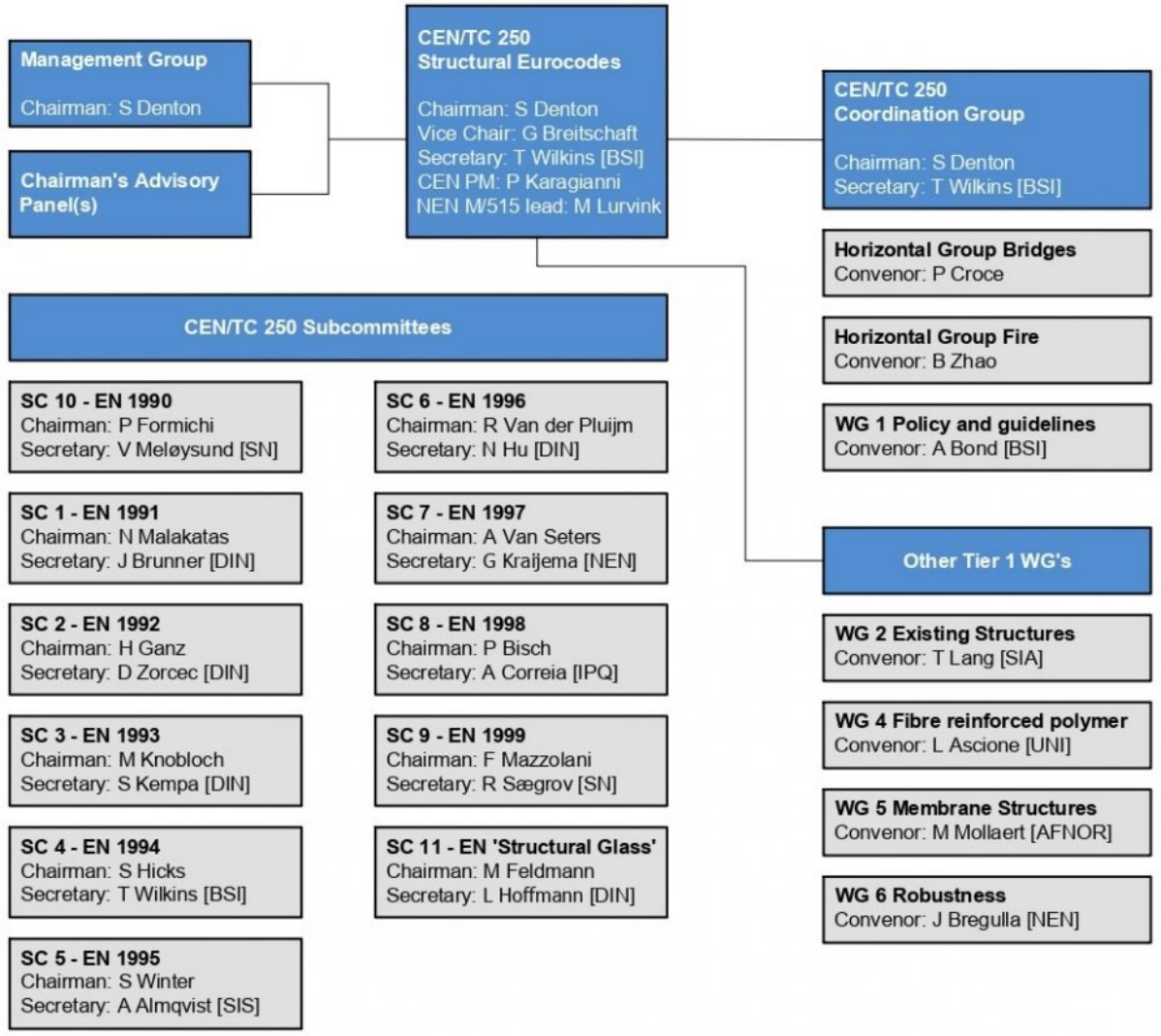


Figure 9. Structure of second-generation Eurocodes **Error! Reference source not found.**

It is anticipated that the second generation of Eurocode 4 will result in the following documents (N.B. the prefix 'prEN' is used throughout the remainder of this paper to differentiate the second-generation Eurocodes from the current published versions):

1. prEN 1994-1-1, Part 1-1: General rules and rules for buildings.
2. prEN 1994-1-2, Part 1-2: General – Structural fire design.
3. prEN 1994-2, Part 2: Bridges.
4. prCEN/TS 1994-1-101 Design of double and single skin steel concrete composite (SC) structures.
5. prCEN/TS 1994-1-102 Design rules for the use of Composite Dowels.
6. prCEN/TS 1994-1-103 Design rules for composite columns comprising high performance columns.

2 References

Eurocodes: Building the Future, Joint Research Centre, European Commission, https://eurocodes.jrc.ec.europa.eu/ (accessed 26 March 2023)

ID-273

Efficiency and Cost Effectiveness of Ground Source Heat Pump for Five Storied Office Building

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ABSTRACT

Non-clean energy resources cause pollution, climate change, greenhouse gas emission. Therefore, in present scenario it is very much required to use renewable energy resource as sustainable solution. Geothermal heat energy stored within the earth is one of the biggest source of renewable energy. Shallow geothermal energy can easily be extracted using the close or open looped geothermal system and it is very effective for building heating or cooling purpose. Ground source heat pump (GSHP) is a closed loop system where vertical boreholes are equipped with HDPE/PVC pipes (primary circuit) through which heat exchanger fluid are circulated and when passing through boreholes it exchanges heat with the surrounding ground (Fig. 1). Heat pump is used to take out the fluid and circulate inside the building through pipes (secondary circuit) embedded in concrete floor to exchange heat with surrounding air.

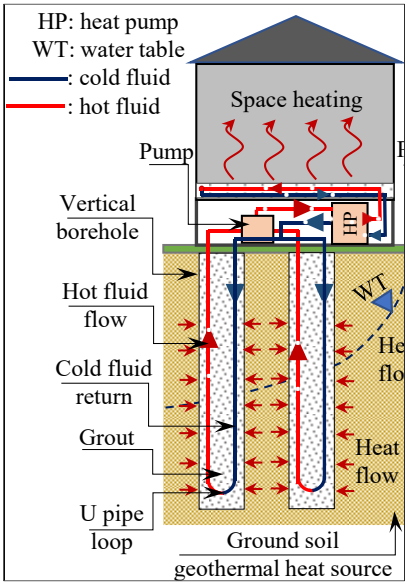


Fig. 1 A schematic diagram of GSHP

A five storied office building (Fig. 2) is studied to estimate energy requirement for heating and cooling demand in summer and winter for sizing GSHP using Energy-Plus software. Climatic and soil conditions for ten different metropolitan cities located mostly in tropical regions are considered. Ground loop design (GLD) software was used to design vertical GSHP system for heating and cooling of office

building considering different ground conditions in different cities. Coefficient of performance (*COP*) (Fig. 3) and installation as well as operational costs (Fig. 4) were used to compare efficiency and cost-effectiveness of GSHP system in various cities. It is observed that several influencing factors which control performance of GSHP system are local climate, ratio of heating and cooling loads and underground soil.

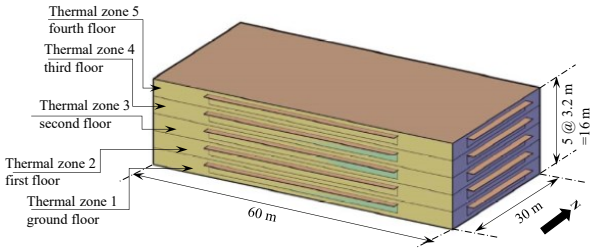


Fig. 2 Typical details of five-storied office building modelled in EnergyPlus software.

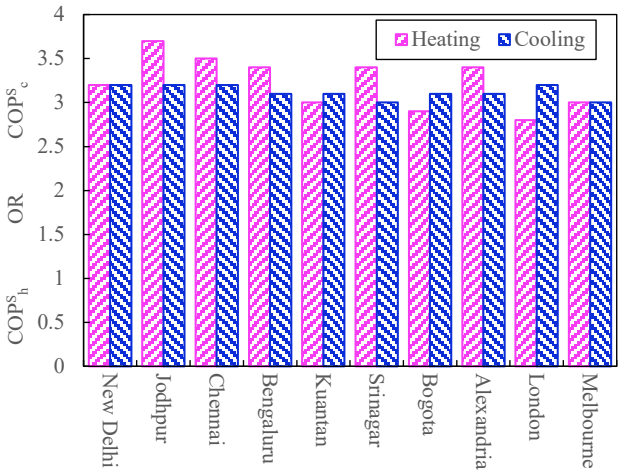


Fig. 3 COPs of GSHP system in different cities during peak load of typical office building

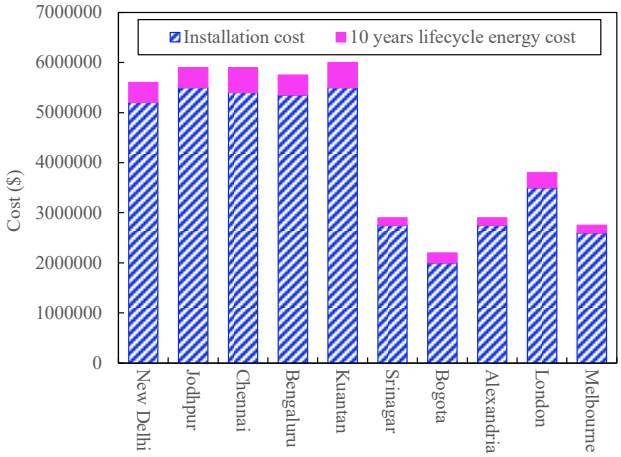


Fig. 4 Cost analysis of GSHP for different cities

ID-293

Restructuring Construction Thinking for Urban Material Reuse

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Abstract

Construction and demolition waste (CDW) is a significant contributor to global waste. CDW accounts for nearly 1/3 of the total waste worldwide. Much of this is concrete, brick, and wood and is disposed in landfills or incinerated, resulting in environmental pollution and greenhouse gas emissions. Upcycling CDW is increasingly important for a sustainable waste management approach. Digitalization can play a significant role in promoting reuse of construction waste by enabling effective and efficient tracking, sorting, and processing of materials, through Building Information Modeling (BIM). BIM can help identify reusable components and provide real-time data on the quantity and quality of materials available for reuse. This paper proposes the architecture of a digital platform to facilitate the CDW upcycling by connecting construction companies, material suppliers, and waste management firms.

Keywords: Construction; Demolition; Waste; Upcycling; Reuse; Repurpose.

1 Introduction

The construction industry is the largest global consumer of raw materials and accounts for more than half of the planet's raw material extraction. This high demand for natural resources creates pressure on the environment and contributes to deforestation, soil erosion, and other forms of environmental degradation. Additionally, the construction and demolition of buildings generate a significant amount of waste, which accounts for about one-third of global waste. Unfortunately, only a small fraction of this waste is recycled or reused, with the majority ending up in landfills or incinerators, causing environmental pollution and health risks.

Construction Debris and Waste (CDW) presents the third largest waste flow after mining and farming industries [6]. The substantial volume of CDW presents significant pressure to landfill capacities and have led to considerable environmental concerns [7]

There is, therefore, a need for more responsible ways of producing and using building materials as Development Goals. Circular construction, aims to close building material loops by reusing, sharing, leasing, repairing, refurbishing, upcycling, or recycling rather than continuing the traditional take-make-dispose process. well as managing our infrastructure and buildings more sustainably.

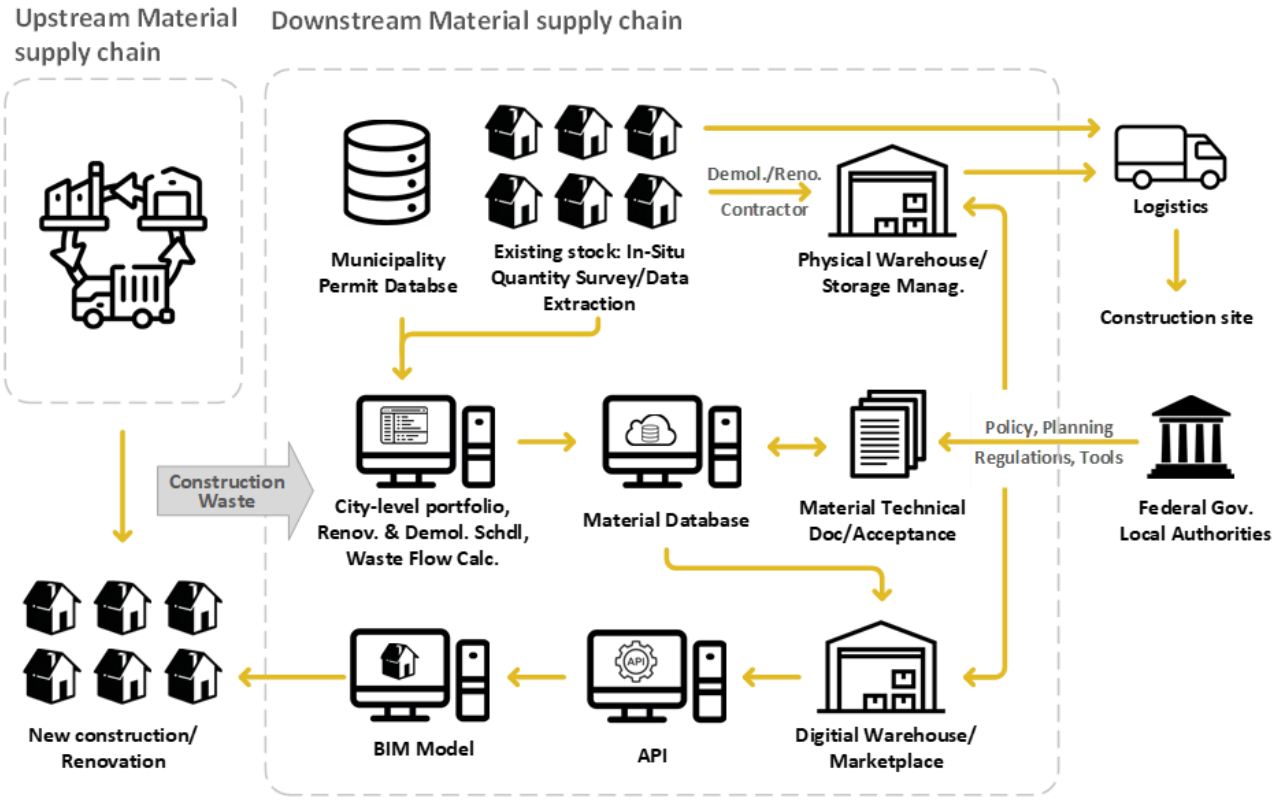


Figure 10. Proposed digital platform

Upcycling reclaimed building materials is not without challenges. While the problem is an intertwined one of education, standards, and enterprise, none of this can happen at any scale without an integrated and accessible framework in which the element-by-element composition of a city's building stock can be known, as well as anticipated construction and demolition projects and the actual waste flows. Designing a framework for reusing and repurposing construction and demolition waste involves several important components, including waste assessment, transportation and logistics, sustainable upcycling solutions, and design. Such a framework would need to couple municipal permitting processes with digital design aided by building information modeling (BIM). As permitting is now a digital process in most communities and BIM is already used on more than 70% of all new construction projects, their intersection to build the intended framework can be realized on a digital platform. Additionally, digital platforms can connect waste generators with potential reuse partners.

2 Digital platform for CDW upcycling

Logically marrying these processes to the larger eco-system of material production, fabrication, recycling, and disposal is needed (Figure 1). Yet, this only makes sense if emissions and costs related to reuse (e.g. transportation, potential temporary storage, and any cleaning or refinishing) are less than all costs and emissions from disposal of the previously used materials and those affiliated with the manufacturing and delivery of new materials. What needs to be minimized is the extensive hauling, reprocessing, and redelivery.

[1] Dorsthorst B., Kowalczyk T. Design for recycling. Design for deconstruction and materials reuse. In: Proceedings of the International Council for Research and Innovation in Building Construction (CIB) Task Group 39 – Deconstruction Meeting, Karlsruhe; 2002: 70–80.

[2] Esin T., Cosgun N. A study conducted to reduce construction waste generation in Turkey. Build. Environ. 2007; 42 (4): 1667–1674.

ID-378

Sustainable Facade Constructions

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Abstract

The building envelope has a significant contribution to the CO2 footprint of a building. This applies to both new buildings and existing buildings. The life cycle of a building can be extended through intelligent façade renovation or renewal, which of course has a positive effect on the overall balance. The decisive factor is a holistic approach from planning, construction, operation and maintenance including refurbishment and deconstruction. Current developments in facade construction will be shown. It is not just a matter of finding the best heat transfer coefficient for a window, for example, but of finding intelligent, object-related solutions.

Keywords: facade; glass; sustainability; cradle to cradle.

1 Introduction

The climate change and rising energy costs have increased society's awareness of energy-saving measures. To reduce CO2 emissions, many buildings from the 1960s and 1970s are now being refurbished. New buildings also have to be planned and built in a way that conserves resources, are as climate-neutral as possible, and have a long service life.

2 Types of facade

The construction of facades is very diverse. There are different types of facades, e.g. transom and mullion facades, element facades, double facades or simple perforated facades. All facades have transparent areas and opaque areas in common. Transparent areas are usually made of glass, opaque areas of thermally separated aluminium profiles and filling elements or "only" masonry with ETICS. Adaptive facades follow the position of the sun, building technology is already integrated in element facades and the facade can generate energy with photovoltaics. Plastics, membranes, composites and additively manufactured materials are also increasingly used in facades.

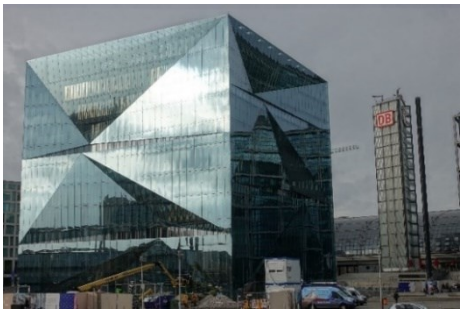


Figure 11. CUBE in Berlin with Double-skin façade

3 Approaches and solutions

There are various approaches and solutions for making facades more durable, more energy-efficient during use, and at the same time less energy-intensive during production.

3.1 Building Material Glass

In order to improve the sustainability of glass, which is usually the most important component of a façade, various approaches are currently being pursued:

- Saving energy in glass production, which is currently still operated with natural gas.
- Basic extension of the service life of multi-pane insulating glazing.
- Re-introduction of LG and LSG panes into the manufacturing process.
- New developments such as vacuum insulating glass (VIG).
- Reuse of old glass panes with appropriate post-processing of surfaces. This raises further questions, e.g. about the load-bearing capacity and long-term serviceability of the waste glass panes.
- the production process including the PVB film including the PVB interlayer.
- Use of new interlayer Materials like stiff PVB or multi-Layers to reduce the thickness of the glass.

3.2 Façade Maintenance and Façade Monitoring

Maintenance is an important aspect to ensure the safety of buildings and also to prolong their life.

The guideline VDI 6200 contains assessment and evaluation criteria and practical instructions for the regular inspection of the structural safety as well as recommendations for the maintenance of buildings. Building constructions are classified according to the possible consequences in the event of global or partial failure and their structural design. However, only few know, that the guideline VDI 6200 must be applied also for facades. Currently, an adaptation to facades with corresponding explanations is being developed within the framework of the UBF (ubfassade.de). Monitoring of facades is important to detect changes during the lifetime. In the full paper a research project is presented.

3.3 Importance of planning and design

Unfortunately, the targeted service life of a facade is often not achieved because there are deficiencies already in the planning phase. Facades are underestimated in the planning phase, planning steps are omitted or the facade is not planned at all in advance, and there is often a lack of expertise on the part of the engineers involved. This is valid for facade planning and facade statics. Thus, even with facades that are only a few years old, the experts have to deal with leaks and structural problems, up to and including falling facade elements and thus "danger to life and limb". These facades then have to be refurbished at great expense, which is definitely not sustainable. So, with good planning, the lifespan of a façade can be improved, and with it its sustainability.

3.4 Photovoltaics in the façade

The building envelope provides plenty of space to generate energy with photovoltaics. While in the past often only optimal orientations to the sun were used, the application of modern high performance modules is useful and effective in many facade and roof areas. Here, too, there are many things to consider. In addition to issues of efficiency and also electrical current (inverters,...), the integration of photovoltaics (e.g. as BIPV, Building integrated Photovoltaics) can also be demanding in terms of building law and statics.

3.5 Rehabilitation

Refurbishment of facades is often caused by energetic aspects or architectural aspects. For reasons of sustainability, it is of course better to gut a building down to the supporting structure and provide it with a new façade than to demolish it. To safeguard the well-being of the user by providing any cooling or air conditioning systems, nowadays double skin facades are often a main point of refurbishment, especially for high rise buildings.

4 Conclusions

Sustainable facades can make a major contribution to overcoming the climate and energy crisis. This applies not only to thermal insulation, but also to aspects of sustainability, resource conservation and the principle of conservation. New, intelligent facade solutions can be an important aspect here.

5 References see full pape

Session 18

Heritage Structures, Poverty Alleviation and Social Sustainability

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Engineering for Sustainable Development

ID-387

Bridge Construction Using Decommissioned Wind Turbine Blades as A Poverty Alleviation Centric Technology: Possibilities and Implementation Example

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Abstract

Wind energy is the second most popular renewable energy source (RES) in the world after solar energy. The most important problem of using wind energy is the recycling of turbine rotor blades, which are made of FRP composites. Thanks to their shape and mechanical parameters wind turbine blades can be used in construction industry i.e. as bridge girders. Reused in this way, as a component of cheap house or bridge wind turbine blades can contribute in poverty alleviation. The paper presents the example of reusing wind turbine blade as a footbridge main girder. The design, numerical simulations as well as static and fatigue tests with the use of a distributed fibre optic sensors to assess the behaviour of the structure under load are described. Successful examination in the laboratory led to the first Polish implementation of a footbridge made of reused wind turbine blades. The main conclusions from this project and plans of the research team for future development of hybrid wind turbine blade - concrete bridge girder are also presented in the paper.

Keywords: decommissioned wind turbine blade, recycling, FRP, footbridge, structural and material testing.

1 Introduction

Structural recycling is a promising alternative end-of-life (EoL) solution for composite wind turbine blades. The process reuses the blades as large parts or construction elements. Several repurpose methods are under development in many ongoing research projects to involve decommissioned blades for civil engineering applications that benefit from the structural properties of the blades, such as: urban furniture, affordable housing and bridges. Repurposed in this way, as a component of cheap house or bridge wind turbine blades can contribute in poverty alleviation. The last field of wind turbine blades repurposing is the main subject of the current R&D project carried out by the authors The main goal of the project was to develop and demonstrate a footbridge made of decommissioned wind turbine blades, suited for pedestrian and bicycle traffic. This paper describes the concept of the new footbridge system and presents the initial research results on its structural behaviour. Based on the output of this research the first Polish footbridge made of decommissioned wind turbine blades was built in 2021 (Fig. 1).



Figure 12. The concept of a footbridge

2 Experimental investigation

In order to check the mechanical parameters of the wind turbine blades before footbridge designing, two full-scale blade sections with a total

length of 11.6 m were prepared for structural testing. The both sections were cut out of the two entire actual blades of LM 13.4 type. Static test of the girder was carried out in a four-point bending scheme using two hydraulic actuators with a maximum force of 625 kN each (Fig. 2).



Figure 13. The full-scale model under testing load

Under maximum load of 1260 kN, the girder exhibited no global destruction. However, the girder suffered the severe local damage at the final load stage. The analysis of the plots from the DFOS sensors (Fig. 3) showed that the crack occurred at a load of 1050 kN, which could be considered as a ultimate capacity of the girder. However, during the full loading range the girder behaved linearly until the maximum load of 1260 kN was applied and no residual displacements were observed after unloading. It revealed that the detected local failure of FRP shell had no influence on the global structural behaviour of the girder.

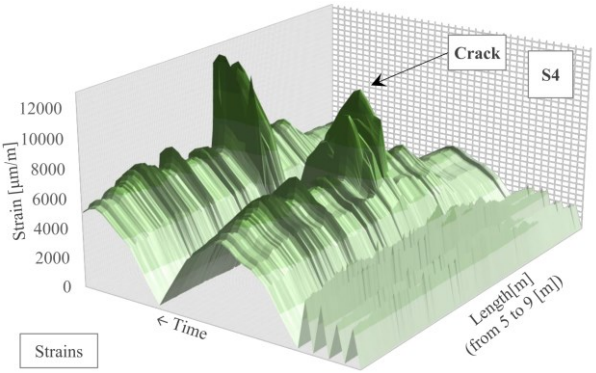


Figure 14. Strain distribution from DFOS

3 Site implementation

The results of the experimental investigation were used to design and analyse the superstructure, as well as, to develop the details, specifications, and construction methods needed for the footbridge constructed in Szprotawa, Poland in 2021. The main load-bearing element of the footbridge is a girder made of two sections of composite wind turbine blades, connected in the middle of the span by means of a bolted flange connection. Both girder elements were cut from two typical composite blades with a length of about 25 m and variable height in the range from 1.685 m (blade hub) to 2.365 m. The girder elements were created after cutting off the nose (end) of the blade, and their total length is 10.65 m. Steel flanges were used to connect both parts of the girder, in which the hubs of typical composite wind turbine blades are equipped. After connecting both elements, the girder has a total length of approx. 21.3 m. Prior to transportation to the site and installation in the field, the superstructure was constructed in full-size in the Anmet's factory in order fine tune the assembly process. After the composite blades were properly cut to the designed size, a steel structure of the platform (crossbars, stringers, grate) was attached to each element with bolts, which had previously been manufactured and protected against corrosion in the factory. After connecting both parts of the span on the assembly site, it was moved in its entirety by means of a light crane over the supports and supported on bearings (Fig. 4).



Figure 15. Installation of the footbridge span

4 Conclusions

The results of the research proved the possibility of repurposing wind turbine blade as a main bridge girder and were used to design of the world's first footbridge made of decommissioned wind turbine blades built in Szprotawa, Poland.

D-397

Mobility Architecture as a Driver of Social Sustainability Outcomes

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Abstract

From small footpaths to large ocean spans, bridges connect people, reduce travel time, and generate economic opportunity. Successful mobility solutions strengthen social cohesion and provide a strong sense of place to local communities. Today's infrastructure must deliver an ever-increasing list of ESG outcomes. Within complex infrastructure value chains, architects can collaborate with engineering partners to prioritize social sustainability and centre the human user within the design process.

Dissing+Weitling presents three bridges across a spectrum of functions to demonstrate how design can be a key driver of social impact and sustainability outcomes. Together, the Great Belt Bridge, Køge Nord Station, and Copenhagen Bicycle Snake present a case for bridge design as social value drivers through landmark placemaking, improvement of urban life, and universal design.

Keywords: social cohesion; social impact; suspension; bicycle bridge; placemaking; user centred mobility; universal design; cultural heritage; sustainable transportation

1 Mobility Architecture as Social Sustainability Driver

A bridge is an opportunity: a functional solution to a mobility problem, a safe crossing for human users. This holds true regardless of scale or geography – the smallest pedestrian bridges can fundamentally transform both individual and communal rituals of movement just as meaningfully as a large ocean crossing.

Mobility architecture drives social impact by centring the human user. In striving for long-lasting infrastructure that provides focal points for good experiences, bridges hold the potential to be socially sustainable across scales and geographies.

The nature of a bridge's potential for social value creation is embedded within the mobility problem it seeks to solve. Therefore, architects facilitate a collaborative discovery process with the entire project development value chain. A comparison of three Danish bridges – Great Belt Fixed Link, Køge Nord Station, and the Copenhagen Bicycle Snake – provides insight into how centring social sustainability within the design process can lead to better social sustainability outcomes. Each case serves as an example of how mobility architecture can result in social value creation across project scales, user groups, and social sustainability themes.

2 The Great Belt Fixed Link

The Great Belt Fixed Link changed the social fabric of Denmark forever. In replacing the ferry service from Zealand to Funen and providing efficient crossing over Sprogø Island via a combined suspension bridge and railway tunnel, Danes gained both literal and symbolic connection. Today a symbol of Danish engineering, design, and craftsmanship excellence, the Great Belt Fixed Link is an example of how large-scale contemporary mobility solutions can be embraced as symbols of national identity.

Practically, the bridge enhances the connection of trains and motorists between Zealand and Funen – and eases travel throughout Denmark. Reduced transit time between islands from one hour to

twelve minutes increases for individuals and businesses to move between population centres. Becoming a part of Danish cultural heritage – how citizens embrace, celebrate, and live alongside the bridge is a testament to the infrastructure's ability to both impact quality of life and serve as a visual landmark.

The grand scale of the Great Belt Fixed Link allows the bridge system to transcend from transit solution to national cultural heritage. In the elegance and simplicity of the rising pylons and receding suspension, The Great Belt Fixed Link has been embraced as a symbol of Danish design excellence – creating both tangible and intangible social value.

3 Køge Nord Station

Køge Nord Station is more than a commuter railway station – it is a transit pathway allowing users to move seamlessly from car to foot to high-speed rail. Connecting Greater Copenhagen's S-Train system to a new high-speed rail line between Copenhagen and Ringsted, Køge Nord Station is simultaneously a transit hub, a train station, and a safe crossing across the busy Køge Bay Motorway.

With a distinctive architectural expression that is both a point of entry and departure from Køge – the station bridge represents the connectivity and dynamism of public transit – incentivizing green mobility.

Køge Nord Station is a social sustainability driver: as a transit hub, the station provides access to sustainable urban mobility for a wide spectrum of users – and ensures easy access to economic and educational opportunity, as well as health services. By promoting alternatives to car commuting, the station also inspires greater wellbeing by reducing sedentary behavior.

From a building regulations perspective, the station performs well with regard to accessibility performance – however the nature of the architecture goes further. Embracing Universal Design principles – Køge Nord Station is a designed environment ensuring as many users as possible can access the site.

4 The Copenhagen Bicycle Snake

The Copenhagen Bicycle Snake reflects how the local municipality intentionally prioritized sustainable urban mobility – and how the user experience of a bicycle bridge can unlock urban space and increase commuter wellbeing. The Copenhagen Bicycle Snake creates social value across two dimensions: the direct impact on the quality of life of cyclists and the indirect impact of uplifting urban space.

The Copenhagen Bicycle Snake is both an experience and a destination. The ritual of movement across the path during peak commute hours creates a shared experience for over 12,500 daily cyclists. The user experience of the cyclist is embedded within the project's design DNA. In prioritizing the user, the bridge allows for Copenhagen's cyclists to place themselves within the city – while also allowing the city itself to embrace its cycling identity.

5 Movement as Danish Design

Taken individually, the Great Belt Fixed Link, Køge Nord Station, and the Copenhagen Bicycle Snake exemplify how infrastructure can create social value.

What these projects share is a commitment to answering the question: what do you feel when crossing? They are grounded in the design ethos that to incentivize sustainable mobility, the infrastructure must give something back to the community at large. Together, these three Danish bridges highlight how connectivity is both highly contextual - and that the user context is the key to unlocking the eventual aesthetic solution. Through the mobility architecture process – and grounded in the unique user needs – bridge design can drive social value creation across infrastructure scales.

ID-611

Sustainable and Resilient Structures

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Abstract

Housing for the urban poor is a very challenging task and to make them environmentally friendly with modern facilities and infrastructures like Layout Electrification, Water Supply and Sanitation, Arboriculture, Roads, Drains, Culverts, Rain Water Harvesting Re-charge pits, Lifts with DG back up, Boundary Compound wall with Entrance Gate, Guard Room, motor room, control room for electrical, water supply, uninterrupted power supply, parking space, activities for community events, solar energy power for lighting in common areas and for street lighting. Firefighting. Keeping in view all the objectives in mind the design and execution is done by adopting the new alternative better Technologies like Shear wall (IVAN Shuttering). Poverty alleviation can be achieved by providing multi storied buildings with all modern facilities mentioned with an additional benefit of reducing the slums in the metro cities.

1 Introduction

Tenders were called for EPC in a fixed price, no variation mode. The agencies have been given the choice to choose above proven technology approved by the Building Material and Technology Promotion Council (BMTPC/ IITs)

2 General instructions

Keeping in view the challenges faced by the agencies like the fixed price, no variation contract to be executed within a very short time frame of 2 years with 2 years free-maintenance and another 3 years of maintenance to be done by the agencies only with the amount collected from the allottees/beneficiaries. The project has to be built with all infrastructure facilities like roads, STP, street lighting, drains, underground sump, rain water harvesting pits, parks, outside parking for vehicles, commercial space, security guard room etc. The shear wall technology has been chosen by using Mivan/Aluminium shuttering for the efficient and speedy construction.

3 Challenges before Agencies

By choosing the shear wall technology, sustainability of the structure is ensured wherein block work with 30% wastage is avoided and plastering can be done away with resulting in reduction of thermal radiation to the surrounding environment. Neat finishing can be ensured for the external surface by applying putty and by usage of thermal paint, thermal radiation can also be minimised. Solar energy is used for lighting of common areas and street lighting, thereby reducing the dependency on regular power supply and considerable cost saving in maintenance. Rain water harvesting is done and will be used for vehicular washing and for development of land scaping alongwith usage of treated water from STP.

As the wall thickness is reduced from 200 mm to 160/120 mm there is a considerable reduction in common areas and thereby maintenance costs are minimised.

Construction time is considerably reduced as 3 units can be cast in a month with the same set of aluminium shuttering.

The design and structural analysis is done to achieve the following objectives.

- Structural and functional integrity
- Desirable structural performance under characteristic service design loads.
- Resistance to loads due to natural phenomena i.e. earthquake and wind loads
- Structural durability and maintainability.

Structural system adopted is an Ordinary RC structural wall analysed by creating three dimensional models with finite element method and designed as per the latest relevant applicable Indian Standards codes.

Dynamic structural analysis is made with Response Spectrum method.

The project is executed by adopting standard construction practices using Mivan/Aluminium shuttering. Heavy machinery is deployed to save on skilled labour cost which has become scarce after COVID Pandemic.

4 Architectural and design aspects



Fig.1 Sadenahalli (G+3)-128 Units.



Fig.2 Navaratna Agraharaa (S+7)-140 Units.

Conclusion

By adopting this technology, substantial time saving is ensured with a minimum long term maintenance cost. Dependency on skilled labour is substantially reduced by using heavy machineries. There is considerable reduction in the dead loads thereby ensuring reduction in the cost of foundations. As the shear walls are constructed right from the ground level, the structure is quite resilient against horizontal forces. In view of the many advantages as mentioned above, this technology is used in this Mass Housing Project.

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Deep Vision-Based Stone Deterioration Assessment of Indian Heritage Structures Using Synthetic And Real-Time Environment

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Abstract

The conservation or preservation of heritage-like historical structures is the inclusive part of sustainable development. Manually monitoring the damage and deterioration of historical structures over time is time-consuming and laborious. The workforce is significantly expanded, along with the likelihood of mistakes, in situations involving huge quantities of priceless cultural assets. As incorrect degradation diagnosis may lead to long-lasting structural damage in historic buildings, it's important to work on developing new inspection techniques. Computer vision techniques provide a practical way to reduce or do away with the need for human intervention in the field. The fundamental objective of this research is to create a fully automated visual inspection system to replace existing, costly approaches. The present study uses Convolutional Neural Network (CNN) to detect damage in historic stone structures. Therefore, this research aims to use the computer-vision technique known as the Mask R-CNN algorithm to identify, localize, and plot the deteriorations in historical stone structures (defect considered vegetation class).

Keywords: automatic inspection; convolutional neural networks; damage detection; deep learning; segmentation.

1 Scope of work

The primary goal of this study is to develop a fully automated visual inspection system that can replace expensive inspection methods currently in use. The research should not be overly complex, requiring only basic knowledge of structural health monitoring. The following objectives summarize the purpose of this study:

- To utilize Convolutional Neural Networks (CNN) to detect damages in historical stone structures and identify the different types of defects and damages that exist.
- To design a visual inspection model that can accurately classify and pinpoint defects in collected images.
- To evaluate the performance of the model by analyzing various performance metrics from the training, testing, and validation of the image dataset, while also considering the necessary image processing techniques to optimize the model configuration.
- To conduct a comparative analysis with the Mask RCNN-based Res-Net object detection model and analyze various metrics to determine the best model for defect detection.

The ResNet50 and ResNet101-based Mask RCNN deep learning models produce automatic defect detection. A total of 2049 images are used for training the model, including 1545 synthetic images created in the Blender 3D program and 545 real-world collected images from Udaygiri Caves,

Khandagiri Caves, Lingaraj Temple at Bhubaneswar, Odhisa, and Golconda Fort at Hyderabad, Telangana, India. The innovative aspects of this work are the creation of synthetic images for the vegetation class and the modification of the model for automated defect identification to create an algorithm for detecting flaws in historical stone buildings.

2 Methodology

To develop an automated inspection system, a deep learning-based object detection model is utilized for automatic defect detection. The project's methodology is described in detail, and a schematic diagram outlining the steps is presented in Figure 1.

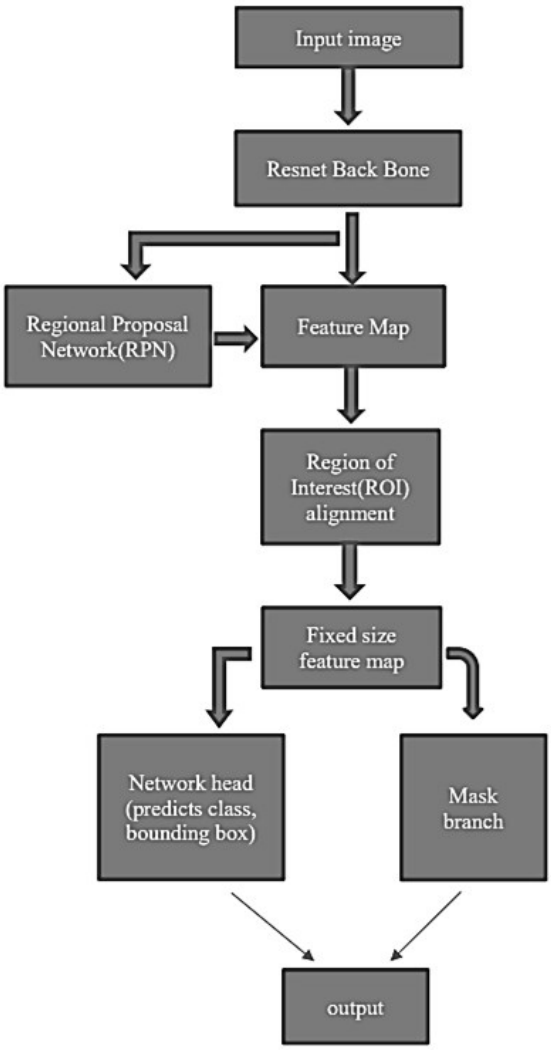


Figure 1: Custom RCNN based Res-Net network

To validate the model's performance, a set of 105 real-world images that were not used during the model training were used as inputs, and their corresponding outputs were illustrated in Figures 2 and 3. The model exhibited higher accuracy in predicting the grass class with segmentation masks and bounding boxes.

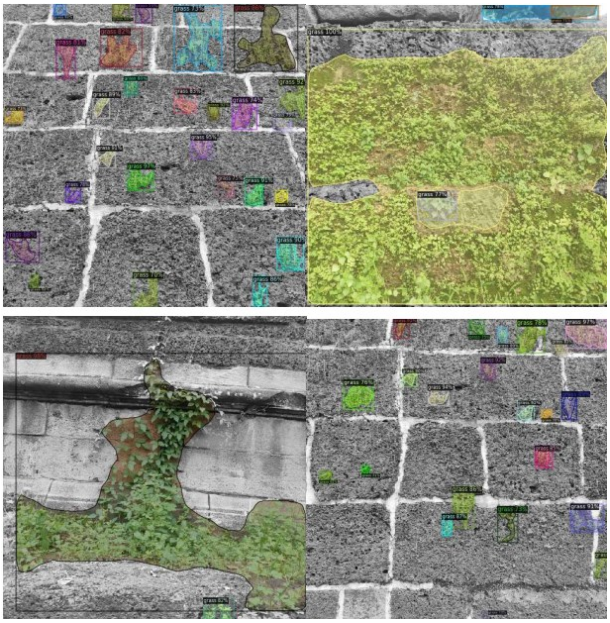


Figure 2: Proposed Faster RCNN based on Res Net 50 defect detection model

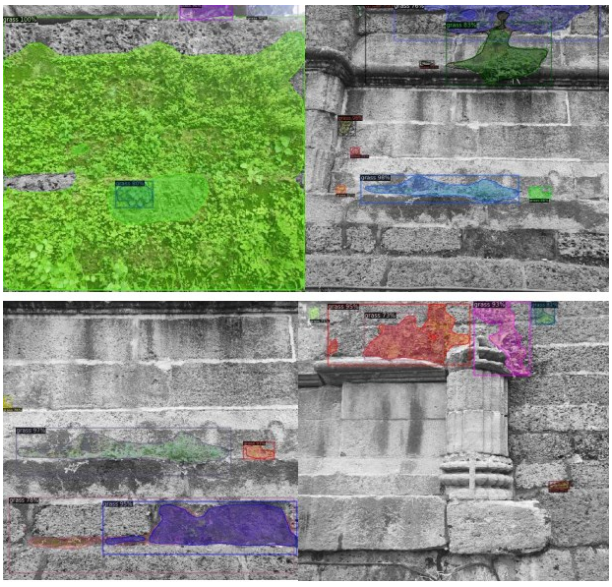


Figure 3: Proposed Faster RCNN based on Res Net 101 defect detection model

ID-1174

Poverty Alleviation: Habitats and Infrastructures for the Under Privileged

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Abstract

Keywords: Habitats for the poor; new materials; new technologies; energy efficiency; environmental degradation; transfer and diffusion of technology

1 Introduction

More than a billion people worldwide, particularly in developing and least developed countries, live in habitats that do not enhance or widen people's development pathways. – lacking in potable water, basic sanitation, sustainable livelihoods, and other enabling features of life, but most importantly, a roof over their heads, in extreme cases. Poverty has been historically accepted in some parts of the world as inevitable. In the middle of 2021, about 84 million people were living in severe deprivation. More than 40 million families are homeless in India. Habitats, which comprise homes that automatically integrate themselves into their communities through robust infrastructure, are the strongest developmental needs. Poverty is a deprivation of a person's ability to lead his/her life in a manner he/she values.

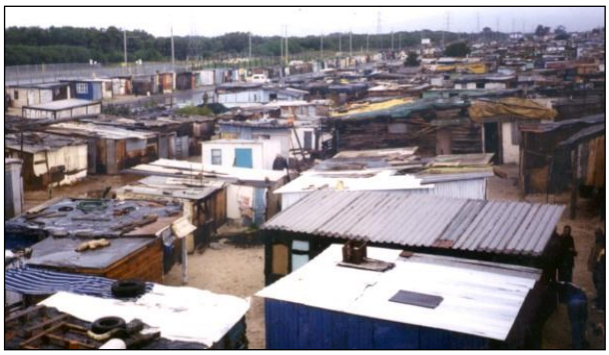


Fig. 1 Shanty dwellings

The government has been attempting hard to eradicate poverty through various poverty alleviation programs. Various schemes have been undertaken by governments to eradicate poverty; in India, i) Integrated Rural Development Program ii) Jawar Gram Samridhi Yojana iii) Pradhan Mantri Grameen Awaas Yojana iv) National Social Assistance Program.

Structural engineers help within the constraints, including cost, and try their best to create houses with a range of infrastructure facilities.

Solution Strategies are the strategy of access to cost-effective building materials and technologies. As a structural engineer, one must look to, amid increasing urbanization and industrialization in developing countries, an assured supply of durable, affordable, innovative, and environmentally friendly building materials. Technology plays a crucial role in achieving more while using less. Appropriate technologies are defined in the context of natural-resource endowment and exploitation, available skills, and the socio-cultural and economic milieu.

Around half of the poor in the least developed countries live in slums and squatter settlements. Habitats for the poor lead to developmental deficiencies: i) overcrowding and facilities, ii) water supply, sanitation, and power, iii) poor hygiene iv) environment. The focus in development planning

must be on economic opportunities, a path that is paved with skill development measures.

2 Employment

Economic growth has the indirect potential to alleviate poverty, though there is no guarantee, because of increases in formal employment opportunities and labour productivity. The International Labour Organization (ILO) estimates 40% of workers in India are poor.

3 Reuse of waste material

Building industry has not only become a major consumer of materials, it has also become a source of pollution. Environmentally integrated production and reusing/recycling is of high importance and shall ensure the feasibility of technical, environmental, and economic feasibility. One of the greatest technological advancements in building materials industries is the recognition of their potential to incorporate wastes from agriculture and industry, both as raw materials and as fuel substitutes, thus simultaneously reducing pollution, carbon footprint, and raw material demand.

Likewise, steel scrap is reprocessed locally in mini-mills to produce rebars. Other products are phospho-gypsum produced as a by-product of fertilizer manufacture; sulphur removed from chimney stacks and used for producing sulphur blocks; and alumina “red mud” used both in block production and cement. The utilization of these industrial wastes can also help control environmental pollution. It brings down the cost and increases affordability.

Timber waste and agricultural waste are processed forming building boards. The residues from rice processing and palm nut processing, and coconut and peanut residues can be used as fuels in brick burning and lime burning. An example in Mexico using plastic pet panels is Walls made of recycled plastic pet bottles. The total wall thickness of 12 cm comprises two 1 cm layers of sand mortar enclosing plastic pet bottles. The ceiling comprises two such panels, one atop the other. The house was built by local people, trained in supervised self-construction.

4 Innovations in soil-construction

In recent years, new and innovative techniques for the production of high-quality, low-cost blocks have been made from the earth using a stabilizer. It uses a small quantity of cement or lime to make the blocks strong, durable, and impervious to water. The stabilized soil block is a cost-effective alternative to burnt-clay bricks and concrete blocks.

Compressed earth blocks (CEB) have applications in the foundation, load-bearing walls, arches, vaults, domes, etc., and in hot or cold climates as well as dry or humid areas. The strength of CEB is often better than country-fired bricks.

New Materials A generation of stronger, lighter, and more sustainable building materials is coming to solve the construction industry’s main challenges. Here are 18 materials that are currently making a buzz in construction. These new materials are i) Self-healing Concrete ii) 3D Graphene, iii) Aero Graphite, iv) Laminated Timber v) Modular Bamboo, vi) Transparent Aluminum vii) Translucent Wood viii) Light-Generating Concrete ix) Microbial Cellulose x) Spider Silk xi) Aluminum Foam xii) Nanocrystal xiii) Wool Brick xiv) Pollution-Absorbing Brick xv) Hydro Ceramics xvi) Biochar xvii) Bioreactors xviii) Invisible Solar Cells.

5 Transport Network Development

Besides shelters, as an element of poverty alleviation, affordable and time-saving corridors/networks are critical for the reduction of poverty. As such commuting needs of people and goods transportation have increased multifold and the supply-demand gap is increasing continuously due to problems of resource crunch, constraints of land acquisition, price escalation, and many others. Addressing the first of the above problems, Indian Metropolis has tried to attract investment, the primary engine of growth, to feed the development process. But the investment would be forthcoming only if the existing infrastructure, the road network being one of the primary ones, matches the expectations of the funding agencies.

ID-1239

Sustainability 0f Heritage Structures: Conservation Issues & Challenges

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Abstract

Conservation of heritage structures for their sustainability requires an interdisciplinary approach. The challenges in understanding the structural behaviour and the ability to make correct decisions for structural intervention become complex and tedious due to non availability of exact documents and drawings, data regarding actual use of materials and methodologies , constructional techniques, processes of decay and damage, present safety level & possible risk of consequential distress. Present article briefly explains some of these challenges in conservation of heritage structures while emphasizing their sustainability aspects. Two case study examples are presented describing the historical, structural and architectural investigations, condition assessment, safety evaluation and structural intervention to highlight these issues.

Keywords: Heritage Structures, constructional techniques, condition assessment, safety evaluation, structural intervention, structural risk, challenges.

1 Introduction

Heritage Structures by their very nature and history (material and assembly) present a number of challenges in conservation, diagnosis, analysis, monitoring and strengthening. Knowledge of the history of architecture, material characteristics, instruments and techniques for investigations, diagnosis and restoration are all vital aspects for correct understanding of structural behaviour and the ability to make correct decisions for repair and strengthening / retrofitting. The conservation challenges and possible risk for structural intervention as investigated in case of two historically important heritage structures located in the state of Odisha, India are briefly presented in this article.

2 Case Study

Lord Jagannath Temple located at Puri and Sun Temple located at Konark constructed during 12th Century are two majestic heritage structures of Bharat (India) declared as National Protected Monument with conservation and maintenance responsibility under Archaeological Survey of India (ASI). Sun Temple at Konark is also UNESCO listed heritage structure. A cluster of various geometrically shaped stone masonry structures are found in the premises of both the above two temple complex. The case study pertains to the structural conservation challenges of the pyramidal shaped stone masonry structures inside the temple complex, popularly known as "Jagamohana or Mukhasala (i.e the Prayer Hall) as per the local Kalinga style of temple Architecture (Shilpa Sastra).

2.1 Jagamohana (Mukhasala) of Lord Jagannath Temple at Puri, Odisha

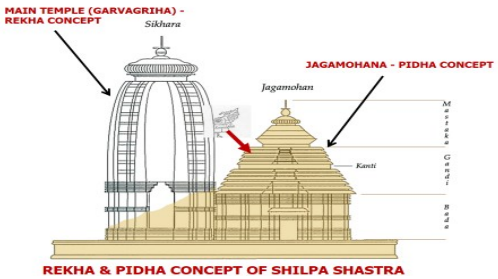
JAGAMOHANA Structure (Mukhasala) , refereed as the "Prayer Hall" of the Puri JAGANNATH temple complex, is an integral part of this 900 year old historical monument of Odisha. It is a living temple with complex rituals through out the year with restriction on time of work. Similarly, ritualistic restrictions prohibit on use of certain modern materials and machineries for any investigation / diagnosis / construction /conservation purpose, which is another major challenge. The original construction was made in ashlar stone dry masonry with blocks of Khandolite (a local stand stone) laid in courses. For the construction, no mortar has been used.

Instead the stones have been jointed with help of wrought iron U-shaped clamps or dowels and have been supported one over another resulting fascinating wall and corbelled roof, in the shape of frustum of pyramid. Falling of stones and plaster blocks were initially reported in the year 2004 from its connecting corridor. Acute distress were subsequently observed at the roots of projecting cantilevers which are supported outside. Various form of distress was observed during the July 2015 joint inspection by a high level Committee comprising multidisciplinary conservation experts from Archaeology, Structural Engineering and Chemical Science.

Figure 16. Lord Jaggantah Temple Complex at Puri



Dislodging / cracking of capitol stone layers atop the pillar head on North-West supporting column, numerous structural cracks on all the



four column-beam system supporting the Jagamohan including the ceiling roof, falling of corbel stones from inside pidha layer pockets on West & South face, dislodging of stone/ out of plane deformation at corbelled locations, acute corrosion induced cracks near the bearings of Wrought Iron beams and clamps, dead and weak plaster at many location were observed.

Figure 2. Kalinga Style of Temple Architecture

The visual observation of distress observed during July 2015 gave clear evidence of deterioration of the monument. As it is a living temple of high cultural and heritage value, it was considered imperative to carryout urgent repair and conservation measures with appropriate structural & chemical intervention so as to prevent further deterioration of the monument, while ensuring its global stability & longevity for the future. The high level Committee with multidisciplinary conservation experts suggested major structural retrofitting and conservation work after several round of field visits and interaction with other stake holders. Alternate structural interventions were analyzed based on in situ condition assessment, laboratory testing of materials and change in load path after occurrence of structural distress in the stone beams and column capital. Major structural intervention in the form of confinement of column capitol layers, local jacketing / confinement of all the four distressed columns, structural support system inside the distressed pockets and an integrated support system with portal box frame near the four central columns to support the cracked stone beams were carried out to safeguard the structures. The structural load bearing behavior after the structural intervention are being monitored with load sensors to examine the consequential effects (if any).

2.2 Jagamohana (Mukhasala) of Sun Temple at Konark

The Sun Temple at Konark, known as the **BLACK PAGODA** of Odisha is considered to be the eighth wonder of the World. This outstanding masterpiece of architecture, which has been declared by the **UNESCO** as a **WORLD HERITAGE** structure, constitutes a precious witness of our civilization. As per the historical documents, the main temple of this monument had collapsed in stages. However, the reasons of failure have not been established till date. The remaining parts of this magnificent masterpiece of art and sculpture fell in ruins subsequently, due to human negligence.



Figure 3. Jagamohana of Sun Temple at Konark

During 1903-1909, the Jagamohana (Mukhasala) of this temple was sealed after filling the interior with sand, probably, after observing certain structural deficiency in the monument and to avoid possible collapse. Here also, the historical sources do not furnish an exhaustive description of the causes and of the damage that led to the filling by sand and the safety level of the monument at that stage. The paper briefly presents the results of historical and recent pathology study of the Konark Mukhasala including the conservation measures so far undertaken. Results of recent investigation includes the data generated by using GPR technique, laser scanning, video endoscopy, rock core extraction, detailed geotechnical investigation, chemical analysis of surface deterioration etc.

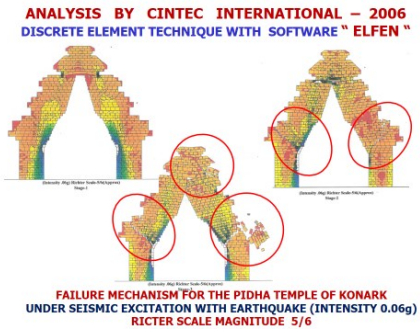


Figure 4. Numerical DET Analysis of Failure

Detailed intervention scheme has been proposed for global strengthening and stability of the monument on the basis of condition assessment and structural health monitoring parameters with non-destructive techniques. Removal of sand and dry-stone lining from inside with structural consolidation and anchoring of the interior loose masonry / hanging stone block progressively by use/ extension of a telescopic structural support system is one of the major structural intervention proposed. The associated risk is requirement of an entry passage from outside to the interior with options of either widening any of the four existing small vent or by cutting through the stone masonry of about 5 meter thick. As per the insitu test results, it is observed that fascia fabric of Konarak is relatively poor and any physical intervention need to be undertaken with full knowledge/responsibility of the consequences of any irreversible process of intervention. Evacuating sand fill and regenerating interior stone column system, stabilization by chemical grout or pinning, re-establishing the original stone column beam support system are some of the major challenges. Numerical analysis for the structure, as it is and as per the conservation / strengthening scheme need to be done carefully with validity checks. Degree of porosity of stones at various levels and effect of hygro-thermal stresses on the porous stones including their chemical stability also need to be assessed alongwith their consolidation mechanism for identification of parameters for chemical analysis for long term stability & monitoring purpose. Effect of stress relief on the plinth and foundation inside and outside need to be analysed in details to yield parameters for monitoring purpose

3 Discussion, Conclusions and Acknowledgements

Comparative conservation challenges for structural intervention of two historical monuments located in Odisha, India are presented in this article with brief of their historical & structural investigations, condition assessment, safety evaluation, proposed / executed intervention schemes and associated risk parameters.

Acknowledgement with gratitude expressed to DG ASI and the team of multi disciplinary experts from ASI with whom Author has worked since 1993 for the above two monuments. Author is grateful to the Chairman of Core Expert Committee Prof. A. P Gupta from IIT Kharagpur & Working Chairman Late Padmashree Dr. G. C. Mitra , Ex Secretary PWD Govt of Odisha and Technical Committee Member Prof Dr S. K. Bhattacharyaa, Ex Director CBRI Roorkee for their technical guidance and motivation.

4 References.

[1] Bhattacharya S.K.,and Gupta A.P., *Earthquake Analysis of Lord Jagannath Temple , Puri, Odisha ,Technical Report IIT-Kharagpur , India;* 1994

Session 19

Sustainability in Transportation Structures

ID-210

Structural Rehabilitation of Viaduct Cernicchiara

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Abstract

Structural rehabilitation of existing bridges and viaducts as an environmental sustainability effort. It is frequently possible to execute activities aimed at reaching new safety standards on existing structures: not only does this promote decarbonisation in terms of sustainability, but it also prevents the production of large quantities of waste material.
The article covers the rehabilitation of a 1962 viaduct in Salerno, Italy, made of reinforced concrete cast-in-situ and therefore subject to notable realization issues. The existing structure's analysis and the rehabilitation technique adopted (CFRP reinforcement of beams and arches) made it possible to adapt the structure to new mobile and seismic loads.

Keywords: existing bridges, arc bridges, viaduct, structural rehabilitation, fibre reinforced, CFRP reinforcement, reinforced concrete, slab, pillar reinforced, seismic improvement, moving load

1 Introduction

The challenge was started when "**Valori Scarl – Consorzio stabile**" asked a better solution to solve the problem of "Cernicchiara Viaduct" Structural Rehabilitation.

The viaduct's structural improvement was realized using CFRP (Carbon Fiber Reinforced Polymers) techniques. In Italy, this kind of technical improvement in an infrastructural context is quite recent and represents an innovative aspect in structural rehabilitation activities.

2 Cernicchiara Viaduct

Having six spans and a central arch, each span is traceable to the pattern of a beam resting on its extremities, represented by the pylons, while the central one is traceable to an arch wedged at the base. The pylons are frame-type in two directions. Each pylon is therefore made up by four columns, linked by two levels of horizontal beams on the viaduct's transversal axis.

The entire viaduct was realised in reinforced concrete cast on site.



Figure 17: the arch of Cernicchiara Viaduct

Structural analysis was implemented on FEM software. Studying the viaduct permitted the

identification, in different load conditions and their combinations, of the elements most stressed by accidental, dynamic loads and by seismic strains.

3 The structural degradation.

The viaduct showed signs of extensive degradation after fifty years of use. The reinforced concrete piers, pierheads and cast-in-place girders were affected by carbonatation with substantial concrete cover spalling in many areas.

4 Numerical Models and Materials' Characteristics

Two numerical models were implemented for the structure's analysis, both based on the Finite Element Method (FEM), although with a different grade of detail and separate aims:

- a global model, representing the entire viaduct
- a local model describing a deck, isolated and with real end constraints.

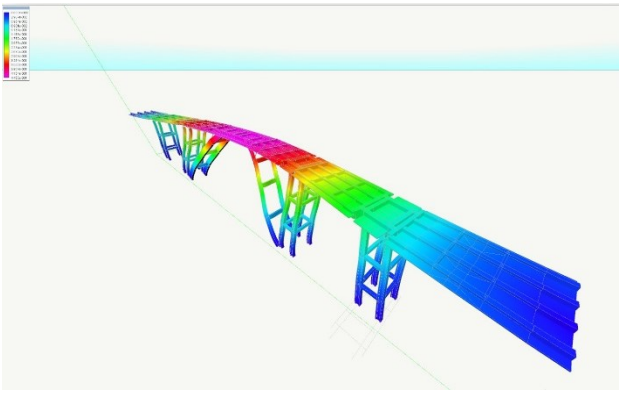


Figure 18: seismic behavior

5 Flexural Reinforcement Systems and Central Shear

Roadbed beams were reinforced against bending through CFRP plates placed on each beam's intrados. Four plates were applied to the external beams in a parallel pattern, whereas internal beams were reinforced with three juxtaposed plates.

6 Rehabilitation and Sustainability.

We all know that reinforced concrete is not eternal, sooner or later it reaches the end of his design life. Until then, we can maximize the use of its strength.



Figure 19: view of Cernicchiara viaduct

In this contest it is very interesting to see how the structural rehabilitation had operated to minimize the CO_2 emission.

You can compare the demolition and subsequent reconstruction of a new bridge with structural rehabilitation of this one.

As predictable "embodied" carbon A1-A3 is drastically lower: almost 89% less considering that used resins quite "not eco friendly" and mortars reinforcement just as "green" while for the cls of the bridge used a C30 37 Mpa with low emissions because are assumed that for such large works already use the low emission cements below the numbers in terms of total GWP emissions A1-A3.

7 Conclusions

The retrofitting activities, when are possible, extend the life of structures and parallel the activities contribute to environmental sustainability. Structural rehabilitation must be carefully assessed and, above all, must be carried out properly. Like evidenced the relationship in terms of decarbonisation is of one to ten regarding the realization of a new work.

ID- 196

Designs and Associated Carbon Footprint – Showcasing Mumbai Trans Harbour Link

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Abstract

The introduction of sustainability as part of the evaluation criteria in Design-Build projects broadens the requirements to both designer and contractor and reinforces attention to the choice and source of material, embodied carbon in material, in transport and installation and reinforces the need for having a technically efficient design even further.

To showcase the influence of efficient design examples are presented from the near complete Mumbai Trans Harbour Link (MTHL) project in Mumbai, India. The project was split into three contracts of which COWI provided design services to package I for contractor JV consisting of Larsen & Thoubro and IHI and with Mumbai Metropolitan Region Development Authority (MMRDA) as end client.

Keywords: Sustainability, carbon footprint, efficiency of design, Mumbai Trans Harbour Link (MTHL).

1 Introduction

The MTHL project is used to illustrate the impact key design decisions have on the achieved efficiency of the design and therefore on the associated carbon footprint.

The tender process for the MTHL project was characterised by several tender addendums and clarifications that significantly altered the basis for the design and influenced key design decisions. Examples of how clarifications directly impacted tender design will be given with CO2e as a measure of impact.

The project site is to a large extent governed by the seismic load combinations. To provide an optimal design the influence of the articulation on the overall consumption of material and therefore CO2e was investigated in detail during tender by the contractor JV and COWI as designer. The investigation led the package I team to choose an articulation with a floating deck structure for the marine concrete viaducts. The floating deck articulation gave significantly lower quantities in comparison with an articulation with rigid connections between deck and piers.

In conclusion it is reflected on how the development of designs always should seek to identify optimisation potential and seek towards finding optimal and efficient design that in the end drives down CO2e.

ID-374

Bridges – A Catalyst as well as a Driver for Sustainable Development

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Abstract

The 2022 Buildings-GSR finds that the buildings and construction sector accounted for around 37% of energy- and process-related CO2 emissions and over 34% of energy demand globally and hence, it has got significant responsibility in making the earth a better place to live and towards achieving the United Nation's Sustainable Development Goals by 2030. To achieve these objectives, there are few strategic trends that will shape the future of Civil Engineering Sector and can be summarized as below:

A) Climate Crisis: The net zero and sustainability benefits will become central to project outcomes and that can be achieved through various means.

B) Accelerating digital transformation: Digital (BIM, Digital Twins, etc.) will create a demand for people with the adaptability needed to understand and work with a wide and rapidly changing set of digital technologies.

C) Productivity: Engineers will need to master the skills and behaviour that will allow innovative practices Automation and Standardization, Drone Survey, Accelerated Bridge Construction, 3D printing.

D) Resource Diversity: Diverse Workforce, Inclusion, Staff Motivation and Retention, Staff away from traditional civil engineering background.

E) Value replacing volume as the basis for financial reward: Revenue based on the economic, social, and environmental outcomes in Asset Life Cycle.

Bridge construction is one of the major elements in construction industry and it is very important to achieve sustainability in planning and execution of Bridge projects. Jacobs strategic framework for sustainability revolves around three core pillars - People, Places and Partnerships. In running our own operations and in delivering client's projects we strive to deliver economic, social, and environmental values. This is not always as simple as it sounds. With development often comes unintended consequences. Balancing opportunity with risk is an ongoing challenge for us all. The more we understand and face these challenges – in collaboration with our clients and partners – the more resilient business and more sustainable future we will create.

Bridges are an integral part of the infrastructure development. They can contribute in many ways towards the United Nation's Sustainable Development Goals. This paper will try to highlight how the bridge design and construction can make a positive impact on various UNSDG like SDG 5: Gender Equality, SDG 9: Industry, Innovation, and infrastructure, SDG 10: Reduced inequalities, SDG 11: Sustainable cities and communities, SDG 13: Climate action and SDG 17: Partnerships for the goals.

This paper will demonstrate the achievements of the sustainability aspects on live bridge projects covering various aspects like construction efficiency, optimised use of materials and resources, innovation, gender equality, inclusion, community development, etc. The list of projects showcased in this paper are as follows:

1) A1 Birtley to Coal House, UK
2) A12 Chelmsford to A120 Widening Scheme, UK
3) Dubai Marina Pedestrian Bridge, UAE
4) New Ganga Bridge, India
5) Mumbai Coastal Road, India

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ID-398

Experience as Incentive: Promoting Sustainable Urban Mobility Through Bridge Design

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Abstract

Bicycle infrastructure creates environmental, social, and economic value in urban environments across cultures. Cities that invest in bicycle infrastructure reduce the number of cars on the road, save on infrastructure maintenance costs, and preserve greenspace within development plans. A bridge must not only solve specific traffic challenges but catalyse value creation and incentivize sustainable urban transport.

Exploring the intersection of architecture and user experience across bicycle bridges in Copenhagen, Denmark and Xiamen, China - Dissing+Weitling demonstrates how cycling infrastructure is a powerful tool for cities to incentivize sustainable urban mobility.

Keywords: bicycle; cycling infrastructure; urban mobility; user experience; social value; site-specific; traffic solution; public health; commuting

1 Experience as Incentive

Bicycle infrastructure can incentivize citizen adoption of socially and environmentally sustainable mobility. To be a driver of sustainable value creation, bicycle bridges and larger urban cycling systems must be contextual, dynamic, and deliver a riding experience that reinforces enjoyment.

What makes cycling infrastructure a true change catalyst is the designed user experience. Mobility architects' partner with engineering and civic planning teams to ensure that crossings are not only functional but enticing. Bicycle bridges can be scaled from small crossings to large systems – and Dissing+Weitling explores how two cycling systems in Denmark and China incentivize sustainable mobility by delivering dynamic and engaging user experiences across scales, cultures, and geographies.

2 Cykelslagen

Copenhagen's Cykelslagen is a physical manifestation of two Danish traditions: design and cycling. At the same time, it is infrastructure as experience – the act of crossing allows cyclers a moment of roadway isolation an otherwise integrated urban plan.

The slim, curvilinear pathway takes the form of an elevated 230 metre two-way bicycle crossing located at the first-floor level. Wriggling like a snake across the quay between Vesterbro and Copenhagen harbour, it is a seamless connection between the Quay Bridge and a major roadway situated five metres above the quay.

The Cykelslagen's evolution from ramp replacement to bicycle bridge can be mapped to a genuine desire to provide cyclists with a fun commute. As the lead consultants, Dissing+Weitling worked with Copenhagen Municipality to determine an alignment ensured an

enjoyable ride. This meant ensuring the curves snaked through buildings without feeling claustrophobic, with brief glimpses into the inner harbour and surrounding architecture. Additional considerations were made to the gradient of the bridge – it was essential to find a way to make the elevation gain gradual to ensure the commuter path remained easy and accessible. A harmonic flow, a fun ride, a ritual of movement – the Cykelslagen's spatial feeling and visual impact contribute to thousands of commuters embracing the crossing as a part of their daily lives.

The mobility architecture of the Cykelslagen exemplifies Copenhagen's urban planning ethos: it is not enough for new infrastructure to 'just' be functional solutions – they drive sustainable value creation and contribute to the wellbeing of all members of society. Danish design thinking supports a convergence of user experience and aesthetics.

3 Xiamen Bicycle Skyway

The Xiamen Bicycle Skyway demonstrates how bicycle infrastructure can be adapted and optimized to fit differing regional needs and scales – creating social impact within a distinct cultural context. Developed for the Xiamen Municipal Planning and Design Administration, the Bicycle Skyway enhances mobility, connectivity, and accessibility for cyclists on the island city.

A 7.6 kilometre six-lane bicycle path – Xiamen Bicycle Skyway is China's first suspended cycling path and the world's longest elevated bicycle bridge. With eleven access points, the skyway connects commuters across the city's five major residential areas and three business centres – and serves as a connection point for eleven bus stations and two subway hubs.

The initial need for the Skyway stemmed from the unsafe road conditions for cyclists on the traditional motorways. The elevated system – separating cyclists from cars – provided safety while also ensuring that the act of riding was a good travel experience – slow travel as enjoyment. However, cycling is only one aspect of slow mobility – and it became clear after the initial months of operation that there was equal enthusiasm in Xiamen for walking – and a need for pedestrian paths.

When it became clear that there was equal enthusiasm for walking paths – the Skyway's lanes were shifted to open half of the 4.8 metre platform width to pedestrian traffic. This supported foot traffic alongside cycling within the boundaries of the Skyway – and demonstrates how a client can adapt the function of a bridge more accurately deliver mobility solutions based on user needs, should they shift.

4 Copenhagen and Xiamen in Conversation

Bridges are more than crossings – they are experiences that can support both movement and stillness. They provide visual coherence and strengthen communities. When treated with attention and respect, designed with a user-experience focus – public infrastructure can revitalize public spaces and directly impact the quality of people's lives. Mobility architecture has the power to revitalise underdeveloped parts of cities and create dynamic, fun, and safe connection points.

Both the Cykelslagen and Xiamen Bicycle Skyway achieve this – they are design solutions which create transportation efficiencies, but also reinvigorate the local built environment, contribute their own architectural value, and are embraced by users as icons of place. Despite their vastly different scales, they shared an ability to catalyse sustainable development. In expanding access to safe bicycle infrastructure – both projects generate social and environmental value within urban centres, and inspire slower, greener ways of living and moving. Understanding that the benefits of a dynamic cycling path are not limited by distance – the curving pathways, controlled inclines, and intentional consideration of visual note points. In designing an infrastructure solution that unlocks cycling's ability to create both social and environmental value – both the Cykelslagen and Skyway brought economic vitality by reinvigorating lesser-utilized parts of their respective cities. Together the exemplify how bicycle infrastructure can deliver across the triple bottom line irrespective of project scale.

ID-416

Net Zero Implementation on Transportation Projects

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ABSTRACT

Net zero has been a hot topic in discussion in the current timeline. Since the effect of global warming impacting the coastal zones, lot of attention have been garnered by Net Zero. The carbon emission has increased significantly from 8 billion tons CO2 per year to almost 40 billion tons CO2 per year.

Global atmospheric carbon concentration has gone up rapidly from 290 PPM to 370 PPM in 2000 and finally up to 413 PPM in 2020. The rate of CO2 concentration has increased from 0.61 PPM per year to 2.15 PPM per year now.

The current global warming is alarming at the rate of 0.18 °C per year which has caused significant reduction of polar ice and increase in sea levels.

Atkins- Member of SNC Lavalin group have developed an extensive system to reduce carbon footprint and to approach Net Zero in transportation and infrastructure projects base on PAS 2080 framework.

PAS 2080 is a global standard for managing infrastructure carbon and has been authored to meet World Trade Organization requirements. The framework looks at the whole value chain, aiming to reduce carbon and reduce cost through more intelligent design, construction, and use.

It starts with building nothing to build efficient. A lot of our work focuses on capacity enhancement of existing structures where we have been able to reduce material and labour use to make it future proof and take us towards the Net Zero goal.

This paper will discuss few examples on transportation projects where carbon reduction has been achieved.

ID-457

An Update on Carbon Footprint of Bridges

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Abstract

Transport infrastructure accounts for a significant proportion of the worlds carbon dioxide emissions. Bridges and viaducts use a significant amount of steel and cement, these two industries alone amount to about 16% of total worlds carbon emissions. The carbon footprint of bridges and viaducts has been studied and documented [1]. This paper summarises the published data and adds some additional data from the Arcadis bridges database and other sources. Revised plots of carbon with crossing length and bridge area are given. New datasets of bridge carbon with time, with span and carbon in substructures are introduced to note progress towards net zero and to address issues noted in the original research.

The previous data [1] was mainly for smaller span bridges, and no significant relationship of span and carbon was noted. With the additional data there is a clear trend of increased carbon with increased span. The previous data noted the variability in the data for shorter span bridges could be related to foundations and substructures. This was investigated by plotting the normalised carbon with the proportion of carbon in substructure (Figure EA1a), the data confirms the relationship of increased carbon with increasing substructure proportion. A simple Good, intermediate, poor rating system is proposed for bridges based on the data (Figure EA1b).

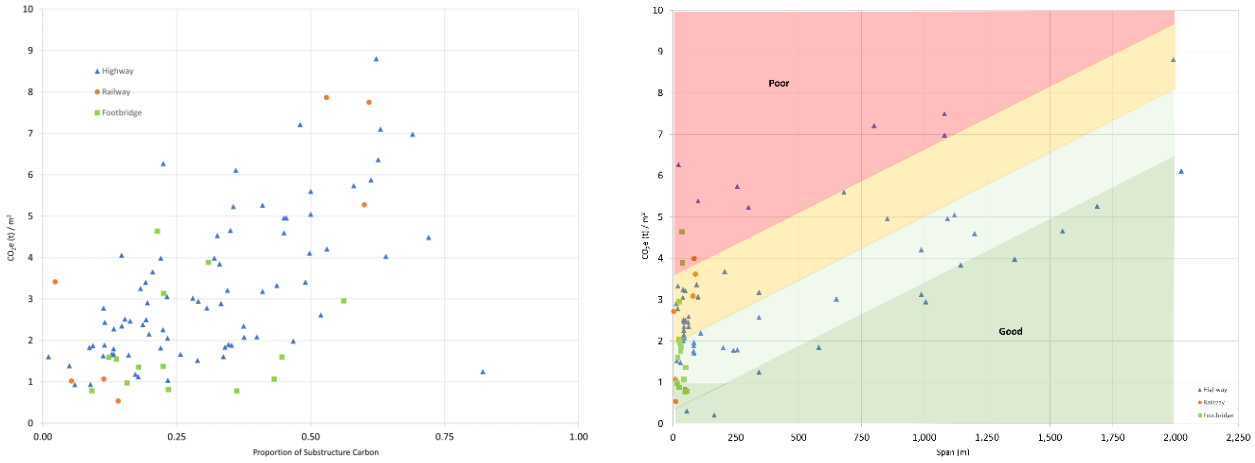


Figure EA1. Normalised capital carbon (tonnes CO_2e/m2) with a) proportion of substructure b) span and with bridge carbon rating system (good-green, poor-red).

The previous data [1] discounted bridges before the year 2000. The full data with time is analysed, providing an insight on the progress towards net zero. The trendline for the data is flat indicating that carbon over the

last 60 years has been relatively constant, with no signs of improvement in recent years. Hence there is a need to now consider carbon and aim towards net zero.

Conclusion

The paper summarises the key conclusions and gives 4 key recommendations towards net zero:

1. Aim to reduce and minimise the size (length or area) of all bridges.
2. Aim to reduce the bridge span to the minimum.
3. Aim to reduce the substructure, optimise piles caps and piers.
4. Benchmark new designs against the data presented (Figure EA1b), if not in the lower (good) quartile redesign until it is.

Keywords: bridges; carbon emissions; climate change; bridge carbon KPI; net zero; sustainability.

Reference: [1] Collings D. The Carbon Footprint of Bridges. Structural Engineering International. 2021; 32:4, 501-506, DOI: 10.1080/10168664.2021.1917326.

Session-20

Case Studies in Sustainable Materials,

Technology and Practices

ID-381

Cable replacement of Fernando Reig Bridge in Alcoy, Alicante

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Abstract

This article summarizes the cable replacement works carried out on this bridge constructed in the city of Alcoy (Spain) that was reopened to vehicular and pedestrian traffic in April 2018, 31 years after its inauguration. The sequence followed in the cable replacement and the lessons learned are explained in detail. From the authors point of view, the transmission of this experience can help others to technically manage similar bridges not only in Spain but all over the world.

Keywords: cable injected with grout, cable break, autopsy, replacement.

1 Actions carried out prior to replacement

In July 2016 one of the stays (T-41 left) broke. At the beginning of September of the same year, the stay was replaced by another of new technology.

The uncertainty generated by the state of the remaining stayss led to completely close the bridge to traffic, to the study or autopsy of the broken stay, and to a campaign of external recognition of the state of the remaining stays with the support of the most advanced means of auscultation of stays. As a result of these studies, finally it was decided to undertake the replacement of all the stays.

2 Guiding principles for the replacement of the stay cables

Due to the uncertainties regarding the capacity of the bridge stays, it was considered that during the replacement phases, the tension in the stays should not be increased. A detailed study of the replacement process was carried out to assess the maximum deck length (assuming the accidental breakage of consecutive stays) that could withstand the stresses produced by the permanent loads, resulting. The conclusion was that two consecutive stays could be missing without affecting the integrity of the deck. For this reason, shoring towers were provided for every third stay.

The new stays are of new technology, made up of a system of parallel strands with triple protection: galvanised, oil wax and individual high-density polyethylene sheath, and additionally enveloped by an external high-density polyethylene sheath. This new system allows any strand to be inspected and replaced individually during its service life.

3 Removal of stays for replacement

The replacement of the stays has two distinct phases: the un-stressing and removal of the pre-existing stay and the installation of the new one.

The first phase is highly complex as there are no comparable precedents. The second phase, the installation of the new stay, is relatively conventional using well known technology and proven methods.

The operating procedure must make it possible to remove the load supported by the stay cables before cutting them and then lowering them, with all the guarantees of safety for the operators and also for the other structural elements of the bridge (the other stay cables, the deck, the pylon, etc.).

The operating process designed by FCC's technical services, and validated by FHECOR, consists in the arrangement of a by-pass or connection frame in the free section of the stay cable, very close to the deck, to facilitate the work. At this point, the stay can be cut in the segment inside the frame and then the connecting frame can be unstressed, which results in a loss of load on the rest of the stay. In practice, this process takes place without increasing the load on the stay in relation to the previous one, which is a guarantee of safety in the process.

This system, previously used by FREYSSINET, although not in the form in which it has been applied on this bridge, has involved essential experimental developments and contrasts in order to fine-tune the procedure with sufficient guarantees.

First, to guarantee the friction between the stay and the clamps that are responsible for transferring its load to the transversal beams of the connecting frame, the high-density polyethylene sheath and all the cement grout protecting the strands had to be removed using hydro demolition technique.

It has also been necessary to develop a system to ensure that the spaces between the strands are completely filled and to create suitable friction conditions for the clamps to take the full load of the stay.

With the proposed system, the friction conditions must be such that, in order to reduce the length of the clamps to a minimum, it is guaranteed that no slippage will occur at three different levels. In order to improve the steel-steel friction conditions at the interface between the half pipes and the clamps by increasing the roughness, sand blasting was used. This system was tested in the BBR workshops. From this solid experimental base, the system was designed. This involved defining the clamp length that had to be kept to a minimum to guarantee the correct behaviour of the assembly in the minimum space.

Once the stay has been cut and the frame has been partially unstressed, it is necessary to remove the stay. It should be noted that the stay force is not reduced to zero, because it becomes a catenary under the action of its own weight. The deflection it adopts cannot be such that it interferes with the stays located below, so it was necessary to maintain equipment on the deck that holds the stay vertically and is capable of pulling it horizontally. The tower crane holds and lower the upper ends of the stay from the exit of the formwork tube to the deck, while a truck crane simultaneously holds the lower end of the stay suspended and moves it until it reaches a horizontal position on the deck, in a controlled manner.

After dismantling the stays, new technology cables were installed. This procedure is no different from the usual procedure for newly built bridges.

4 Conclusions

- The actions undertaken have been absolutely necessary to restore and improve the functionality of the bridge, its durability and, most importantly, the safety of the users.
- Special emphasis has been placed on health and safety in the execution of the works, given that this is a pioneering intervention in bridges of this type.
- The work was completed in less than 10 months, reducing 3 months the original work schedule.
- The technical team, from the last operator to the engineers responsible for the Administration, including the consulting engineers and the suppliers of materials and equipment, carried out the work with great precision and professionalism.
- The bridge, thanks to this intervention, once again acquires an innovative status because of the techniques used and will be a world reference for other similar works that will undoubtedly have to be undertaken at the end of the corresponding life span, as it will be necessary to replace the stays with new ones.

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ID-405

Multi-faceted Approach to School Earthquake Safety in Westernmost Nepal

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Abstract

Introduction: Nepal lies along the Himalayan mountains, one of the most seismically active areas in the world. Western Nepal (Sudurpaschim province) is of particular concern as the fault system in this region can produce high-intensity earthquakes. Schoolchildren are particularly at risk. Although there have been several efforts to strengthen school buildings, most have focused on central and eastern Nepal, and tens of thousands of schools remain vulnerable. The destructive 2015 M7.8 Gorkha earthquake in central Nepal was a stark reminder, killing over 9,000 people and destroying over 7,000 schools.

GeoHazards International (GHI) is a small, globally-focused non-profit that aims to save lives empowering at-risk communities worldwide to build resilience *ahead of* disasters and climate impacts. Since 2016, GHI has focused its efforts in Nepal on the westernmost part of the country. As is common in many developing countries, integration of disaster risk reduction in development is sparse, particularly in Westernmost Nepal's rapidly growing cities. GHI is working here to encourage integrating disaster risk reduction into development as it is the most effective way of saving lives before the next earthquake.

Earthquake Scenarios: From 2016 to 2019, in Westernmost Nepal (Sudurpaschim and Karnali provinces), GHI worked closely with local leaders and technical experts in creating earthquake scenarios for three districts. These scenario studies found widespread building and infrastructure vulnerabilities to future earthquakes and triggered landslides. Resulting scenario damage estimates for each district were sobering—over 50% of collapsed buildings, with an additional 30% or more buildings deemed unsafe. However, these estimates were for an expected earthquake magnitude event, not a worst-case scenario.

School Building vulnerability: Vulnerable school buildings emerged as a significant concern. The seismic safety of schools was identified as a critical area for future work, especially since the Gorkha earthquake had already exposed vulnerabilities of educational institutions and caused widespread damage to over 7000 schools. Many schools collapsed in the most affected districts in central and eastern Nepal, and it was most fortunate that the earthquake happened on Saturday, the only day of the week that schools are closed.

Multi-faceted approach: Given limited resources, many collapse-prone school buildings, and the fact that an earthquake can occur any day, a multi-faceted approach is needed to protect schoolchildren. The safety of school buildings has to be the priority in most communities, especially in locations likely to be affected by high-intensity earthquakes. However, structural safety is only one of the important ingredients of school earthquake safety. It is also essential to enable schools to identify and mitigate non-structural risks, to help them develop capacity in disaster preparedness, and to develop disaster management plans. In addition, it is crucial to work out solutions to protect children who remain in unsafe school buildings until these are assessed, retrofitted, or replaced.

Retrofitting: Nepal was among the first countries in the region to carry out school assessments and

initiate retrofitting of schools. Nepal's School Sector Development Plan has been retrofitting seismically vulnerable schools at a rate of approximately 120 schools each year. At that rate, it would take about 191 years for all of Nepal's schools to be safer. Seismically retrofitting or reconstructing schools are ideal solutions, but this process takes time and resources. Despite slow progress, assessments and retrofitting of schools are crucial to building the resilience of schools and capacities in retrofitting.

It is also essential to ensure that all new school buildings, whether constructed by the Government or the community, be built earthquake resistant. Though the government-approved school designs consider earthquake resilience in all new school buildings, it is important to demonstrate these technologies and build technical personnel's capacities in constructing earthquake-resistant buildings that will protect children in future earthquakes.

Though the structural solutions above are time-intensive, other components of comprehensive school safety, such as school earthquake preparedness and planning activities, must be continued along with the pursuance of interim solutions.

GHI's efforts in the region have attempted to cover all the multi-facets of comprehensive school safety including capacity building of technical personnel on vulnerability assessment, technology demonstration for new school construction, school preparedness and planning, and interim solutions such as earthquake desks.

Capacity Building: GHI organised IABSE foundation-funded training programs that provided municipal and local engineers with experience in carrying out school building rapid vulnerability assessments (RVA). As part of our ongoing initiatives in western Nepal, GHI has trained local masons on earthquake-resistant construction techniques. In alignment with the action plans developed under the earthquake scenarios described in the preceding section, an IABSE Foundation-funded effort focused on better understanding the extent of school vulnerability in the region.

Technology Demonstration: At the time of writing, the team is initiating the construction of an earthquake-resistant school building in Godawari Municipality, Sudurpashchim Province, that will serve three purposes: (1) to demonstrate earthquake-resistant technologies for the construction of school buildings, (2) provide local students with an earthquake-resistant school, and (3) to carry out hands-on training of local masons in earthquake-resistant construction. The demonstration construction began in April 2023 with the demolition of a highly vulnerable building on the site, and the initiation of the new building construction by trained masons.

Interim solution: In most schools in the region, the advice given to school children for protective action during an earthquake is to take cover under sturdy furniture such as a table (best known as Drop, Cover, and Hold On). However, this needs to consider the capacity of the furniture to protect children against falling debris during an earthquake. One promising interim solution that GHI implements is specially designed 'Earthquake Desks' in certain vulnerable school buildings. These desks are designed to be stronger than typical school desks and can protect schoolchildren from falling debris during earthquake shaking. Earthquake Desks cannot guarantee safety; instead, they offer increased protection for schoolchildren in vulnerable buildings. GHI has been conducting a multi-year feasibility assessment of Earthquake Desks in Nepal to determine if these Desks can serve as a useful interim solution to protect Nepali schoolchildren.

Call for action: Sooner or later, a high-intensity earthquake will happen during school hours placing tens of thousands of young lives at risk. All stakeholders must focus efforts on comprehensive disaster risk reduction in schools, including vulnerability reduction and capacity building. High-risk and limited resources argue for a multi-faceted approach to protect schoolchildren, including new earthquake-resistant buildings, seismic retrofit of current schools, and interim measures when neither of the first two options are possible in the near term. Our work is a race against time, as the next earthquake can happen anytime.

ID-462

Underground Metro Projects-Structural Engineering Challenges

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Abstract

The most dramatic development in the field of urban infrastructure in recent times has undoubtedly been the introduction of the metro as a transportation system in many cities across India. Apart from providing the predominant mode of travel, the metro has been instrumental in reducing pollution and making a significant contribution to the improvement of quality of life for the citizens.

In the urban environment underground construction is always preferable instead of the alternative of employing elevated viaducts that would eventually remain a permanent part of the city's skyline, resulting the severe restrictions on planning for developments in the future. Also, since urban space at the ground level is at a premium, a large proportion of the city's transportation infrastructure must be planned underground for it to be sustainable.

This paper discusses the challenges experienced during the design and construction of underground structures for the Metro constructions in some of the heavily built-up areas in cities where the authors' company has worked. Underground constructions are a unique blend of structural and geotechnical engineering, and a special set of skills, judgment, and experience are required to evolve concepts and carry out detailed engineering that would ensure safety of the built environment and minimum disturbance to everyday life during construction and yield sound and durable structures in service.

The underground stations present the most challenging portions of the metro constructions as they can present uncertainties and difficulties during execution in close proximity (sometimes within 1.0m) of existing buildings. Several construction options have to be explored for the earth retaining systems depending on the substrate and local conditions. The tunnels connecting the stations can be equally challenging especially when they encounter major utilities or traverse below existing buildings. Some typical situations encountered and the engineering solutions that were evolved will be discussed in this Paper.

Keywords: Secant Pile; Guide wall; Tunnel; Underground Metro; Concrete Decking; Trench cutter; Struts; Rock Anchors; Temporary utility.

ID-717

Construction of 4-lanes Signature Bridge between Okha and Beyt Dwarka in Gujarat State

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Abstract

Government of India, Ministry of Road Transport and Highways is constructing a 4 lane Signature Bridge connecting missing link between Okha and Beyt Dwarka on EPC mode including construction of approaches on new NH 51 in the state of Gujarat. **Beyt Dwarka,** located on the western coast of India is famous for its archaeological, historical and spiritual importance and is better known as **Dwarkadhish Temple.** However, the **Beyt Dwarka** is inaccessible by road being an island and **Dwarka** is located near port **Okha**, which is an all-weather minor port. The people from all over the country and from outside visit this pilgrim place and they have to use the passenger ferry service operated by Gujarat Maritime Board near **Okha** port to reach this Island.

To obviate this problem, The Government of Gujarat has decided to join Beyt Dwarka by land by providing a bridge from Okha to Beyt Dwarka. Ministry of Road Transport and Highways has awarded the project to S.P. Singla Constructions Pvt. Ltd. The bridge is meant to provide direct road connectivity from Okha to Beyt Dwarka and provides pedestrian lane also so that pilgrims coming to Beyt Dwarka on foot can avail this bridge.

The Signature Bridge connecting Okha port and Beyt Dwarka is 2320 m long. A length of 900 m long three span cable-stayed bridge is provided in the central portion of Signature Bridge having main span of 500 m (main navigation span) with side spans of 200m each. Pylons for cable stayed bridge are constructed as modified A-shape and cable arrangement is semi-fan type and provided in two planes. Fig. 1 shows the elevation of the main cable stayed bridge. Vertical clearance of 18 m is provided below navigation span as per coast guard requirement. For remaining portion of the bridge, span length is kept 50 m and minimum vertical clearance above HTL is provided as per relevant IRC code. Approach roads of 2.452 km length (1 .241 km on Okha side and 1.211 km on Beyt Dwarka Side) are developed as a four-lane divided carriageway highway along the project stretch. The bridge is in advanced stage of construction and is expected to be completed by October 2023.

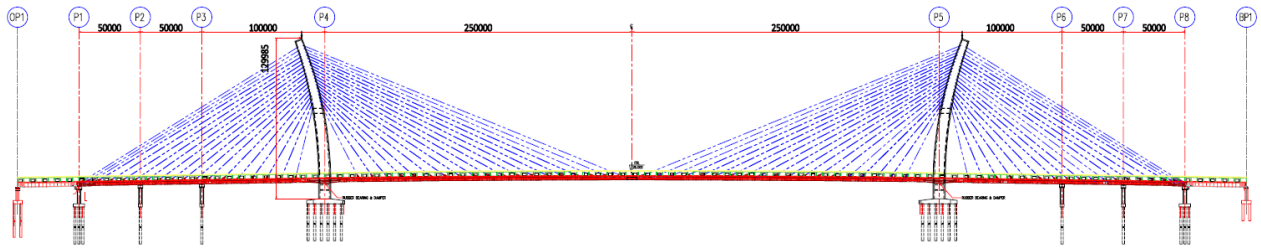


Fig. 1 Elevation of Cable Stayed Bridge

The 27.2m wide bridge deck comprises of 4 lane vehicular carriageway (9.5m + 9.5m) with a central median of 1.2 m & two separate corridors of 2.5 m clear width each for golf cart/cycle track/pedestrian walkway respectively as shown in Fig. 2 below.

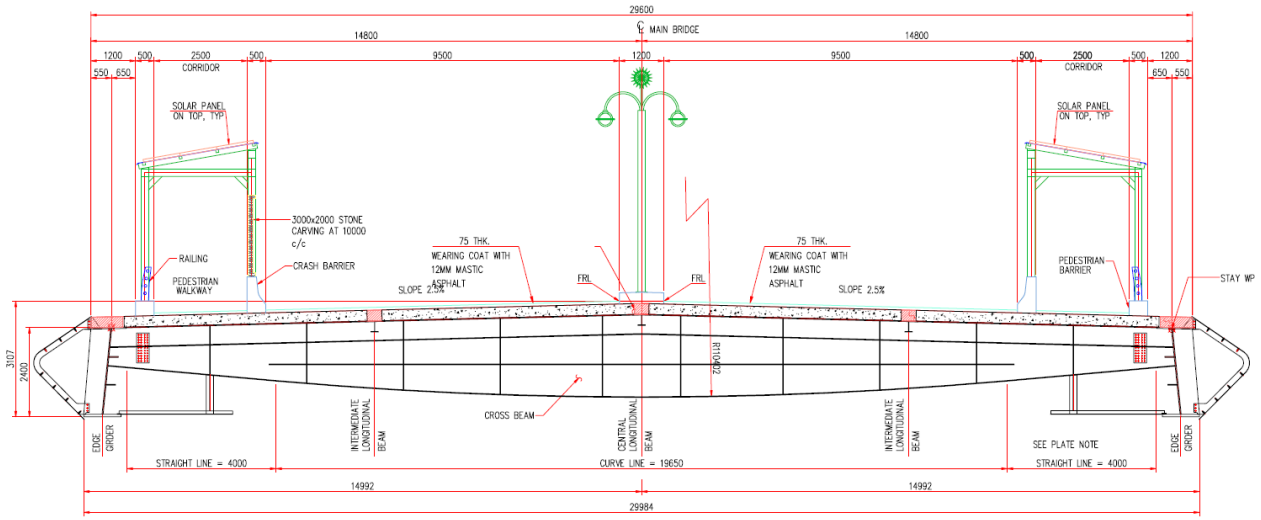


Fig.2 Superstructure Deck Cross section -Main Cable Stayed Bridge

Constructing this bridge over a sea creek posed several challenges which include Casting of Pile caps of size 29m x 18.5m x 4m, transportation of 12m long steel segments each weighing 90 to 100 t from fabrication yard located 1550 km from the site, transportation of segments and transit mixers on large size barges, high wind speed, tidal variations and disruption of work due to COVID-19 pandemic.

This paper describes the salient features of the bridge, construction methodology adopted and the challenges faced.

Keywords: Piles; pile foundation; pylon; steel deck; stay cables; stressing; erection traveller

ID-1146

83.92 m Wide Rail Over Bridge – Chipiyana, Gautam Buddha Nagar, UP, India

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The paper deals with the planning, design & construction of the widest Rail Over Bridge (ROB) at Railway Km. 1429/6-8 between Ghaziabad & Maripat Railway Station on NH-24 at km. 20+213 at Chipiyana, Gautam Buddha Nagar, Uttar Pradesh, India. This ROB is a part of package-II of India's widest, 96 km long, access-controlled Delhi-Meerut Expressway (DME). There is an existing ROB of width 23 m & 60° skew to the main expressway alignment. To provide additional lanes of expressway, new bridges are constructed on the left and right sides of existing ROB. The ROB comprises four new carriageways viz. 15 m & 9 m wide for LHS & RHS traffic of NH-24 & DME respectively at around skew angle of 60° with existing railway tracks. The LHS carriageway of NH-24 is supported by two spans i.e. 10 m in RCC Solid Slab and 115 m in Steel Truss (Pratt-Type) and the LHS carriageway of DME is supported by two spans of 21,725 m & 74,41 m in Steel Concrete Composite (SCC) while RHS carriageway of both NH-24 & DME is supported by two spans of 22.101 m & 66.375 m in SCC. The SCC spans are having a skew angle of around 60° with the existing railway tracks. The Superstructures are supported on Spherical Bearings having a design service life of not less than 50 years which in turn rest on multiple legs (depending upon the width of the structure) portal frame type Substructure. The foundation system comprises multiple numbers of 1,0 m diameter bored cast-in-situ piles of length 21m connected by the rigid pile cap. The maximum safe load on a pile is 320 t verified by the independent pile load test.

As per the Contract Agreement, this new ROB was proposed after dismantling of 23m wide existing ROB at this location having a span configuration of 20 m + 60 m + 25 m at a skew angle of 60,81° with different widths of 20,5 m for LHS carriageway of NH-24, 34 m for LHS/RHS carriageway of both NH-24 & DME and another 20,5m for RHS carriageways of NH-24. But at the site, as per the actual survey of the spans suggested above was not in line with the existing railway tracks leading to the present span configuration mentioned in paragraph '1' above.

The analysis of the various structural components is carried out using STAAD.Pro & In-House Excel Sheets and the design forces such as SF, Torsion and BM in both SLS/ULS using the load combinations as per IRC:6 were calculated at various sections and the design has been carried out using the design principles of IRC: 112 for RCC and IRC: 22 & 24 for SCC & Steel.

The construction of each structural component was implemented at the site with utmost safety and precaution due to the proximity of the busy existing railway tracks. The erection of the Steel Girders assembly (Two Girders braced together) was carried out by the cranes after transporting the girders from the fabrication yard using mutli-axle trailer. Also in the case of the Steel Truss, various members were fabricated at the fabrication yard & assembled at the site forming a giant 2185 t, 115 m Long Steel Truss. The connections of Steel members were done using High Strength Friction Grip Bolts & welding.

The existence of 4 railway tracks in addition to 1 future track along with the High Tension electrical cabin itself challenges the construction of the substructure & foundation as well as the erection of the superstructure. At this particular Bridge location, the Ganga Jal pileline was also laid which leads to the non-standard foundation shape resulting in the specialized design & additionally limits the reduced level of pile cap bottom to about 260 mm above it. The challenging aspect of the construction is the erection of 65 m long steel girder between P1-RHS & A2-RHS. As the length of

the assembly (comprises of two girders braced together) was too high needed two cranes for lifting it from the ground. The limited space available between the abutment A1-RHS and pier P1-RHS posed a challenge for the second crane to lift the other end of the steel girder assembly. As a result, an 11 m long launching nose was added to the assembly of longitudinal girders to be erected at their respective location. The launching nose allowed for a longer lifting point, which allowed the second crane to lift the other end of the entire assembly from the approach side of the abutment A1-RHS, despite the limited space available behind pier P1-RHS. The addition of a launching nose to the assembly of longitudinal girders was a smart engineering solution to overcome the space constraint issue and complete the lifting operation safely and efficiently.

The launching of a 115 m long Steel Truss at their respective location posed another challenge during the construction of this project. Initially, the plan was to launch the steel truss using the Cantilever Auto Launching technique with an additional launching nose attached to it. However, the Railway Authority instructed that only a block period of around 2 hours a day could be allocated for the Auto Launching over the existing railway tracks. This meant that the cantilever part of the launching assembly could not be hung over the existing tracks all day during the period of launching. To overcome this challenge, it was suggested to erect a separate assembly (beam) along the direction of auto launching, taking support from the columns proposed in between the tracks at frequent intervals. These columns are resting on massive RCC foundations. This solution demonstrates the importance of flexibility and adaptability in construction projects.

Initial conceptualization of this unique structural scheme and planning for execution above the busy existing railway tracks were only possible with effective communication and collaboration among project stakeholders for successful project completion. Moreover, the construction of this new ROB achieved an important milestone in sustainability by repurposing the existing ROB, which is now serving as one of the carriageways of the "Delhi-Meerut Expressway."

Keywords: DME; ROB; Existing Railway Tracks; Steel Truss (Pratt Type); Steel Concrete Composite (SCC); Profile Sheet; HSFG Bolts; Sustainability; Planning, Design & Construction.



Figure 1. Bird Eye View of ROB

ID-1227

Optimal Solution for Shallow Tunnel at Dwarka Expressway

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1 Introduction

As part of Development Plan 2031 of Gurgaon Manesar Urban Complex (GMUC), Dwarka Expressway also known as Northern Peripheral Road (NPR) was proposed to be developed as northern ring road thereby providing additional connectivity between Gurgaon and Delhi apart from NH 8, Old Delhi Road, and MG Road. The entire expressway is divided into 4 parts based on homogeneous sections. Out of them, Dwarka Expressway Package I starts from Shiv Murti, NH8 and ends near RUB at Sector 21, Dwarka. It is expected to serve more than 1,60,000 annual average daily traffic in the next 20 years of design period. The entire package length is 5.9kms out of which, the main expressway is an eight-lane divided road of structure type “Shallow Tunnel”. The entire Package I is aligned parallel to New Delhi Airport and as such AAI had objections to elevated corridor in this zone. This led to the proposal of Shallow Tunnel in this stretch. Shallow tunnels are underground structures where finished road levels are at a shallow depth (10-15m) from the ground level. This tunnel once completed will be one of its kind in India because its large span and parallel movement of traffic over the tunnel.

2 Salient feature of shallow tunnel

Total length of the shallow tunnel is 3.6km. Clear width varies from 36m (this includes 14m carriageway+1.5m paved shoulder+1.25m drain cum footpath+0.5mshyness cum edge strip+.75m walkway/crash barrier on either sides) to 43, height of shallow tunnel is 7m (5.5m clear+1.5m for ventilation and other utilities).

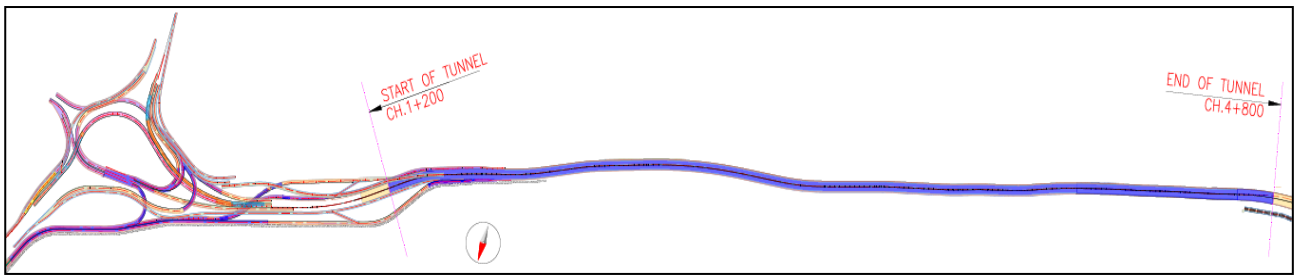


Figure 1. Key plan of shallow underpass MC10

3 Typical cross section as per tender drawings.

The cross section of MC-10 as per the tender document was a twin cell box. The proposal included two outer diaphragm walls, one central diaphragm wall with 1000mm diameter piers at 3000mm c/c. The central piers were proposed to support an inverted T beam, which supports the deck of structure. The bottom raft was proposed to be integrated with diaphragm wall. The deck was proposed as precast prestressed voided slab with 1000x800mm planks and 200mm thick cast in situ slab over it.

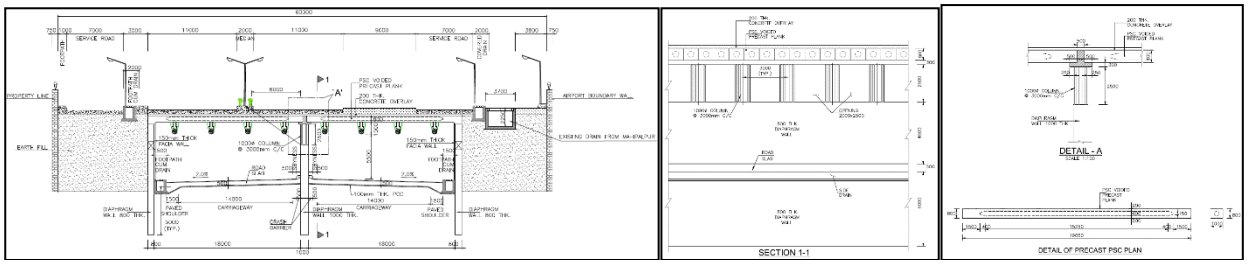


Figure 2. Typical cross section as per tender

4 Construction sequence as per tender drawings

As per tender construction sequence, the construction was to be initiated with the formation of an outer and internal diaphragm wall. Following this, excavation work was to be undertaken, and raft foundation was to be constructed. Subsequently, the deck, which forms the upper surface of the tunnel, was proposed to be completed. Upon the successful completion of this first cell, traffic was to be diverted to utilize this segment of the tunnel. Next, the construction process was to be replicated for the second cell of the shallow tunnel. Another outer diaphragm wall was proposed to be casted and the subsequent steps of excavation, raft construction, and deck completion were planned as per tender.

5 Typical cross section used in detail design.

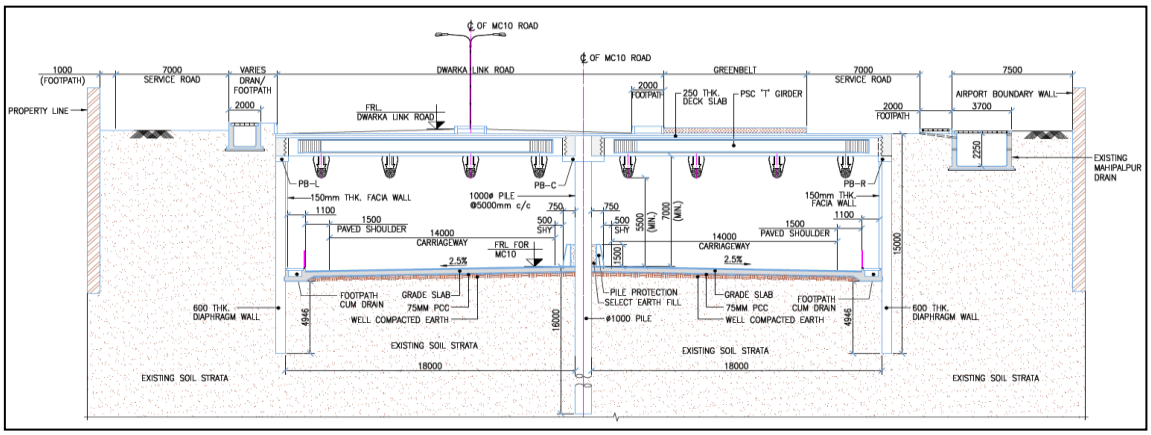


Figure 3. Typical cross section used in detail design.

During detailed design, Structural system was modified from tender drawings as shown in Fig 3. Internal diaphragm wall was replaced with 1000mm pile with spacing of 5m. Embedment length of pile is 16m as per capacity requirement. Bottom slab is connected to diaphragm wall with hinge connection at interface. Precast pretensioned T-girders (1350mm depth) with 150mm thick cast in situ slab are proposed at spacing of 2.5m.

6 Proposed construction sequence in detail design

During detailed design various options were worked out to optimise the concrete & reinforcement consumption for structure. It was identified that major component of quantity for concrete and reinforcement were concentrated in the diaphragm wall both outer as well as central. The detailed design for both central and outer diaphragm was governed by the significant forces during the construction stages as per tender drawing. To optimise the quantities the focus was to identify alternate construction sequence. The construction sequence was modified by replacing central piers along with D-wall as per tender with central piles of 1000mm Dia spaced at 5.0m center to center. Also, the excavation for shallow tunnel underneath the deck was proposed to be started after the deck/superstructure for both carriageways had been erected as shown in Fig 3

7 Analysis and design:

For shallow tunnel proposed construction sequence plays an important role in analysis and design. Detailed construction stage analysis has been performed for the structural frame including all construction stages in Sofistik FEA software. Soil structure interaction has been considered in analysis since deformation in structural elements (diaphragm wall and piles) and resistance offered by adjacent soil are interdependent. A 30-meter-long finite element model is developed for detailed analysis.

8 Conclusion

The sustainability assessment of the Shallow Tunnel project has provided valuable insights into enhancing the environmental and resource-efficiency aspects of infrastructure development. By evaluating the project's construction sequence optimization, we have observed significant material savings, contributing to its overall sustainability.

The adoption of a top-down construction approach, as opposed to bottom-up method, has proven to be a game-changer in reducing the sway effect and minimizing design forces. This reduction has led to decreased section requirements, directly resulting in substantial savings in construction materials. Such material conservation not only translates to cost-effectiveness but also aligns with environmentally responsible practices by reducing the project's carbon footprint. As infrastructure development continues to play a pivotal role in shaping our urban landscape, the lessons learned from this assessment can be applied to future projects, promoting a holistic and responsible approach to infrastructure development.

9 References

[1] John Orr, Orlando Gibbons and Will Arnold, (2020) ‘A brief guide to calculating embodied carbon’, IstructE Journal, Structural Engineer, July 2020

[2] IRC: 6-2017 - Standard Specifications and Code of Practice for Road Bridges, Section-II Loads and Load Combinations (Seventh Revision)

[3] Draft feasibility report including schedules to the concession agreement Dwarka expressway (NH 248-BB) Package - 1 (Km - 0+600 to Km 5+300) Volume III : Technical Schedules, April 2018

[4] Draft feasibility report including schedules to the concession agreement Dwarka expressway (NH 248-BB) Package -1 (km - 0.600 to km 5+300) from Shiv murti (Dwarka link road-NH 8 intersection) to railway under bridge (RUB) near Sector 21 Dwarka Volume IV: Drawings April, 2018

[5] CIRIA Report 143 The standard penetration Test (SPT): Methods and Use.

[6] CIRIA C580: Embedded Retaining walls-Guidance for economic design.

Session 21

Analysis, Research and Standardisation

ID-254

Comparative Study of the Statistical Methods of Fragility Curve Generation

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Fragility function is defined as the graphical representation using the curves to express the occurrence of undesirable event as a function of some measure. The common form of seismic fragility function is Log-normal Cumulative Distribution function (CDF). The main objective of the study is to develop the best method to find the value of mean and the standard deviation which gives minimum deviation to that of real observed Cumulative Probability Density (CPD).

The data for the formulation of the curves has been taken from [1]***VULNERABILITY ASSESSMENT OF MRT 205:1994 BUILDING***, a thesis by Roshan Shilpakar, Regd.: 035-3-3-02638-2013, Purwanchal University[i]. This study shows the reliability of "Minimum Difference Method" in comparisons to the others existing methods i.e. Efficient analytical fragility function fitting suggested by Jack W. Baker and Creating Fragility Functions for Performance-Based Earthquake Engineering by Keith Porter.

The study done in the thesis, has taken a typical frame complying with the Mandatory Rule of Thumbs [2]with 4 conditions of in-fills. The building has been excited with 20 different ground motions and inter-storey drifts, as suggested by T. Rossetto [3], has been analysed.

This paper has proposed a simpler method of "Minimum Difference". The equation of Log-normal CPD is;

$$CPD = \int_0^x \frac{\exp\left[-\frac{(\ln(x)-\mu)^2}{2\sigma^2}\right]}{x\,\sigma\sqrt{2\pi}}$$

A set of random "Mean (μ) and Standard Deviation (σ)" is assumed and the Log-normal CPDs of these 'g's are calculated using the Python© code, which is the numerical integration of the above equation , from 0.0 to the value x (x represents a value of 'g').

The Mean (μ) and Standard Deviation (σ) are varied with very small number DeltaV1 and DeltaV2 respectively by four ways;

(i) Myu+DeltaV1, Sigma +DeltaV2

(ii) Myu+DeltaV1, Sigma -DeltaV2

(iii) Myu-DeltaV1, Sigma +DeltaV2

(iv) Myu-DeltaV1, Sigma -DeltaV2

Using these 4 sets of μ and σ, corresponding 4 sum of square of the difference of observed CPDs and calculated CPDs, are calculated using the code done in Python.

It can be graphically represented as shown below.

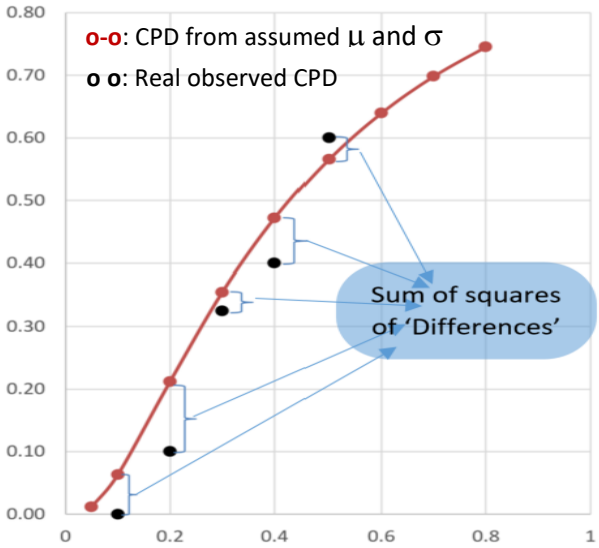


Figure 20. Concept of Residue

The 'Sum of Squares of Differences' is considered to be 'Residue'. Among 4 new μs and σs, the one with the minimum Residue is taken as the new 'μ and σ' for new trail.

This whole process of varying the Myu and Sigma, in 4 possible ways and finding new 'Myu and Sigma', is repeated until the value of newly calculated minimum 'Residue' becomes greater than the previously calculated 'Residue'. At that point, the set of Myu and Sigma is considered as the Sigma and Myu of the best fit CPD curve. This method has been applied and tested using Python[(c)] codes.

Conclusions

The deviation of CPDs calculated from two existing methods and the proposed method have been compared. An example of comparison, of Bare-Frame Mild Damage is represented graphically as *(O:Observed, J:JW Baker, K:K Porter and the P:Proposed methods)*

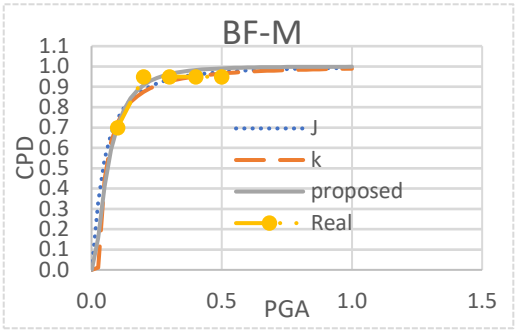


Figure 2. CPDs from different methods

The sum of square of differences of CPD obtained between the one of the methods and observed CPD, has been calculated for the comparison and it is found to be as tabulated below.

Table1 : Comparison of deviation from observed

	Square of Deviation		
PGA	$(J-O)^2$	$(K-O)^2$	$(P-O)^2$
0.1	0.002032	0.007011	0.000106
0.2	0.004144	0.003196	0.001680
0.3	0.000196	0.000224	0.000179
0.4	0.000096	0.000035	0.001075
0.5	0.000519	0.000328	0.001682
	0.006986	0.010794	0.004723

Like shown above, the deviation, measured as 'sum of square of differences' is the minimum from the proposed method in all the 6 cases damages.R. Shilpakar, "SEISMIC VULNERABILITY ASSESSMENT OF MRT 205:1994 BUILDING," Purwanchal University, Nepal, 2019.

[1] "MANDATORY RULES OF THUMB REINFORCED CONCRETE BUILDINGS WITHOUT MASONRY INFILL," Ministry of Physical Planning and Works,Government of Nepal, Babar Mahal, Kathmandu, NEPAL, 1994.

[2] A. E. T Rossetto, "Derivation of vulnerability functions for European-type RC structures based on observational data," *Engineering structures,* vol. 25, no. 10, pp. 1241-1263, 2003.

[3] R.P.Kennedy and M.K.Ravindra, "Seismic fragilities for nuclear power plant risk studies," *Nuclear Engineering and Design,* vol. 79, no. 1, pp. 47-68, 1984.

[4] Cornell and Vamvatsikos, "Applied incremental dynamic analysis," *Earthq Spectra 20,* vol. 2, pp. 523-553, 2004.

[5] K. Porter, R. Kennedy and R. Becham, "Creating Fragility Functions for Performance-Based Earthquake Engineering," *Earthquake Spectra,* vol. 23, no. 2, pp. 471-489, 2007.

[6] J. W. Baker, "Efficient Analytical Fragility Function Fitting Using Dynamic Structural Analysis," *Earthquake Spectra,* vol. 31, no. 1, p. 579–599, 2015.

ID-256

An Evaluation of Human Bouncing Force Excitation

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Abstract

The increase in the structural material strength such as the yield strength of steel, optimized methods of analysis and design, and the popularity of open-space floor plans have resulted in numerous cases of excessive floor vibrations due to human movements. This so-called 'vibration serviceability phenomenon' is even more common when people engage in rhythmic activities on dance floors, at fitness clubs, grandstands, or balconies overlooking performance stages. It is important that the structural engineer can provide a reasonable prediction of floor dynamic response when subjected to such excitations as the use of safety factors in vibration serviceability analysis results in significant over-conservatism in the design and unnecessary use of construction materials, which would be against the sustainability idea in structural design. This requires a reliable definition of bounce-forcing functions. A bounce is defined as a rhythmic human movement in which the person does not lift his/her feet from the floor while engaging in body motions. Such activity generally occurs when dancing or aerobics. This paper presents a study of bounce ground reaction force (GRF) using the results of a series of tests conducted by a group of volunteers on a force platform at different bounce frequencies. A Fourier series analysis was conducted from which the dynamic load factors (DLF) and their associated phase angles were computed from the obtained Fourier coefficients. Considering 75% and 95% exceedance of a specific DLF harmonic to represent different conservatism levels, a surface fit of the measured forcing functions for different bounce frequencies was conducted and closed-form equations were developed. Using the developed bounce forcing function equations, closed-form equations were obtained for the DLF which were compared with the results of the direct linear regression analysis of the DLF assuming a Gaussian Distribution and the 75% and 95% exceedance levels. This showed that the former approach is more conservative for all the DLF harmonics except for the second harmonic.

ID-330

Analysis of A Cross-Section of a Steel-Concrete Composite Beam

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Abstract

Steel-concrete composite bridges with encased continuous shear connectors are constructions in which the basic mechanical advantages of both materials are effectively used. The cross-section of a steel-concrete composite short-span road bridges is usually of rectangular shape. This paper presents an analysis of such cross-section in order to adjust the ratio and amount of material to make it more environmentally friendly and economic and therefore sustainable. It compares the analytical as well as experimental resistance and displacement of a rectangular and lightened beam cross-section with regards to the amount of materials used.

Keywords: steel-concrete composite, composite bridge, steel-concrete, shear connector

1 Introduction

Research of composite steel-concrete bridges has been ongoing since the 80s of the last century. Most of the research focus has been on the development of continuous shear connectors and overall improvement of the longitudinal shear connection. Different types, such as perforated strips **Error! Reference source not found.**, dowels REF _Ref132464341 \r \h **Error! Reference source not found.**, truss **Error! Reference source not found.**, trapezoids **Error! Reference source not found.** and Y-shaped **Error! Reference source not found.** connectors have been proposed.

The typical cross-section of the short-span steel-concrete composite bridge is in a shape of a rectangle, or, for longer spans, the T-shape cross-section can be used. In Europe, the PrecoBeam beams (see **Error! Reference source not found.**) h ave been a popular steel-concrete composite solution for short to middle span bridges **Error! R eference source not found.**.

When constructing short-span bridges, the rectangle shape does seem as the simplest solution. However, if the prefabrication is considered, other solutions could be considered. Such solutions could bring a significant decrease in mass and weight as well as cost reductions, which would make it more sustainable.

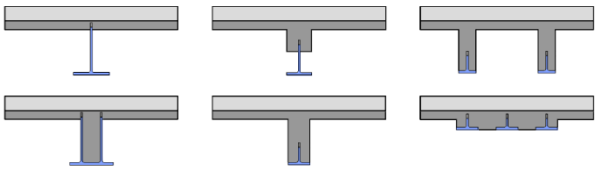


*Figure 21 PrecoBeam steel-concrete composite cross-sections **Error! Reference source not found.***

This paper deals with the following research questions:

a) Could the cross-section of the steel-concrete composite beams be reduced in order to save material?
b) Would the reduction in material influence the beam resistance?

Several laboratory tests (four-point flexural tests), material property tests have been performed, as well as theoretical analysis considering the effect on the position of the plastic neutral axis and the

flexural resistance of the beam were investigated in order to answer these questions.

2 Acknowledgement

The paper has been supported by the projects: VEGA 1/0172/20 'Stress and deformation analysis of load bearing components made out of steel, glass and composite materials' of the Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences and by the project Slovak Research and Development Agency under the contract No. APVV-15-0486 'Analysis of Shear Connection Influence in Bridges with Encased Beams'.

3 References

[1] Da. C. Vianna, J., De Andrade, S. A. L., Da, P. C. G., & Costa-Neves, L. F. (2013). Experimental study of Perfobond shear connectors in composite construction. Journal of Constructional Steel Research, 81, 62–75.

[2] Lorenc, W. (2020). Composite dowels: The way to the new forms of steel-concrete composite structures. IABSE Symposium, Wroclaw 2020: Synergy of Culture and Civil Engineering - History and Challenges, Report, 98–138.

[3] Bezerra, L. M., Barbosa, W. C. S., Bonilla, J., & Cavalcante, O. R. O. (2018). Truss-type shear connector for composite steel-concrete beams. Construction and Building Materials, 167, 757–767.

[4] Németh, Gábor; Kovács, N. (2021). Experimental and numerical investigations on steel-concrete interaction of embedded corrugated. Ce/Papers, 4, 558–563.

[5] Kim, K. S., Han, O., Gombosuren, M., & Kim, S. H. (2019). Numerical simulation of Y-type perfobond rib shear connectors using finite element analysis. Steel and Composite Structures, 31(1), 53–67.

[6] Seidl, G., Viefhues, E., Berthellemy, J., Mangerig, I., Wagner, R., Lorenc, W., Kożuch, M., Franssen, J. M., Janssen, D., Ikäheimonen, J., & Lundmark, R. (2013). Prefabricated enduring composite beams based on innovative shear transmission. In Economical Bridge Solutions Based on Innovative Composite Dowels and Integrated Abutments: Ecobridge.

ID-340

The usage of Polymer-based materials in Civil Engineering

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Abstract

This paper aims to show the advantages and disadvantages of the usage of polymer materials. The properties will be demonstrated in the experiment designed in the Laboratory of Excellent Research at the Technical University of Kosice, which cooperates with the faculty of civil engineering. Materials based on polymers are often used in the world, for example in mechanical engineering, aeroplanes structures, prosthetic medicine, etcetera. The effective adoption of polymer materials in civil engineering is important. These materials have properties such as corrosion and humidity resistance, and flexibility, while at the same time maintaining their physical form. They can provide all this at 10% of the weight compared to steel.

Keywords: FRP material, composite bridges, corrosion resistance, GFRP concrete bridge.

1 Introduction

This article will address the advantages and disadvantages of FRP materials in construction. Based on some facts gathered from previous research at the Centre for Research and Innovation in Construction, the characteristics and behaviour of FRP materials in civil engineering were identified. This article will show some of the results of the research as well as a comparison with steel.

2 FRP materials and their characteristics

The abovementioned FRP materials have different uses and types, but their price varies according to the fibres used and the composites' production type.

2.1 Fibres in FRP Materials

Figure 22: Types of fibres in FRP materials

2.2 Methods of Manufacturing the FRP Materials

Several technologies and techniques are used to produce composite materials. To achieve sufficient quality and a high level of mechanical and physical characteristics, it is necessary to choose the right technology and preparation. Manufacturing technologies and processes shall be developed in such a way as to be suitable for both laboratory and industrial environments.

2.3 Matrix of FRP materials

In addition to the fibres themselves, an important component of composite materials is the matrix, which is its reinforcing material. May be of metal, polymer, or ceramic type. Currently, the most used polymer matrix is suitable for temperatures of 120 ° C. Metal and ceramic matrices, which can be used up to 1200 ° C, are preferable for higher temperatures.

3 Usage of FRP materials in Civil engineering

In construction, the use of composite matrices is relatively limited and does not find its place in such a progression as in other sectors. At present, several structural elements are produced from FRP materials which replace or supplement commonly used materials such as steel.

3.1 Advantages of FRP materials

- The low weight
- The high strength
- Fatigue resistance
- Resistance to corrosion
- Resistance to electromagnetic

3.2 Disadvantages of FRP materials

- Anisotropy
- The production
- The fire resistance
- The price

4 Conclusions

This article describes in detail the manufacturing procedures, materials, material characteristics, advantages, and disadvantages as well as the demonstration of the acquired knowledge in a specific laboratory experiment. The conclusion of this article is therefore that composite materials constitute a future sustainable substitute for steel in the construction industry, but the development of these materials is not progressing sufficiently.

5 Acknowledgement

The presented paper was supported by the project: VEGA 1/0172/20 “Stress and deformation analysis of load-bearing components made out of steel, glass and composite materials” of the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic.

6 References

[1] Hass, R.; Meyer-Ottens, C.; Richter, E. (1993) Stahlbau-Brandschutz-Handbuch. Berlin: Ernst & Sohn.

[2] Haenel, J.; Kina, J.; Schaumann, P. (1994) Zur Erweiterung des Anwendungsbereiches von Stahlträgerverbundkonstruktionen. Stahlbau **63**, H. 4, pp. 279–283.

[3] EHRENSTEIN, G. W. Polymerní kompozitní materiály. Praha : Scientia, 2009. ISBN 978-80-86960-29-6.

[4] JANG, B. Z. Advanced Polymer Composites: Principles and Applications. ASM International : Materials Park, 1994.

[5] HOSFRORD, W. F. Mechanical Behavior of Materials. USA: Cambridge University Press, 2005. ISBN 978-0-521-84670-7.

[6] ROVŇÁK, M., ĎURICOVÁ A., KUNDRÁT K. a NAĎ Ľ. Spriahnuté oceľovo-betónové mosty. Košice : Elfa s.r.o., 2006. ISBN 80-8073-485-2.

[7] J. da. C. Vianna, S.A.L. de Andrade, P.C.G. da S. Vellasco, L.F. Costa-Neves, Experimental study of Perfobond shear connectors in composite construction, Journal of Constructional Steel Research, Volume 81, 2013, Pages 62-75, ISSN 0143-974X, https://doi.org/10.1016/j.jcsr.2012.11.002.

[8] K.P. Shaik, D.K. Vaddi, and R.R. Bsv, Experimental Investigation of Glass Fibre Reinforced Polymer Laminates (SCHOLARS' PRESS, Beau Bassin, Mauritius, 2020).

ID-386

The Smart FRP Panel for Bridge Redecking – Development and Experimental Validation of "Panel – Panel" and "Panel – Girder" Connections

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Abstract

The paper presents the smart FRP deck system, called Optideck, which was developed as a sandwich panel in which the core is ribbed by a vertical laminates forming a honeycomb structure. The panel is equipped with distributed fibre optic sensors for structural health monitoring. The sensors are built into the panel during the infusion process and fully integrated with the structure. Taking into account the design and transport constraints, the final parts of the deck slab have to be connected longitudinally or transversely on site, which is quite a challenge due to the irregular form of the ribbed core. The panel has to be also efficiently attached to the main girders of the bridge. The paper presents the stages of creating the concept of panel-panel and panel-concrete and steel girder connections, their design, production of prototypes and finally their static and fatigue tests in the laboratory. The conclusions drawn from the individual stages led to the selection of the best solution and its use in the future in the final deck panels.

Keywords: FRP deck, glass fibres, distributed fibre optic sensors (DFOS), connections, FE analysis, adhesive, anchors, panel, concrete, steel.

1 Introduction

The deteriorating technical condition of existing bridges and increasing live loads force engineers to look for new solutions in the field of bridge decks. FRP bridge decks, thanks to their high load-bearing capacity, lightweight and durability can be a remedy for this problem. Few dozen basic composite FRP deck systems have been developed in the world, which are used both for the construction of new as well as reconstruction and renovation of existing bridges. Crucial part of the FRP deck are connections between panels divided into shipping elements and panels between main bridge girders. These connections must ensure proper load transfer, flexural, shear, compressive capacity and composite action with girder.

2 Optideck system

The designed FRP panels are consisted with outer laminates and vertical ribs filled with the foam (PUR) cores. It was decided to use a sandwich panel with rigid and flat external laminates. They are separated by a ribbed core made of PVC foam. The stiffening of the core was made in the form of a honeycomb made simultaneously with the outer laminates during infusion process (Fig. 1).

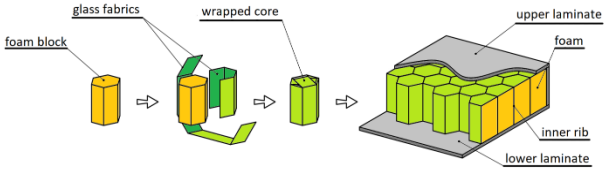


Figure 23. Concept of construction of a deck panel with full foam core and honeycomb ribbing

3 Conceptual design

The concepts of all connections analysed during the research (panel-panel, panel-concrete and panel-steel girder) have been developed in two variants, differing in the structure of the connection and the materials used. Panel-panel connections (Fig. 2) were designed as a tongue and groove adhesive connection (PP-W1) and connection with the use of filling mortar (PP-W2).

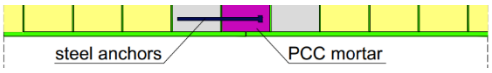


Figure 24. Panel-panel connections: PP-W1 (top) and PP-W2 (bottom)

Panel-concrete girder connections (Fig. 3) were designed as mechanical-bonded connection (PB-W1) and mechanical connection (PB-W2).



Figure 25. Panel-concrete girder connections: PB-W1 (left) and PB-W2 (right)

Panel-steel girder connections (Fig. 4) were designed as mechanical-bonded connection (PS-W1) and connection with the use of steel studs and filling mortar (PS-W2).



Figure 26. Panel-steel girder connections: PS-W1 (left) and PS-W2 (right)

4 Experimental tests

Panel-panel connections tests were carried out in three load schemes: four-point bending, shear and compression. The tests of panel-girder connections were carried out under shear load.

In case of flexural and shear load-bearing capacity of the PP-W1 connection was over 3 times higher than PP-W2, under compression failure modes were similar but mean loads of PP-W1 was 27% higher. In terms of the load capacity, values for both variants od panel-concrete connection were similar. Differences were observed in the behaviour of both connections under load. In the case of PB-W2, higher values of vertical displacements were measured in relation to PB-W1. The mean failure load of PS-W2 was 39% higher compared to PS-W1. Moreover, the variability of results for PS-W2 was much lower (2.6% vs. 14.2%).



Figure 27. Failure modes of the connections

5 Conclusions

Based on the experimental investigation one variant of each type of connection was selected for further fatigue tests and for use in the panel prototype analysed in next stages of the project. In the case of panel-panel connections, variant 1 (PP-W1) with tongue and groove adhesive joint was selected, for panel-concrete girder connection, also variant 1 (PB-W1) with mechanical-bonded joint was chosen and in the case of the panel-steel girder connection, variant 2 (PS-W2) with the use of steel studs and filling mortar was selected.

Selected variants of each connection were built into this prototype and has undergone the final verification in the laboratory test.

ID-664

Influence of endurance of stud shear connectors on the reliability of steel-concrete superstructures of road bridges

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Abstract

The research considers the influence of fatigue failures of shear stud connectors on the overall reliability of steel-reinforced concrete superstructures. There are considered possible models of failures of the joint members and steel-reinforced concrete superstructures as a whole both for the First (Ultimate) Limit State (ULS) and for the Second (Serviceability) Limit State (SLS). There have been developed scenarios for excluding joint members from the operation of the superstructure and a list of basic scenarios and levels of their progress has been compiled. For five models of road bridges steel-reinforced concrete superstructures, there was conducted a numerical experiment to simulate the exclusion of joint members from the work of the structure. The calculation results for each scenario and scenario level are analyzed with regard to possible structural failures. There are also drawn conclusions about the risks of violating the normal operation of superstructures due to the exclusion of the joint members from operation.

Keywords: bridge, superstructure, steel-reinforced concrete, joint member, shear stud connector, reliability, failure, fatigue, endurance

1 Introduction

Reliability is one of the most important properties of road bridges due to their responsibility level and strategic importance for the transport system. Recent studies of world statistics show that there is an increasing trend in the collapse of operated bridges, including fatigue defects. A distinctive feature of the operating modes of bridge structures is the non-stationary dynamic loading mode. In such operating modes, the endurance of structural elements has significant influence on the formation of failure.

For the steel-reinforced concrete superstructures, one of the least studied is the question of the endurance of the joint members that connect steel beams and reinforced concrete slabs. The results of the field experiments performed by the authors of showed that the joint members of steel-reinforced concrete superstructures are actually in difficult operating conditions with a large number of stress strain behavior change cycles.

The failure of single joint members cannot lead to the destruction of the span structure. There were noted a number of cases of superstructure failures according to SLS criterions. Some of them are significant increase in structures sagging (from dead load) and deflections (from live load). The probable cause of that is a significant stiffness decrease or complete destruction of the joint members.

In this research, the authors conducted a study of the impact of possible joint members failures due to the accumulation of fatigue damage on the overall reliability of steel-reinforced concrete structures.

2 Methods

The study is performed under the hypothesis that the failure of a certain set of joint members (according to the FLS criterion) will cause the failure of the superstructure as a whole due to excessive deflections (according to the SLS criterion) or according to the strength condition (ULS criterion). The failure conditions for SLS are given in formula (1), for ULS – in formula (2). In current research the authors decided to consider the failure of the joint member according only to the FLS criterion.

$$K_{d,LL} = \frac{d_{LL,j}}{l_j} \geq [K_{d,LL}] = 1/400, \quad (1)$$

$$\sigma_{tot,j} \geq R_y, \quad (2)$$

where $d_{LL,j}$ is the maximum deflection in j span from the live load; l_j is the length of j span; $[K_{d,LL}]$ is the limit ratio, $\sigma_{tot,j}$ are the maximum normal stresses in superstructure steel beam in j span from full load; R_y is the design resistance of the steel.

For the analysis of superstructures, 5 FE models of bridge superstructures (4 of existing bridges in Russia and 1 from the Eurocode manual) were made in SOFiSTiK software, using the plate-rod construction method. The connection between plate and beams was modeled using elastic bonds. Such as it is obvious that the failure of one joint member is unlikely to seriously affect the rigidity of the superstructure, therefore, groups of elements were used to simulate failures. 3 main scenarios of superstructure failure were considered. 5 models of superstructures were analyzed for the impact of moving load A14, considering exclusion of element groups by 16 design combinations. According to the calculations results, the envelopes for maximum deflections and stresses were plotted for analysis.

3 Some results

Figures 1 show the distinct envelope curves of maximum and minimum displacements the beam B1 of the span structure №1 at the extreme levels of scenarios; Figure 2 shows diagrams of stress changes depending on the scenario level.

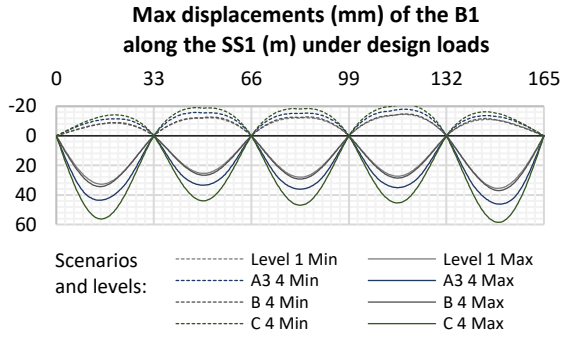


Figure 1 Envelope curves of maximum deflections from the live load for B1 SS1 at extreme levels of various scenarios.

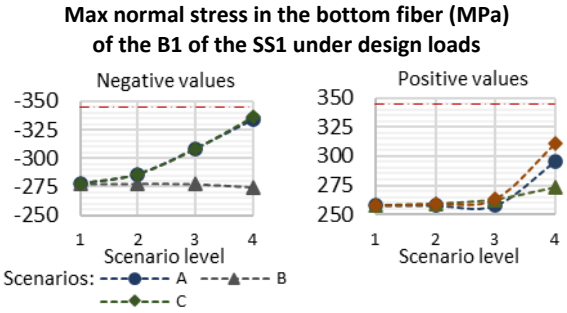


Figure 2 Diagrams of changes in normal stresses in the lower fiber of the beam B1 SS1 depending on the scenario level.

4 Conclusion

The analysis showed that for existing steel-reinforced concrete superstructures (based on a set of 5 objects), the risk of failure of superstructures in normal operation due to the joint members exclusion from operation is low, even with the almost incredible complete exclusion of all joint members from operation. Nevertheless, the joint members exclusion from the operation may be more critical in cases of non-standard operation of a bridge

Session 22

Digital Initiatives (BIM, Artificial Intelligence, 3D Printing)

ID-36

Integration of BIM in Bridge Management - Enhanced Predictive Functionality

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Abstract

Bridge Information Model [BrIM] is being evolved as a possible solution to become the one-stop solution for bridge design to management. Research is ongoing to present a concept of integrating BrIM as the front end or back end and incorporating functionalities of the Bridge Management System [BMS]. Such integration is envisaged to maximize the utilization of the core capabilities of both BrIM and BMS. Integration of BrIM and BMS will yield analytics essential for the prediction of deterioration models, risk analysis and prioritization and optimization of fund allocation. The use of 3D geometric models, Digital photography using photogrammetry software and Structural Health Monitoring to evaluate the performance of the bridge, have all resulted in enhanced capabilities, reliable prediction of deterioration models, and risk analysis based on a scientific approach. Integration of BrIM with BMS has resulted in enhanced sustainability and predictive functions.

Keywords: Unified Bridge Management System; Bridge Information Modelling (BrIM); Photogrammetry; Artificial Intelligence; Deterioration model.

1 Introduction

Ageing of bridges globally requires the maintenance of existing bridges to be prioritized. New bridge construction is more costly than maintaining an old bridge. Most of the current BMS's are based on 2D information. They do not utilize data related to shape, orientation, and geospatial information. This resulted in research on the integration of Bridge Management Systems [BMS] with bridge information modelling [BrIM] gaining importance. BrIM are the best tool to monitor a project from conceptualization to end of construction process. It is essential to provide more accurate and useful inventory representation beyond the alphanumeric representation in current bridge databases. BrIM will need enhancement to function as One Stop Solution for Bridges from Conceptualization to Demolition. BrIM enhancement will need data that is needed for bridge management systems. It should be noted here that, in addition to data on inspections and maintenance interventions, the digital representation of bridge elements during maintenance or improvement interventions is critical for bridge management.

Benefits of integrating BrIM and GABM: Improved accuracy, Improved visualization, efficiency, risk management, Real-time data analysis, reduced downtime, and increased lifespan of bridges.

Challenges in this integration: Data Integration, Data Quality, Standardization, Cost, Resistance to change, Skillset requirements, Privacy and security concerns.

Global Analytics for Bridge Management [GABM]:

During the inspection process, each bridge element is inspected by the bridge inspectors. Inspection yields an understanding of the behaviour of the bridge structure and enables to correlation various symptoms that are recorded. The inspector can draw his inference as to the probable cause of distress. Based on the prognosis of the deterioration process the inspector assigns ratings from 1 to 5 for various agents of distress. The matrix resulting from this is called the "Cause Matrix". Based on the assigned ratings primary

cause of distress is identified along with contributory secondary causes. Research has led to evolution of Cause matrix based on the symptoms. This innovation migrates from a symptom-based system to a Cause-based system. This is further evolved into a performance-based system. Performance observations will further enhance and fine-tune the cause-based evaluated results to account for the dynamics and real-time behaviour of the bridge structure. Once the primary and secondary causes are defined, it is important to determine the deterioration process over a period and extent. For correct estimation of the deterioration process, multiple performance observations are essentially compared to define the probability of a particular type of deterioration. Based on the deterioration process, estimates for the balance service life of the bridge are made. This provides a guideline for evaluation of the risk involved due to deterioration not being arrested. Structural behaviour is based on the location of loading and the reaction to the loading varies with any discontinuity in the section which also affects the response of the section.

Most of the current BMS are based on 2D information systems and do not utilize bridge maintenance data. The service life of a bridge, which is governed by safety and serviceability criteria, can be extended by regular maintenance and timely rehabilitation interventions. GABM implements deterioration models allowing condition forecasting, maintenance cost to estimate optimal maintenance interventions or scenarios. BrIM provide more accurate and useful inventory representation beyond the alphanumeric representation in current bridge databases. Focus of research is on the extension of the BrIM, to include historical bridge data. Cause matrix enables the determination of Deterioration model which yields risk estimates and further optimization of fund allocations. These are evolved within GABM using a 3D geometric model, Digital photogrammetry software and SHM. By monitoring the safety data of the bridge and analysing the maintenance status, can accurately understand the service status and service life of the bridge, distinguish the more damaged parts intuitively, and make timely and correct treatment.

The monitoring data collected by the system is transferred to the operation and maintenance management system in real-time to identify major structural damage and respond promptly. Bridge management needs to focus on optimising fund allocation to address the deteriorating condition of the bridges, ensuring that sustainability is maintained without compromising the area's economic potential. BrIM application studies for bridge maintenance include safety diagnosis, schedule management, visualization of historical information, maintenance decision-making, and efficient asset management. Currently, the inspection procedure also provides sufficient geometric data of various elements of the bridge to be used to generate a full scale-down 3D geometric model of the bridge. Based on the inspection data it is also possible to have a clear picture of the severity of distress in the element. This study aimed to establish a BrIM-based BMS for the sustainability of bridge maintenance based on the maintenance data schema and its information system, including detailed bridge information relating to diagnosis, maintenance, remaining life, and valuation in a usable data format. Detailed information in the data format of the BMS can improve the usability of information, ensuring cost-effective maintenance is available through connected activities such as proper decision-making. To achieve these goals, the Research provides the required information for inspection and maintenance and the integration of the BrIM in BMS to provide a possible solution by ensuring the Sustainability of bridge infrastructure which is kept in focus on all the Analytics tools it deploys. This ensures that Performance monitoring based on SHM is linked to the decision-making process within GABM. This combined with the resultant cause matrix offers reliability in the estimation of the deterioration model and further in the risk analysis and optimization of funds. Future scope involves the use of AI and machine learning to identify the critical elements of any bridge structure and then evaluate the level of distress in such elements based on the location of distress element [LODE] models. Research-based evolution will take time to create. Sufficient data from ongoing projects will assist machine learning and AI engines in being designed.

ID-212

Restructuring Construction Thinking for Urban Material Reuse

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Abstract

Construction and demolition waste (CDW) is a significant contributor to global waste. CDW accounts for nearly 1/3 of the total waste worldwide. Much of this is concrete, brick, and wood and is disposed in landfills or incinerated, resulting in environmental pollution and greenhouse gas emissions. Upcycling CDW is increasingly important for a sustainable waste management approach. Digitalization can play a significant role in promoting reuse of construction waste by enabling effective and efficient tracking, sorting, and processing of materials, through Building Information Modeling (BIM). BIM can help identify reusable components and provide real-time data on the quantity and quality of materials available for reuse. This paper proposes the architecture of a digital platform to facilitate the CDW upcycling by connecting construction companies, material suppliers, and waste management firms.

Keywords: Construction; Demolition; Waste; Upcycling; Reuse; Repurpose.

1 Introduction

The construction industry is the largest global consumer of raw materials and accounts for more than half of the planet's raw material extraction. This high demand for natural resources creates pressure on the environment and contributes to deforestation, soil erosion, and other forms of environmental degradation. Additionally, the construction and demolition of buildings generate a significant amount of waste, which accounts for about one-third of global waste. Unfortunately, only a small fraction of this waste is recycled or reused, with the majority ending up in landfills or incinerators, causing environmental pollution and health risks.

Construction Debris and Waste (CDW) presents the third largest waste flow after mining and farming industries [6]. The substantial volume of CDW presents significant pressure to landfill capacities and have led to considerable environmental concerns [7]

There is, therefore, a need for more responsible ways of producing and using building materials as Development Goals. Circular construction, aims to close building material loops by reusing, sharing, leasing, repairing, refurbishing, upcycling, or recycling rather than continuing the traditional take-make-dispose process. well as managing our infrastructure and buildings more sustainably.

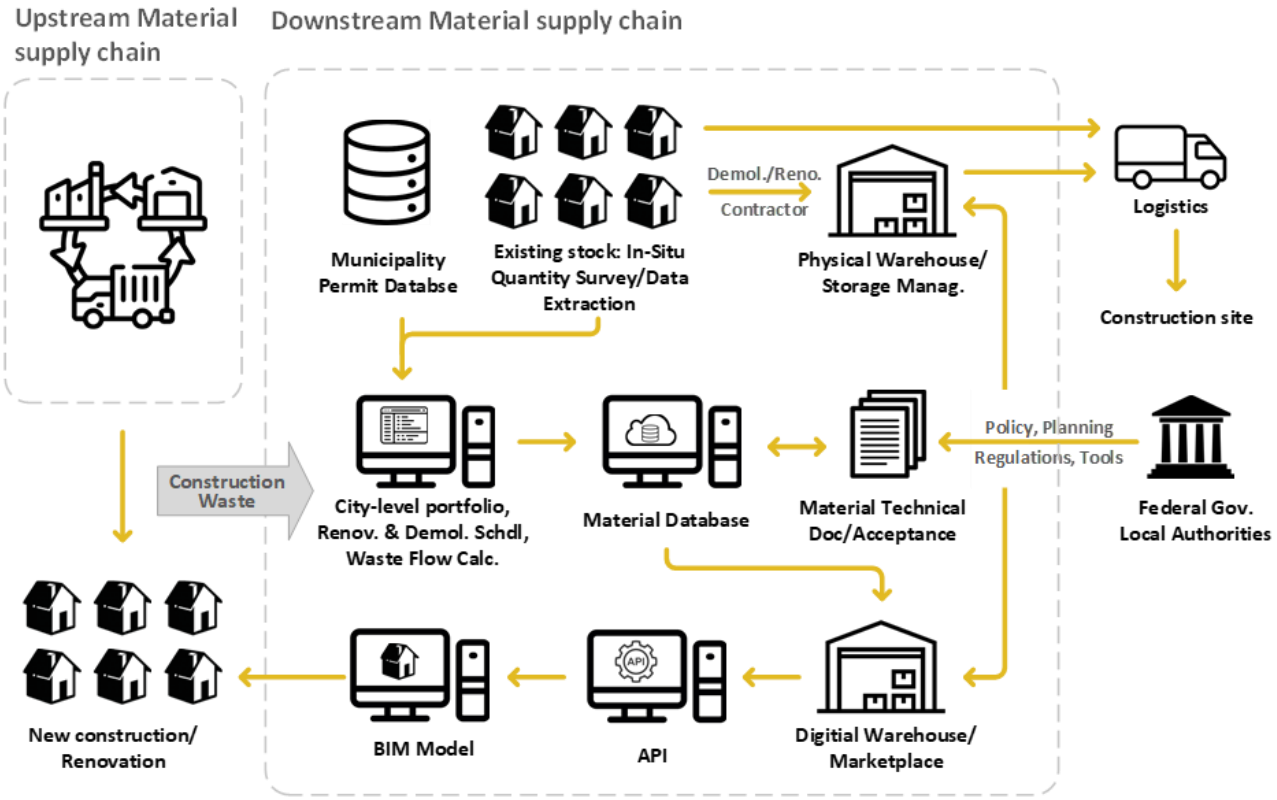


Figure 28. Proposed digital platform

Upcycling reclaimed building materials is not without challenges. While the problem is an intertwined one of education, standards, and enterprise, none of this can happen at any scale without an integrated and accessible framework in which the element-by-element composition of a city's building stock can be known, as well as anticipated construction and demolition projects and the actual waste flows. Designing a framework for reusing and repurposing construction and demolition waste involves several important components, including waste assessment, transportation and logistics, sustainable upcycling solutions, and design. Such a framework would need to couple municipal permitting processes with digital design aided by building information modeling (BIM). As permitting is now a digital process in most communities and BIM is already used on more than 70% of all new construction projects, their intersection to build the intended framework can be realized on a digital platform. Additionally, digital platforms can connect waste generators with potential reuse partners.

2 Digital platform for CDW upcycling

Logically marrying these processes to the larger eco-system of material production, fabrication, recycling, and disposal is needed (Figure 1). Yet, this only makes sense if emissions and costs related to reuse (e.g. transportation, potential temporary storage, and any cleaning or refinishing) are less than all costs and emissions from disposal of the previously used materials and those affiliated with the manufacturing and delivery of new materials. What needs to be minimized is the extensive hauling, reprocessing, and redelivery.

[1] Dorsthorst B., Kowalczyk T. Design for recycling. Design for deconstruction and materials reuse. In: Proceedings of the International Council for Research and Innovation in Building Construction (CIB) Task Group 39 – Deconstruction Meeting, Karlsruhe; 2002: 70–80.

[2] Esin T., Cosgun N. A study conducted to reduce construction waste generation in Turkey. Build. Environ. 2007; 42 (4): 1667–1674.

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ID-347

Long-term shape sensing of bridges with automated ROI extraction of LiDAR point clouds

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Abstract

We discuss a novel scheme for automated Region Of Interest (ROI) extraction of point clouds, long-term deformation, and shape sensing, invariant to the position of a Light Detection And Ranging system (LiDAR). In the era of advanced smart construction, there is an increasing demand for monitoring bridge deformation and shape during the construction phase. Proposed methodology reconstructs a geometric model of the target structure in the context of shape sensing and compares it with the design model. Here, we first measured the Three-Dimensional (3D) point clouds in a local LiDAR coordinate system. Next, we extracted 3D point clouds from the ROI by transforming and processing point cloud data in a two-dimensional image space using a novel image processing scheme. Subsequently, we map the ROI point clouds into a unified world or design coordinate system. We superpose the geometry model of the full-scale bridge girder over a long period to monitor long-term bridge deflection during the construction phase, which is well correlated.

Keywords: LiDAR-based point clouds; Hough transform and edge extraction; long-term shape sensing; displacement monitoring; automated ROI extraction; digital twin; full-scale bridge girder

1 Introduction

Fast, seamless measurement using 3D point clouds and non-contact reconstruction of 3D structures have numerous applications in Structural Health Monitoring (SHM). Noteworthy SHM applications for civil infrastructure include dimensional quality assessment of precast concrete, surface feature extraction, deflection monitoring and shape sensing, 3D surface reconstruction from multiview photogrammetry and classification of bridge components. Long-term bridge deflection monitoring and deflection shape reconstruction with point clouds during the construction phase of a full-scale bridge have not been well reported and require much attention. Although computer vision-based sensing involving two-dimensional (2D) images and multiview photogrammetry are cost-effective solutions for non-contact bridge deflection monitoring; they have numerous limitations for bridge shape reconstruction. 3D point clouds generated using laser scanners are a viable option for long-term displacement measurements and shape sensing thereby overcoming the limitations discussed previously. We propose a scheme for long-term shape sensing of full-scale bridges using point clouds with automated extraction of ROI invariant to LiDAR positions. This scheme combines design information with 3D surface fitting and 2D image processing to extract point clouds in the ROI and reconstruct a digital twin for shape sensing and deformation monitoring.

2 Experimental testbed details

We performed field experiments for long-term shape sensing on a full-scale concrete railroad bridge (**Error! Reference source not found.**), where we measured the point clouds during different phases of bridge construction. Point cloud measurements were obtained using a Riegl VZ-1000 laser scanner that uses a near-infrared laser with a constant pulse repetition rate. The major

dimensions of the bridge girder, such as the span and width of a single bridge girder, were 40 and 2 m, respectively. The laser scanner was placed under the mid-span of the bridge.



Figure 29. Full-scale concrete railroad bridge during the construction phase.

3 Automated ROI extraction and shape sensing of a full-scale bridge girder

The proposed methodology enables long-term shape sensing (deformation monitoring), wherein we employ an efficient automated ROI extraction scheme that is invariant to the LiDAR position. Automated ROI extraction reconstructs a digital twin surface profile using design model information, image processing of point clouds in 2D image space, and 3D surface reconstruction schemes. **Error! Reference source not found.** p resents an overview of the proposed framework for automated ROI extraction and long-term shape sensing.

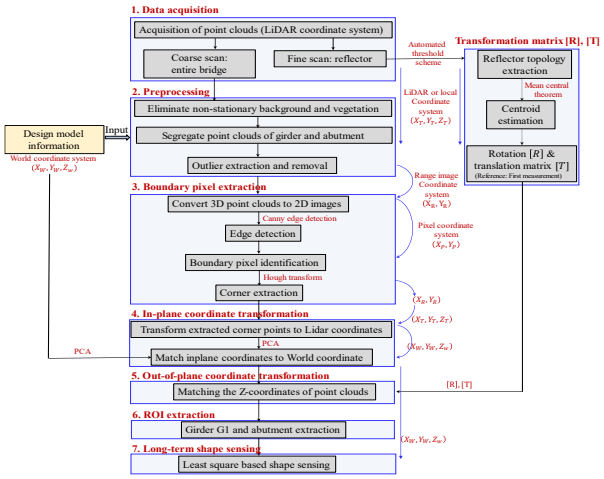


Figure 30. Scheme for long-term shape sensing with automated ROI extraction involving transformation.

3.1 4 Long-term shape sensing

The processed point clouds are reconstructed with the optimal deformation profile using least-squares-based shape sensing wherein we employ quadratic surface polynomial fitting. The reconstructed shapes were compared successively to monitor the shape change over a long period during different stages of bridge construction.

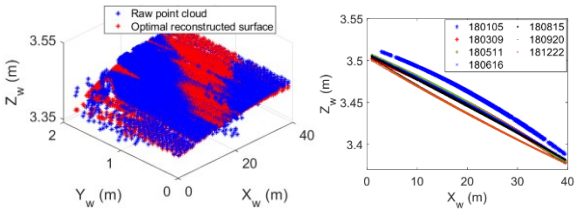


Figure 31. (a) Optimal reconstructed shape using least squares-based shape sensing. (b) The reconstructed shape profile along mid-width involving different construction stages over a long duration for the full-scale bridge girder G1. (Numbers in the legend correspond to calendar dates in the format 'YYMMDD', where YY stands for the last two digits of the year, MM is the month, and DD is the date).

4 Conclusions

This paper presents a scheme for long-term shape sensing of full-scale bridges using point clouds with an automated extraction of ROI, invariant to LiDAR positions. The automated ROI extraction method efficiently removes background information using the design model information and transforms the point clouds in the local ROI into a unified world coordinate system.

5 Acknowledgment

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Use of Terrestrial 3D Laser Scanning Technology for Examination of Transportation Structures

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Abstract

The article considers the possibilities of using ground-based laser scanning technology in solving problems of surveying transport structures (bridges, roads, tunnels, culverts, retaining walls, etc.) located on the territory of the Russian Federation.

Difficult access conditions to structures, often requiring the use of scaffolding or the use of a rope method of insurance (industrial mountaineering), significantly increase labor intensity and reduce labor safety when performing simple tasks. Existing models of laser scanners allow to collect data in the absence of direct operator access to both the measured objects and the scanner itself.

Keywords: structure examination, bridge inspection, survey, terrestrial 3D laser scanning, heavyweight vehicle

1 Introduction

3D laser scanning technology has become widely used as a data collection tool for building BIM models and is often considered from the point of view of building complex and extended high-precision 3D models in solving problems of architectural design, preservation and restoration of architectural heritage, building control, monitoring of structures, etc [1]. Actually, a significant reduction in the cost and availability of technology allow to talk about the possibility (and necessity) of its mass application when performing work on the inspection of artificial structures, including bridge structures, which are characterized by a remote location, lack of access for direct measurement due to height or the presence of a stream. When developing normative documents regulating goals and objectives, as well as recommendations for laser scanning as a part of the survey of structures in transport, the experience gained earlier on real objects and in real conditions is very useful.

2 Used equipment

As the main means of data collection, a compact terrestrial laser scanner Leica BLK 360 G1 is used, additionally equipped with a tablet computer for controlling data collection process, previewing the results and preliminary stitching of the model.

It can be seen from the comparison of the indicators that, with the accuracy declared by the manufacturer, Leica BLK 360 G1 scanner can be successfully used in the inspection of bridge structures with spans up to 40m, at the same time additional measurements of the sagging/camber of beams will be required for metal span structures,

for example, using a tacheometer or an optical level.

3 Example 1. Survey of a transport corridor for the transportation of heavyweight oversized cargo

To select a route and determine the possibility of transporting heavy oversized cargo along a highway located in the Arctic zone of the Russian Federation, a survey was made. Reconnaissance work was carried out in February-March, the main scanning work was carried out in April-May of 2021. The construction and installation work began simultaneously with the scanning work and was completed by the time the cargo was transported in November-December of 2021.

On average, for each span of the surveyed bridges, 4-8 scanner installations were performed under the bridge and 1-2 installations on the roadway. In some cases, to combine scans of the upper and lower parts, additional installations were made to capture large characteristic features of the surrounding area and to abandon the placement of special marks.

Based on the results of the performed scanning, drawings were made and design finite element models of reinforced concrete and steel-reinforced concrete superstructures were built, followed by the determination of the load capacity of superstructures and supports of bridges and overpasses, taking into account the actual technical condition of their elements.

4 Example 2. Diagnostics of bridge structures in the Far East region

When performing work on the diagnosis of artificial structures in the Far East, in addition to the classical methods of work, the under-bridge space of more than 220 bridge structures was scanned. The total number of spans scanned was over 600.

Due to the tight deadlines for the work and a significant number of surveyed structures, laser scanning work was carried out by a separate link of 2 engineers.

The obtained values of the building lift were further compared with the values specified in the standard designs and the requirements of the bridge design standards (according to [2], the beams, after loading with constant loads, must maintain the building lift of at least 40% of the deflection from the temporary moving load). If there is sagging, an additional analysis of the causes of its occurrence was carried out with a change in the assessment of the technical condition and the issuance of recommendations to bring the bridge structure to the standard state.

5 Example 3. Pre-project survey of a stone road bridge

Terrestrial laser scanning technology was used to collect data during a pre-project survey of an old stone arch bridge across the Lugovaya river in Leningrad region. In the course of scanning the bridge with a span of 5.1 m and a width of 9 m, 2 scanner installations were performed in the bridge space (on the upper and lower sides of the bridge), as well as an additional installation of the scanner on the roadway surface.

Based on the obtained geometric data, using the SOFiSTiK 2022 software, a computational finite element model of the arch span was built, followed by analysis and determination of the load capacity.

In addition, the customer (the organization that designs the bridge), was given point cloud files for inclusion of the overhaul object in the BIM model.

6 Conclusions

On the basis of the experience based on the inspection of more than 300 artificial structures (small, medium and large bridges) on highways, it can be concluded that the compact laser scanner Leica BLK 360 G1 has been successfully used as the main or auxiliary equipment for measurements.

The use of terrestrial laser scanning technology in addition to the classical methods of work in the inspection of transport intersections has significantly reduced the time of work and increased the reliability of the results, which is especially important in view of the remote location of the route. The resulting economic effect from the application of the technology turned out to be comparable to the cost of acquiring a laser scanner of the lowest price category.

ID-1064

Role of Artificial Intelligence in Sustainable Bridge Design

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Abstract

Sustainable bridge design criteria seek not only to economise the cost, but also to diminish adverse ecological and socio-cultural impacts and works to balance all the three. This multi-criterion decision-making process is often subject to inconsistent opinions of stakeholders. To address the highly complex issue of the sustainable bridge design, Artificial Intelligence (AI) will be the best tool for decision-making process to determine the finest sustainable design by getting the probability of a particular design being chosen. AI can assist this decision-making by offering profound visions on the sustainability aspects in design problems based on available field data, thereby enhancing the quality of the design process, and concurrently served as directives for novice engineers. In this paper, a novel rating system for sustainability assessment of bridge design has been proposed and an AI based model to predict the sustainability rating of bridges has been developed.

Keywords: Sustainability, Sustainable bridge design, Sustainability rating system, Artificial intelligence, Machine learning, Supervised learning.

1 Sustainability and Sustainable Design

The concept of sustainable development happens at the confluence of three constituent parts: social, economic, and environmental. Nowadays, the idea has developed into specific disciplines, such as sustainable engineering, sustainable design and sustainable construction. Sustainable design is one which imparts durable, robust structures, which sparing material and energy terms and guarantee reduced environmental, ecological, and human health impacts at an acceptable economic cost. A sustainable design would balance both environmental and social costs along with economic costs.

2 Proposed Sustainability Rating System for Bridge Design

The sustainability assessment process in bridge design must be carried out from the planning and design stage to the construction stage and then to the maintenance stage. In the proposed sustainability rating system, the multi-criteria decision-making process is applied to different stages of bridge life cycles which can be categorized as (a) Planning stage; (b) Design stage; (c) Construction stage and (d) Operation and maintenance stage. In each stage, the factors influencing the economic, environmental, and social considerations are listed out and assigned a rating value varying from 1 to 5 points. The point system was assigned in such a manner that criteria with a higher impact have larger point values. The maximum values of sustainability rating for planning stage, design stage, construction stage and maintenance stage are 25, 25,30 and 20 respectively. The Sustainability Rating Value (SRV) of a bridge design is the sum of the rating values of all the four stages and 100 being the maximum value of SRV. If a single target rating value is used for sustainability evaluation, it will be more effective. Any bridge that is equal to or above a

recommended value would be considered as a certified/approved sustainable bridge. The client or controlling organizations concerned can decide the recommended sustainability rating values, even for various categories of bridges.

3 ML based Bridge Sustainability Prediction Framework Model

AI is a branch of computer science that focuses on incorporating human-like intelligence, consciousness and thought process by replicating biological models. Machine Learning (ML) is a major subfield of AI associated with the design, development and application of algorithms that can make predictions using learned data. Depending on the resources of the training dataset,

ML can be categorized as supervised, unsupervised, or reinforcement learning. In Supervised Learning, the machine learning program is both given the input data and the corresponding labelling by a human being beforehand.

A ML based framework model has been developed for predicting SRV of Bridges, which will be useful during design stage. The ML algorithm applied for developing the model was Bayesian Network Classifier under supervised learning category. The model was developed using Python language under Jupyter (anaconda) platform. The ML based framework for predicting sustainability rating of bridges is presented in Figure 1.

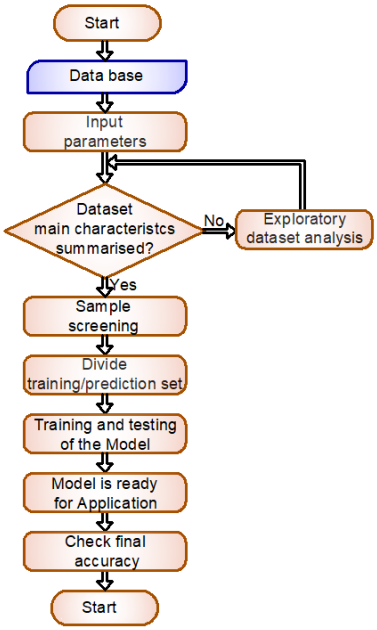


Figure 1. ML implementation framework.

The model was tested with two sample cases, Case-1 and Case-2, with input parameters influencing sustainability. Case-1 is having favourable parameters to sustainability and Case-2 has unfavorable parameters. The prediction of the developed model is presented in Table 1. The model predicted economic, social, and environmental sustainability ratings for Case-1 as 27, 30 and 28 and for case-2 as 24, 0 and 0 respectively. The training to testing ratio adopted for the model was 0.8. The accuracy of the model is obtained as 92.3% and 91.7% for Case-1 and Case-2 respectively. To improve the accuracy and operating efficiency of the prediction model, it was necessary to evaluate the degree of influence of various influencing factors.

Table 1. Predicted Sustainability Ratings Values by *the developed ML model for Case-1 & Case-2*

Sustainability Parameters	**Predicted SRVs**	
	Case-1	**Case-2**
a) Economic	27	24
b) Social	30	0
c) Environmental	28	0
Total SRV	**95**	**24**
Accuracy of AI model	92.3%	91.7%

4 Conclusions

Achieving a sustainable bridge design by comparing the sustainability factors is a very complex challenge and design engineers typically struggle to manually compare multiple sustainability parameters in search of the best sustainable bridge option. A sustainability rating system for bridges has been proposed for all the stages of the bridge structure's life, i.e., design, construction, and maintenance. The objective of this rating system is to urge and recognize effective sustainable bridge design by providing cost-effective guidelines for design and construction. A ML based model has been developed using Python language, which will make predictions for sustainability rating of bridges based on the sustainability influencing factors. Designers will get sustainability rating for various design options and the optimal sustainable design solution can be chosen without consuming much effort and time. The model can be operated globally by modifying the dataset effected, with respect to the standards of each organisation.

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A robotic and automatic solution for identifying frequencies and high-resolution mode shapes of bridge structures – an experimental study

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Abstract

This study presents an automated robotic solution for identifying frequencies and high-resolution mode shapes of bridge structures. In this solution, a programmable wheeled robot, whose movement can be precisely and remotely controlled, acts as the mobile platform that carries an accelerometer, and another accelerometer is deployed on the tested structure as a stationary reference. By exploiting a mobile modal identification scheme, this study adopts an output-only frequency domain decomposition technique to extract frequencies and high-resolution mode shapes from the acceleration signals captured by both the mobile and stationary accelerometers. To validate the solution, a field test is conducted on a footbridge, where the frequencies and high-resolution shapes of the first two structural modes are successfully identified, using only two wireless accelerometers. This confirms the effectiveness and efficiency of the proposed solution.

Keywords: Structural vibration; Modal identification; Mobile sensing; Wireless sensing; Automated robot

1 Introduction

This work introduces a practical mobile sensing approach that utilizes a readily available wheeled robot as the mobile sensing platform. A significant contribution of this study is the selection of a cost-effective commercial robot, specifically the DJI RoboMaster EP, to serve as the mobile sensing platform for sensor deployment. By programming a Python script on a mobile device, the robot's speed, trajectory, and data communication can be precisely and conveniently controlled. Additionally, the robot's Mecanum wheel set allows for movement in virtually any direction with any rotation, making it highly suitable for mobile sensing tasks.

2 Experimental validation

2.1 Devices

In this study, the mobile sensing platform for carrying accelerometers is a commercially available wheeled robot called DJI RoboMaster EP. The RoboMaster EP is shown in **Error! Reference s ource not found.**, in which a cell phone is placed beside the robot to act as a reference of the dimensions.

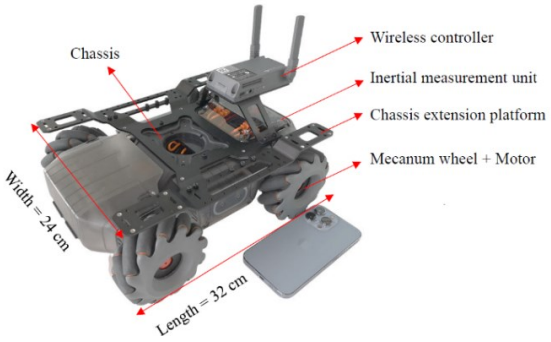


Figure 32. Photo of a Robomaster EP

A wireless accelerometer product named Xnode is chosen. As shown in **Error! Reference source not found.**, the Xnode senor can be easily installed on the robot's chassis extension platform with four magnetic bases.

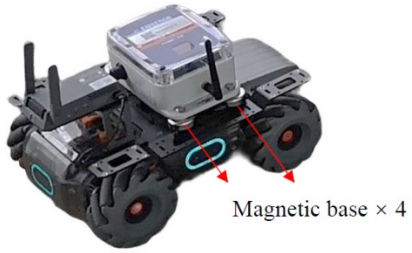


Figure 33. Photos of Xnode wireless accelerometer

2.2 Footbridge test

To validate the proposed approach, a field test was conducted on a footbridge situated in Singapore. As **Error! Reference source not found.** shows, it is a simply-supported girder bridge with a span length of 21.6 meters.

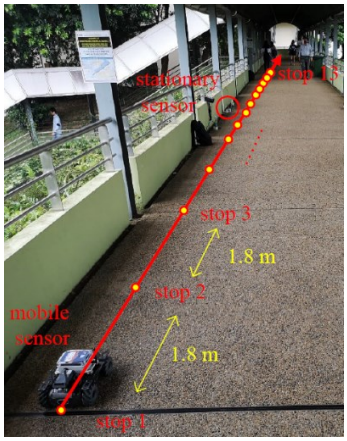


Figure 34. Photos of the footbridge test

A 'stop-and-go' test was conducted to validate the robotic approach regarding mode shape identification. The bridge is equally divided into 12 segments by 13 stopping points. The robot was programmed to automatically keep stationary on each stopping point for 12 seconds and move to the next point then. Only the acceleration signals in which the robot was stationary are delivered to the frequency domain decomposition (FDD) technique to identify the relative mode shape at locations of the robot and the reference stationary sensor. The identified mode shapes of first two bridge modes are shown in **Error! Reference source not found.**, w hich demonstrates a good consistency between the theoretical and identified mode shapes, underscoring the accuracy of the proposed approach.

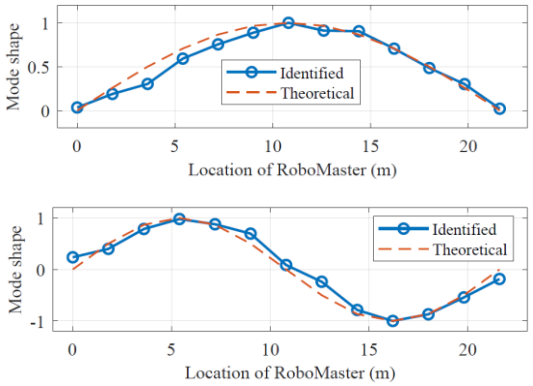


Figure 35. Identified first two mode shapes of the tested footbridge

3 Conclusions

In this study, a practical and intelligent approach is proposed for identifying frequencies and high-resolution mode shapes of bridge structures using a wheeled robot. A field test was conducted to validate the effectiveness of this approach on an in-service bridge. The experimental results demonstrate the feasibility and practicality of utilizing the DJI Robomaster EP as a mobile sensing platform to carry sensors for identifying structural frequencies and high-resolution mode shapes.

In future studies and practical implementations, it is recommended that all sensors be installed on robots. This enhancement would significantly enhance the flexibility of the proposed approach, enabling efficient inspections of many structures across vast areas. Moreover, this opens up the possibility of introducing mobile crowd sensing by utilizing a group of robots collectively.

Session 23

Sustainability in Built Environment

ID-447

Development of Low-Cost Seismic Isolators Using Scarp Rubber Tyre Pads for Sustainable Disaster Mitigation

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Abstract

This research aims to develop low-cost and environmentally sustainable seismic isolator using scrap tyre rubber pads (STRPs), as an alternative to conventional elastomeric seismic isolators, which can be implemented at mass scale to safeguard remote rural communities, dense urban settlements, associated industries and infrastructure vulnerable to seismic events. The STRP bearings are manufactured through die-mould vulcanization of STRP pads and steel shims to achieve mechanical properties suitable for seismic isolation. The green and environment friendly approach is achieved by using the industry leftover such as scrap rubber tyre pads. The STRP seismic isolators would especially be beneficial to communities at high seismic risks which do not have access to advanced and costly seismic retrofit measures.

Keywords: Seismic isolators; Low-cost; sustainable; scrap rubber tyre pads;

1 Introduction

The application of conventional seismic isolation devices is cost prohibitive and restricted due to complexity and proprietary issues. The STRP seismic isolators proposed in this research fabricated using vulcanization-based die-mould fabrication technology which has been developed in collaboration with industry partners for reliable

manufacturing and high capacity. The developed technology can provide two-dimensional and three-dimensional isolation thus catering to wide range of structures and systems. Scrap Tyres Rubber Pad (STRP) isolators provide an environmentally sustainable disaster mitigation way to protect small structures and buildings from damaging effects of earthquakes.

2 Development of STRP Isolators

The STRPs used in the present study are made from nylon tyres. Nylon Tyres, also known as Cross Ply tyres, consist of layers made of Nylon chords.

Both the sidewalls of the tyre were cut and removed, and long rectangular strip type specimen was acquired. This rectangular strip belt is then cut to required size.

2.1 Manufacturing process

Surfaces of tyres and steel plates are cleaned to remove dust so that the adhesive can be applied properly. The layers are glued together for better bonding and to keep them intact and act as a composite unit.

2.1.1 Surface Preparation

Roughing of surfaces of scrap tyre pads is done with help of rough grinding wheel for applying adhesive.

2.1.2 Bearing Plate Surface Preparation

The metal surfaces are thoroughly clean prior to adhesive application. Sand blasting is done to clean the metal surfaces of mild Steel plates from any dirt, oil or any form of surface impurities.

The finalized SRTP specimen is of size 200 × 200 × 130 mm composed of two bearing plates of size 200 × 200 × 25 mm, intermediate steel shim of size 195 × 195 × 2 mm and two scrap tyre rubber

pads bonded during vulcanization by using a rubber-to-metal adhesive as shown in Figure 1.

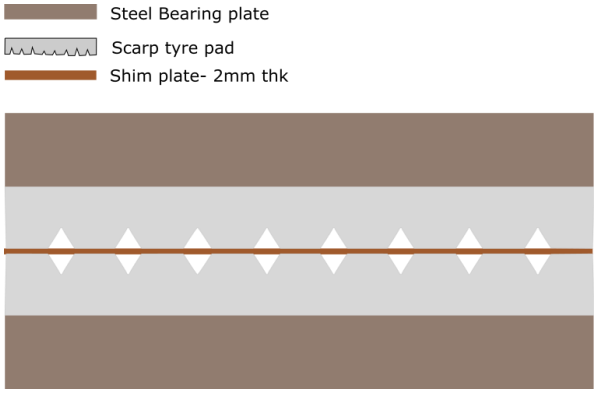


Figure 1 STRP isolator details

2.2 Experimental tests

Experimental tests were conducted on STRP isolators to determine its behavior and mechanical properties under vertical compressive and shear loadings. Experimental tests on the SRTP specimen were conducted in the facility at IIT Bombay.

2.2.1 Axial characterization tests

STRP specimens were tested under pre-determined maximum vertical load of 200 kN, corresponding to an axial pressure of 5 MPa as shown in Figure 2. Axial displacements were measured at four corner points of the isolators and then averaged to get the axial deformations in the isolator. The vertical stiffness calculated from the Load deflection curve for STRP.



Figure 2: Axial characterization tests

2.2.2 Shear characterization tests

In order to investigate the horizontal load bearing capacity and horizontal stiffness, shear tests on STRP samples were conducted. The testing was done on three pairs of samples of nearly equal vertical stiffness, horizontal load of 32kN is applied at a constant vertical pressure of 2MPa. Effective shear modulus (G_{eff}) is obtained from the experimental shear stress strain curve and subsequently the horizontal stiffness.

2.2.3 Compression failure tests

These tests were conducted to obtain failure load under axial compression. All samples showed decrease in load varying between 1200 to 1300 kN.

3 Conclusions

1. The fabrication with a shim plate and bearing plates allow standardization of the geometry and widens the scope of application to a diverse range of structures and systems.
2. The nylon chord tyres or cross ply tyres are used in the proposed STRP isolator for ease of handing, cutting and nylon tyres can be easily cut to required size using cutting knife.
3. The die-mould vulcanization of STRP pads ensures the better bonding and keep them intact and STRP isolator act as a composite unit.
4. The shear modulus of the developed STRP isolator obtained from Shear tests is approximately 0,8 MPa, which is comparable to the conventional elastomeric bearings.
5. The ratio of vertical to horizontal stiffness is 60, which indicates its effectiveness as seismic isolation device.
6. The ultimate compression capacity of the isolator is 30 MPa.
7. During the shear deformation, samples did not show layer separation. This indicates that the bonding agent is sufficiently strong in transmitting the shear forces.

Based on the above observations, it may be concluded that, the STRP isolator provide a cost-effective and sustainable alternative to conventional seismic isolators for wider application to isolate various structural systems.

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Engineering for Sustainable Development

ID-460

Making Sustainability as Core of Engineering Education

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Abstract

Keywords: sustainability; engineering education; environment; curricula; engineering.

All engineering disciplines – chemical, mechanical, electrical, civil, instrumentation, and metallurgy, etc., significantly influence human lives. Engineering as a discipline per se plays a major role throughout an asset's lifecycle from concept stage up to end of life or refitting for other use. Due to its significant influence on system design and subsequent usage, engineering needs to contribute its share towards environmental sustenance. It is not only necessary to pay attention to current engineering practices, but it is equally necessary to ensure that future generations of engineers are well equipped to address needs of sustainability. The educational curricula positively impact students' professional and personal journeys. Unless the thought process towards sustainability gets broadened during the formative years of engineers, their contribution as professionals could be inadequate to address the increasing demands. The engineering profession played a significant role in shaping the industrial revolution and that gave rise to increasing aspirations of the masses. It is a professional and moral responsibility of engineers to work aggressively towards sustainability to ensure that future generations get to sustain a well-rounded life. The research regarding enhancement of the engineering curricula to help prepare engineers of the future is mainly carried out in the developed countries. Sustainability needs all out efforts across the globe and hence it is necessary to address the issue across all regions and continents. During the research of engineering curricula holistically incorporating sustainability within the Indian context, it surfaced that the subject was found to be missing in the research literature. In this paper, the need to address sustainability topics through education curricula interventions is studied from the practitioner's view point. The survey results of 307 senior and experienced engineering professionals on the topic of sustainability are collated and analysed. The paper not only emphasises the need for engineering curricula enhancements but proposes some key themes at a macro level. The paper also articulates possible benefits by making engineering education sustainability focused.

Though industrialization has proved to be a boon to the masses and has helped elevate the standards of living, it also inadvertently and deliberately ignored and overlooked negative the impacts on the environment. As the field of engineering is quite vast, a single case study methodology is followed. The consulting engineering professionals exert a significant impact on creation and usage of assets. Their practical understanding about sustainability is expected to be high. A large Indian private sector firms, operating in the areas of engineering consulting and engineering design was selected for the survey. The firm has operated in the engineering consulting and services business for over six decades and has been part of several iconic projects both in Indian as well as overseas. The firm provides end to end services from pre-feasibility studies, concept design, detailed engineering, construction supervision till operationalization and retirement of assets. Those

assets include high-capacity chemical plants, conventional and non-conventional power plants including nuclear plants, different discrete and process manufacturing plants besides several infrastructural projects in mining and transportation. Each year the organization inducts fresh engineers from various premium educational institutes. The experienced engineers working with the firm are familiar with various facets of sustainability and they also have firsthand understanding about knowledge of fresh engineering talent on the topic of sustainability. Overall, 307 professionals with individual experience of more than 11 years responded to the survey.

The surprising finding is centered around two questions. The respondents were asked if their college education prepared them adequately on the topic of sustainability. The response to this question was not much different from the response to the question 'Does current college education prepare engineers adequately on the topic of sustainability?' All the respondents (who have passed out of formal educational institutes more than 11 years ago) believe that their education provided them slightly better orientation towards sustainability than the current education. It poses an unanswered question. Are respondents connecting professionally acquired knowledge in the field to having roots in their education? Or does it really mean, that despite all the noise about sustainability there is no improvements in orienting engineering students in the areas of sustainability. This aspect needs further probing as current data does not provide clarity about why it is happening.

The respondents were almost unanimous in their response that sustainability is an important topic for them as a person as well as a professional. The respondents were also in the agreement that sustainability is important to their country and to the whole world. The heartening finding was that most respondents felt sustainability is a key important factor from the perspective of future generations. Most respondents believed that all branches of engineering exert impact on sustainability though with different proportions and with a different intensity.

Majority of the respondents believe that Chemical engineering discipline exerts the highest impact on the sustainability followed by Civil engineering and Mechanical engineering. Traditionally more topics related to sustainability are covered in the curricula of Chemical and Civil engineering than that of other disciplines. The data analysis does not provide clarity if the high level of importance attached to the branch of chemical engineering is due to exposure during the education or due to acquired professional knowledge or due to media news coverage.

As articulated in this paper, various educational institutes have successfully undertaken syllabi enhancement initiatives. They have done so by ensuring collaboration of various stakeholders. Indian educational institutes do not need to reinvent the wheel. They can prepare their own approaches towards syllabi enhancements by referring to the studies. India has its own socio-economic structure that is different from those of the developed economies. It thus needs to tailor its efforts. The way forward needs high collaboration amongst policy makers, practicing engineers, organizations and educational experts to arrive at a common minimum program. The budding engineers need to get an opportunity to develop a holistic view of the topic. They need to understand the socio-economic impact that their work exerts. The curriculum needs to go deeper into sustainability rather than providing mere introduction of a topic.

As the survey results point out, that professional engineers get more familiar with sustainability as they advance in their profession. It means not only more exposure, but better hands-on work experience too helps them. One way of accelerating such knowledge is by ensuring industry – academia collaboration at the early stages of education. Both top down and bottom-up approaches of intervention are found to be useful. Apart from formal curricula interventions, creation of more informal platforms fostering exposure and collaboration amongst stakeholders can go a long way towards preparing future engineers to address sustainability challenges.

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Engineering for Sustainable Development

ID-548

Sustainable Development of Sports Stadiums

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Abstract

Sports stadiums have a considerable impact on the urban, environmental and social context. Therefore, the requirements for operation of each stadium after the mega-event are of great importance to ensure sustainability and maximised daily utilization on a long-term basis. Case studies of three different stadium types used for the Olympic Summer Games 2000, 2004 and 2008 are analysed based on literature research, field surveys and interviews with operators. The comparative assessment is conducted in the categories: urban, environmental and social based on a five-point score system. It concludes that long-term utilization of sports stadiums built or modified for the Olympic Games (refer to fig. 1) correlates with the level of urban integration, urban context, building type and usage mix.

Keywords: sustainable; stadiums; long-term utilization; urban integration; usage mix.

1 Introduction

Sports stadiums have a considerable impact on the urban, environmental and social context. In particular, where several new stadiums are built within the same city for a single mega-event like the Olympic Games, the implications are significantly higher. Therefore, the requirements for operation of each stadium after the mega-event are of great importance in order to ensure sustainable integration into the urban, environmental and social context with a maximized utilization of each sports stadium on a long-term basis.

2 Conclusions

In the urban category, existing sites previously used for sport venues or adjacent to other existing venues, are more sustainable, because the site is already integrated into the urban context with a good connectivity and proximity to existing mixed-use areas (e.g. retail, commercial, recreation, residential, etc.) resulting in synergy effects and extended catchment areas.

In the environmental category, the level of sustainability is higher when specific requirements for long-term operation of the sports stadium after the Olympic Games are defined in the project brief. Unless the overlay is required for permanent usage (e.g. roof structure), dismantling the overlay after the Olympic Games reduces consumption of energy and water in subsequent operation of the stadium. Implementation of systems for energy efficiency, power generation, water conservation and environmentally friendly building materials further enhances the level of sustainability and significantly reduces operational costs.

In the social category, a balanced diversified usage mix consisting of regular sport events -ideally by more than one home team, cultural events and other usages/functions (e.g. retail, commercial, recreation, hospitality, etc. as illustrated in fig. 4 and fig. 5) provide a broad diversified mix of activities for the community/public, resulting in a

higher utilization of the sports stadium as indicated in figure 6 below.

The utilization of a sports stadium correlates with a high rating of the indicators: urban integration (location type, building type), urban context (proximity, connectivity), building provisions (overlay, adaptability/flexibility) and usage mix (sport usage, other usages).

The research concludes that the development strategy for utilization of future sports stadiums shall not only consider sport related activities, but also the implementation of a diverse usage mix with integration of other functions for long-term operation. Emphasis should be on day-to-day utilization with ordinary daily activities/events in addition to the weekly events of the home team and potential extraordinary events (e.g. concerts). Results of the case study for the Athens Football Stadium prove that other usages and functions can be successfully integrated to utilize the venue on a daily basis. This type of usage mix allows the community and public to benefit from the sports stadium, built for the Olympic Games in 2004, on a daily basis creating a positive, long-lasting legacy of the Olympic Games.

3 Recommendations

During the election process of the host city for the Olympic Games the impact of permanent sports stadiums on the urban, environmental and social context tends to be underestimated, while the opportunities for utilization of the venues after the Olympic Games are overestimated by the applicant/candidate cities.

Therefore, it is recommended that the IOC establishes more specific guidelines for preparation of the project brief and feasibility studies in order to verify and assess the proposed level of sustainability of each sports stadium in the urban, environmental and social category.

In addition to the feasibility study it is suggested that the applicant/candidate cities should prepare a business plan with reserve funds for maintenance and modernisation of the stadium and entire precinct in order to meet the evolving operational requirements in the long-term operation. Considering the diverse operational requirements for each of the sports stadiums, it is recommended that the applicant/candidate cities involve an operator for preparation of the project brief and feasibility studies. This is to ensure that the focus is not only on the fulfilment of short-term requirements for staging the Olympic Games, but more importantly on the long-term utilization of each sports stadium after the Olympic Games.

1

ID-577

Current Knowledge, Challenges, and Facilitating Factors from the National Survey on Sustainability in the Building and Construction (B&C) Sector

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Abstract

1 Introduction

According to studies, the B&C sector has a positive relationship with most of the UN-SDGs, including SDG 1 on eradicating poverty, SDG 3 on promoting health and well-being, SDG 6 on clean water and sanitation, and SDG 11 on promoting sustainable human settlements. Studies also indicate that B&C sector because of its inherent nature negatively correlates to the UN-SDGs such as SDG 12 on responsible consumption and production, SDG 13 on climate action, SDG 14 on life below water, SDG 15 life on land (SDG 15), and others.

The above studies establish B&C sector's role as not only central but critical in achieving overarching global framework of sustainability i.e., Sustainable Development Goals (SDGs). The real challenge for the B&C sector is to manage these trade-offs and look for synergies between various objectives. The TBL cum decoupling model of sustainability expresses this idea of managing these trade-offs and synergies (Figure 1).

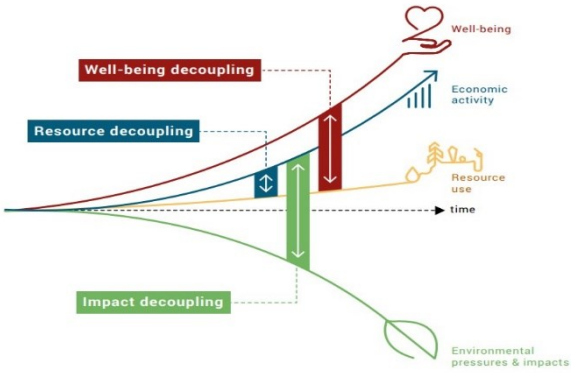


Figure 1. TBL cum decoupling model for sustainability

Decoupling natural resource consumption and environmental impacts from economic activity and human wellbeing is essential for B&C sustainability. Figure 1 illustrates the interdependencies between sustainability aspects through impact, resource consumption, and well-being decouplings.

In developing nations like India, construction and infrastructure demand will soar in the next years. However, these countries' construction methods are resource- and pollution-intensive. This causes rapid resource depletion, including building supply

shortages. In recent decades, agreements and efforts to define a framework for sustainable development have focused on themes like reduce, recycle, and reuse; green buildings; renewable energy; zero waste; and others.

Based on above arguments the critical questions that lie in front of B&C sector include:

1.) How does the B&C sector support global sustainability framework?

2.) Are the targets of UN-SDGs being realistic with respect to B&C sector?

3.) Are we on the right track on delivering sustainability through B&C sector and if no, then what is the way ahead?

Thus, this "National Survey" assesses knowledge, difficulties, and enabling factors for promoting and implementing sustainability in and through the B&C sector in India.

2 Research Design

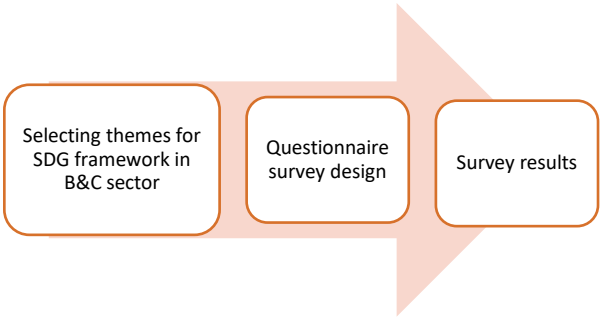


Figure 2. Research Design

2.1 Selected themes for SDG framework in B&C sector

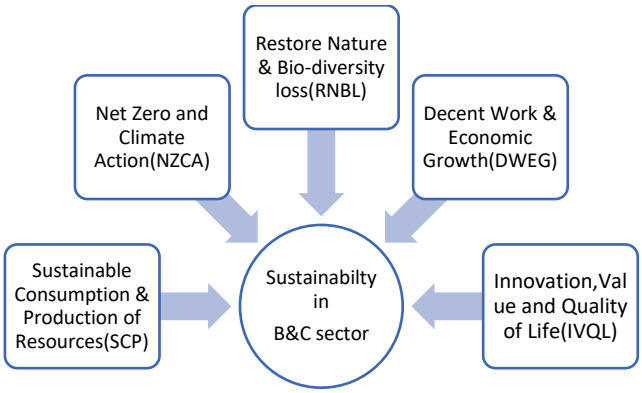


Figure 3. Identified themes for implementing SDG framework in B&C sector [Author's illustration]

3 Findings of the study

Based on the themes/entry points, current study develops sixteen structured/semi-structured questions. These questions around knowledge, challenges, and facilitating factors of the respective themes or entry points are broadly grouped in three sections namely, 'General Awareness about Sustainability', 'Perspective for implementing Sustainability', and 'Sustainability and Organisations'. The key findings from the responses are presented in the following heads.

5.1 'General Awareness about Sustainability'- Findings

The sector's awareness of TBL-based sustainability was low, even though many players knew its components. The UN-SDGs, which represent this TBL-based sustainability, were unknown to most respondents. The majority of respondents overestimated India's standing in TBL-based world indices. SDG 3, SDG 9, SDG 11, SDG 8, SDG 17, and SDG 6 were the most important goals for the Indian B&C sector.

5.2 'Perspective on implementing Sustainability'- Findings

Regarding the implementation of sustainability, it was abundantly obvious from the comments that the government ought to take the initiative in India's B&C sector's drive toward sustainability.

5.3 'Sustainability and Organisations'- Findings

78 percent of respondents said their organisation had sustainability goals. 12 percent of respondents said their organisation has no sustainability goals, and 10 percent said they didn't know. As per the responses, "Knowledge and collaboration across stakeholders" is the biggest problem for organisations in implementing sustainability. Respondents ranked "life cycle assessment (LCA)," "renewable energy," and "water management" as the top environmental impact measures.

4 Conclusion

Sustainability projects are spread across the industry, but a major overhaul is still far off. This study also assesses stakeholders' awareness of sector-wide sustainability adoption and identifies difficulties that can be overcome with facilitating factors. Research supports the absence of industry consensus on sustainability. Political will and regulatory adjustments are essential for industry sustainability, circularity, and climate change goals. The current study will assist stakeholders and industry players in prioritising sustainability (UN-SDGs), climate change (Paris Agreement), and intended national contributions (INDCs).

ID-655

Service-life and Sustainability of Concrete Structure in Tropical Condition

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Abstract

Concept of service-life is elaborated and implication of service life and consequent repair frequency on life cycle performance of structure is highlighted. Concepts of sustainability is explained through the ratio of annual global ecological foot print (EFP) of human consumption and bio-capacity (BC) of the earth The structure would contribute to EFP of construction year(s) and later, on recurring basis during repair whenever undertaken. Taking the issue forward, in the tropical climatic condition of Indian subcontinent with marine environment of long coastline and varying rainfall induced wetting and drying, an approach to service life estimation is presented for sustainability at the and conclusions are summarised.

Keywords: service life, concrete, sustainability, ecological foot print, bio-capacity,

1 Introduction

Whenever repair is undertaken on serviceability failure there is consumption of resources and generation of wastes. Both consumption and waste generation leave a foot print on ecology, i.e., ecological foot print (EFP). The earth has a fixed bio-capacity (BC), as it receives fixed energy from the sun annually. There is a natural annual balance of energy with net zero deficit and surplus. Maintaining this balance is a necessity for mankind to avoid detrimental consequences. Sustainability is linked to ratio of EFP to BC, and this linkage is illustrated in the paper. Implication of quantified value of service life on consumption and hence EFP is also discussed. Frequency of repair and rehabilitation depends on exposure condition, hence role of tropical exposure on sustainability is presented at the end.

2 Life and Service life of structure

Manmade materials those are produced at the expense of energy, would tend to undergo chemical changes in reaction. Such reactions, when results in impediment to performance of structural components or structure as a whole, may signal the end of service life. Service life thus is related to serviceability limit, although physical life up to collapse or demolition, may extend to a much longer period. Service life refers to individual member elements. It is related to repair cycle of the element and maintenance of the structure.

3. Sustainability, EFP and BC

The energy received by the earth from the sole source, that is the sun, in a year is also transmitted back to cosmos and hence internal energy of the earth is also conserved. Materials are transformed from one state to another by expense of energy and there by energy remains stored in the material. The carbon and oxygen are the main carrier in this regard. Burning of fossil fuel for energy and calcination of lime stone for cement etc. produces, extra CO_2 by virtue of consumption of fossil fuel and cement.

The annual consumption by humanity is accounted in term of ecological foot print (EFP). Similarly, bio capacity (BC) is that of the available space i.e., land, water etc. The ratio of EFP to BC is the number of earths required to sustain the current population with its present-day consumption pattern. The carbon land required for capturing waste CO_2 does not appear in BC. Equivalent number of earth contribution of the concrete in structure Nes, thus can be written as:

$$Nes = 1 + \frac{EFP(structure\ \{carbon\})}{BC\ (structure)} \quad (1)$$

4. Service life and Nes

The initial embodied energy of concrete per cubic meter can be written as:

$$IEE = E_{CN} + (E_C W_C + E_{CA} W_{CA} + E_{FA} W_{FA} + E_W W_W + .) \quad (2)$$

Details of the terms are there in full paper. Consider cover concrete as vulnerable at every individual cycle of repair. Thus embodied energy of repair (EER) can be expressed approximately in terms of initial embodied energy IEE as[11]:

$$EER = e_R \frac{2d_c}{d_s} \times \frac{t_{il}}{t_{sl}} \times IEE \quad (3)$$

IEE and EER both would contribute to EFP of the structure.

4.1 Carbon area of EFP

Thus total amount of CO_2 emission during intended design life of concrete (LCCE) in the structure can be written as equation (4) and Nes is given in equation (5):

$$LCCE = V_{CS} \times \left[\begin{array}{c} 0.02 \times FFR \times (IEE + EER) \\ +0.51 \times NCF \times m_C \left(1 + e_R \times \frac{2d_c}{d_s} \times \frac{t_{il}}{t_{sl}}\right) \end{array} \right] \quad (4)$$

$$Nes = 1 + \frac{LCCE \times (EQF_F / CAF)}{A_S \times EQF_B \times t_{il}} \quad (5)$$

As an example, for the purpose of illustration, is also presented

5. Service life of concrete in tropical exposure

All degradation processes resulting in serviceability failure of concrete involve presence of moisture. There is a conducive moisture condition specific to degradation process. Rainy season and humidity condition are annually periodic with their varying seasonal duration depending on location. Rain induced wetting and drying exhibit annual periodicity. Moisture ingress in exposed concrete structure and resulting moisture condition i.e., degree of saturation at the cover concrete region is annually periodic as shown in *Figure 1* in the article. The degree of saturation of concrete can be related to RH through Kelvin's equation i.e., equation (6) and the general equation for pore size distribution i.e., equation (8) through the equation (9).

$$\boldsymbol{r_k = \frac{-2V_m \sigma}{RT \ln (RH)}} \quad (6)$$

$$\theta = -\frac{1}{p} \int_{r_k}^{r_{min}} \frac{dV}{dr} \mathrm{dr} \quad (7)$$

$$V = p \frac{r_{0.5}^d}{(r^d + r_{0.5}^d)} \quad ()$$

Thus, it is demonstrated that service life of exposed concrete is climate specific, especially in tropical exposures. Reference literatures in this context are also cited.

6. Proposed exposure Zones for service life

Based on discussions presented in the previous section durability zones for service life prediction is proposed in line with the climatic zone in Table 1, and is also shown in *Figure 2,* of the paper. Coastal area is prone to chloride induced corrosion, marked with black as marine zone and superimposed over climatic zones in the figure.

7. Conclusions

Concepts of sustainability is explained through ecological foot print, bio capacity of earth and hence its relation to sustainable concrete is illustrated. A model for evaluation of contribution of concrete in structure to number of earth (Nes) is presented, which can be used for comparative evaluation of sustainability performance of concrete in structure. The role of service life on sustainability is demonstrated through the model. Lastly, proposed durability zones for service life estimation of concrete in Indian tropical climatic condition is presented.

ID-1062

A Case Study on the Performance Based Enhancement of Cementitious Systems through Sustainable Nanomaterials

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Abstract

Nanomaterials are possessors of unique nanostructures within the 1 to 100 nanometers range and were recognized as early as the late 1800s. Doping of these nanomaterials within a cementitious composite matrix can provide advantageous properties to the cement composites which could not be achieved hitherto using the corresponding bulk materials. In light of the recent advances in Nanosciences, the use of nano additives has unlocked new vistas in the civil products industry. Moreover, the cementitious products industry is at present facing a tremendous challenge from a sustainability perspective due to the huge amount of carbon dioxide (CO_2) emitted from cement plants. To reduce the amount of CO_2, modern approaches prescribe the use of SCMs as has been advocated by Indian Standards like IS: 456 & IS: 10262. The most commonly used SCMs in concrete mixtures are fly ash (Type C, Type F), slag cement, and, to a lesser extent, silica fume though in a broader sense natural pozzolans & LC3 systems are also included. These materials are by-products of various industries: Fly ash-burning coal in power plants; Slag cement-smelting iron ore; Silica fume-alloying silicon or ferrosilicon.

The better performance of SCMs is attributed due to their high specific areas & fineness leading to researchers' search for more ultra-fine materials. Nanomaterials have their dimensions in the 1 to 100nm range with 10^3 time's higher specific areas when compared to SCMs or micro range materials. Nano silica is also the most economical nanomaterials, the most desirable in performance; the most consumed in cement composites, and has proven helpful in promoting the use of salvaged materials in cement matrices worldwide. Also, India is blessed with huge agricultural production and the novelty of Nanosilica is that it can be produced from agricultural wastes. Last but not the least, the cost economics of nano-enabled composites is much better than their SCM counterparts.

This study concerns the application of a water-saving cement additive that can appreciably better the hardened properties of a cured product of a cementitious composition over a long time period. This advanced cement additive is a Nanotechnology based advanced material also known as Nano Materials at varying dosages by weight of ordinary Portland cement (1 part by weight) in a dry mix with river sand constituting 3 parts by weight of cement. Nanomaterials are insoluble in water so it's dissolved in a polymeric compound of Polycarboxylate Ether through ultrasonication.7.07cm cubes are cast with this mixture with water adjoined as per IS:4031 Standards under the fixed water/cement(w/c) at 0.4. After casting the cubes are cured at room temperature and they are tested for 3 Days, 7 Days, 28 Days, & 365

Days for compressive strength. Not only the results when compared are found to be superior to that of the ordinary cement composite cubes but also were found to be much more economical when compared to Silica Fumed cement compositions.

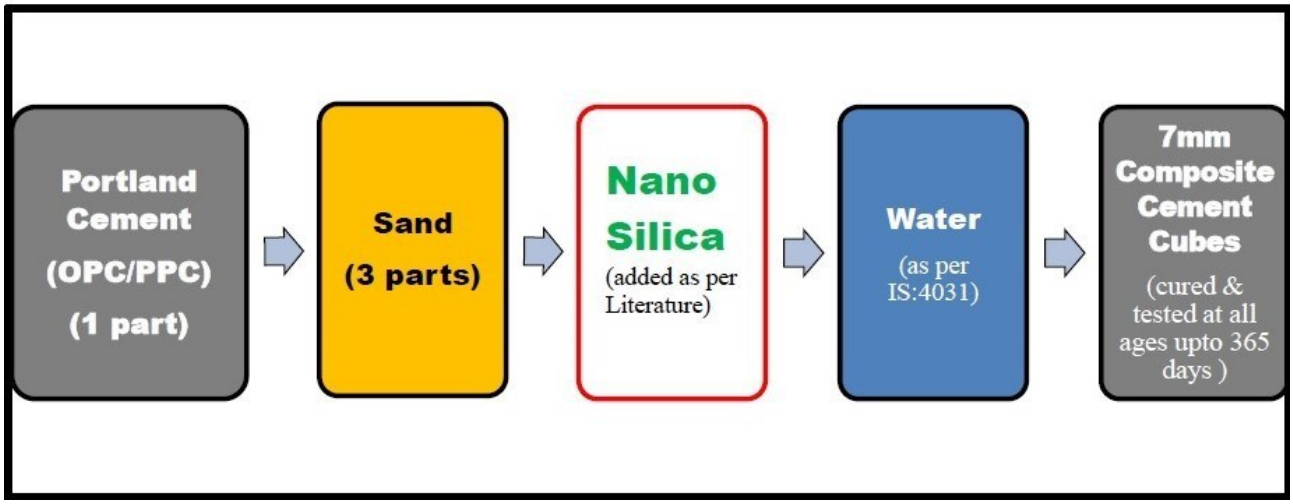


Figure : A Schematic Diagram of the Manufacturing Processes Involved

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Experimental corrosion investigation of untreated suspension bridge main cables

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Abstract

In this research, focusing on the phenomenon that the general part of the suspension bridge main cable located in the mountainous/plain area corrodes unevenly toward the upper surface of the cable and aims to elucidate the corrosion mechanism. As a result of investigating of corrosion environment and a corrosion acceleration test using a simulated rope, it was found that there is a period on the rope surface where the corrosion rate of galvanization reaches the highest temperature range. It was also found that the water that tends to remain on the upper surface of the rope is heated during the day due to rainfall and dew condensation, and that only the upper surface may be unevenly corroded.

Keywords: suspension bridge cables; cable corrosion; corrosion environment investigation; accelerated corrosion test.

1 Introduction

Cables used in suspended bridges such as suspension bridges and cable-stayed bridges are lifelines that support the roads of the entire bridge, and long-term durability is required. However, in recent years, there have been reports of severe corrosion and breakage of cables and hanger ropes of suspended bridges, leading to collapse of the bridge in the worst case, and this has become a serious problem[1)-2)].

This study aims to clarify the corrosion mechanism of the general suspension bridge main cable that is not treated with anticorrosion treatment such as painting or anticorrosion tape, located in the mountainous/plain areas far from the coast. Specifically, a corrosive environment investigation and a corrosion acceleration test is conducted using a simulated rope, and the results will clarify whether the top surface of the rope contains factors that promote corrosion.

2 Investigation of corrosive environment

By conducting outdoor exposure monitoring, it's investigated whether there are many factors that promote corrosion on the upper surface of the rope in the actual environment. Specifically, the temperature, humidity, surface temperature of rope, and wetting time, which are closely related to the corrosive environment are measured.

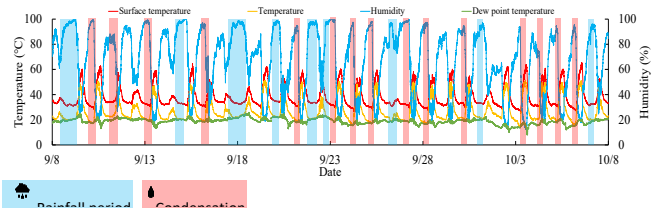


Figure 1. Results of surface temperature, air temperature, humidity, and dew point temperature

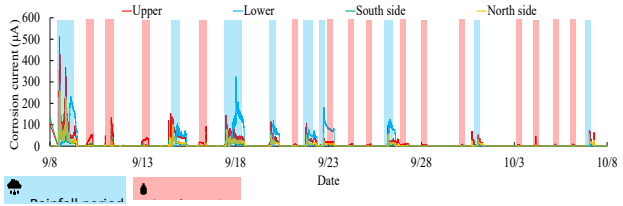


Figure 2. Measurement results of wetting time

As the results, A maximum temperature of 69°C and a minimum temperature of 24°C were observed on the rope surface. Therefore, on the rope surface, it was found that the corrosion rate of the zinc reaches around 65 °C, which is the highest[3] (Figure 1). Also, it was confirmed that there were periods during which the corrosion current was measured at locations other than the rainfall period (Figure 2). This coincides with the location where the air temperature dropped to the dew point temperature. The dew point temperature indicates the temperature at which condensation occurs when the gas is cooled, and the higher the humidity, the greater the amount of water vapor, and if this gas is brought into contact with a substance whose temperature is lower than its saturation temperature, condensation will occur. Therefore, it is suspected that the dew point temperature is reached as the air temperature drops here, and dew condensation occurs on the specimen surface.

3 Investigation of occurrence of condensation

To confirm whether condensation occurred, an investigation based on the relationship between temperature and humidity measured during the condensation period was conducted. The investigation method used a constant temperature and humidity device, set the test environment to the temperature and humidity relationship measured during the dew condensation period obtained in Figure 3, and visually checked whether dew condensation occurred on the surface of the rope test specimen. The temperature/humidity cycle test conditions were #1: temperature of 50°C and humidity of 25% for 1 hour, and #2: temperature of 20°C and humidity of 95% for 1 hour. In addition, from Figure 2, it can be confirmed that the corrosion current mainly on the upper surface is prominent during the dew condensation period. The reason for this is thought to be that dew tends to accumulate on the upper surface of the rope.



Figure 3. Investigation results of dew condensation on the surface of the rope specimen

4 Conclusions

During the summer measurement period of this study, the environment was in the state of repeated high humidity and high temperature environments, and there was a period when the corrosion rate of the zinc galvanizing on the rope surface reached around 65 °C which was the highest. Corrosion is likely to be accelerated during rainfall and condensation when moisture, which is a cause of corrosion, is supplied. In particular, the moisture that tends to remain on the top surface of the rope may be heated during the day and lead to accelerated corrosion.

5 References

[1] Colford, B. R.: Forth Road Bridge - maintenance and remedial works, Proceedings of the Institution of Civil Engineers, Bridge Engineering 161, 125-132, 2008.

[2] Nakamura S. and Miyachi K.: Ultimate Strength and Chain-Reaction Failure of Hangers in Tied-Arch Bridges, Structural Engineering International, Vol 31, pp. 136-146, 2020.

[3] G.L.Cox: Engineering, Vol23, 902-903, 1931.

ID-714

The Need for Research and Innovation to Facilitate Upscaling of Low-Carbon Concrete

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Abstract

For decades, research has been carried out with a focus on concrete structures during curing to mitigate the risk of thermal cracking. Computer programs and aids/tools have also been developed to assess stress and cracking risk analysis of concrete structures during curing. However, today with the recent introduction of low-carbon concretes to reduce the environmental impact of constructions, the reliability of the tools and working procedures, i.e. concrete characterization, is questioned, and a roadmap for research and innovation is called for. The project's primary purpose is to investigate the need for research and innovation regarding upscaling the usage of low-carbon concrete. The nature of the study is based on an industry-focused workshop with specialists from Scandinavia. Increased knowledge of hardening concrete's cracking risk-related properties is of the utmost importance for the construction industry as the need for its understanding has recently increased.

Keywords: Low-carbon concrete; Material design; Construction, Lab testing; Concrete crack control.

1 Introduction

The construction industry faces challenges with adopting low-carbon concrete (LC-concrete). Challenges that become obstacles to a fast development and implementation rate are so much needed for the industry to meet the climate goals of Society. The challenges need to be understood from a sector-wide perspective, and consensus regarding the needs, driving forces (carrots and sticks), and risks is paramount for finding a way forward. This study addresses these questions from an industry-wide and Scandinavian perspective.

2 Purpose and aim

The project's primary purpose was to explore the need for research and innovation regarding upscaling the usage of LC-concrete. In addition, the study aimed to report the discrepancy in the perspectives between the Nordic countries and between the main actors in the industry (client, design engineer, contractor, concrete material manufacturer and academics), as well as identify needs, risks, and driving forces for the usage of LC-concrete.

3 Method

The research in this study is explorative and based on the research method thematic analysis; the study uses an overarching focus group workshop as the main empirical study. The overall approach involves the following steps:

1. Pre-identification of general themes.
2. Identification and selection of focus group participants.
3. Data collection through recording and note-taking.
4. An iterative analysis of the empirics and development of the pre-identified themes.

4 Results

The results of the workshop are summarised in two systematic categories "Enablers and challenges prioritized in order of most important and urgent to stimulate the usage of LC-concrete" and "Needs and driving forces of knowledge, facilities, and competence from a sector-wide perspective to stimulate development and implementation of LC-concrete.", respectively.

5 Discussion

The group discussed the enablers and challenges of stimulating the usage of LC-concrete. Concerning the input parameters and material characterization, the group of experts listed more or less the same parameters as was found during the literature review. Activation energy and a "parameter" describing the rate of temperature development are the two main parameters and are considered the most prioritized parameters to find a solution. While on the method aspects, the group prioritized allowance for cracking and Standardisation to get comparable results between testing facilities. Standardisation was a topic repeated in several of the discussion as a benefit on several levels, e.g. for better international collaboration, availability of testing facilities and defining testing methodologies. On the other hand, it was pointed out that Standardisation often needs to be developed from an academic perspective which may hinder industry-wide implementation.

6 Conclusion

The study has explored the need for research and innovation regarding upscaling the usage of LC-concrete. The study focused on discrepancies between the Nordic countries and between the main actors in the industry (client, design engineer, contractor, concrete material manufacturer and academics). The corresponding aim was to identify the primary needs, risks and driving forces to catalyze the usage of LC-concrete. The study concluded that:

1) there exists a need for:

- More testing resources and standardized test methods.
- Understanding the involved material parameters.
- Increased knowledge of new binders.
- Consider a re-thinking about cracking, if it is feasible to allow for cracking in some cases.
- Increased knowledge about LC-concrete's long-term performance.

2) the main risks are:

- A lack of design experience in LC-concrete,
- LC-concrete's performance in the long-term perspective.
- That the knowledge generation can't keep up with the accelerating demand.

3) and the main driving forces are:

- Requirements on material and testing methods.
- Business incentives for the value chain must exist to catalyze the usage of LC-concrete.

ID-722

Opportunities in Civil Projects with Artificial Intelligence

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Abstract

The concept of sustainability encompasses three categories: economic, environmental and social. Civil projects have a large impact on all these categories and will require extensive adjustments in order to successfully meet this growing demand, especially since the number of infrastructure project is expected to increase in forthcoming years. To address more objectives than lowest price during design, is relatively rare. Sustainability performance is considered important during infrastructure project, although it most often comes down to overall cost, when decisions are made. A holistic view of sustainability could be adapted, where several objectives are optimized, to find a neat trade-off, when objectives are conflicting. The potential in increased digital support is indeed large. The amount of data managed during large infrastructure projects is huge and ever-growing. The future will probably require data-driven decision making with the support of AI, where complex problems are analysed with historic data together with advanced comparison of possible solution alternatives. Automated analysis with AI, also enhances the ability for contractors to engage in creative and innovative tasks, since focus may be shifted towards holistic solutions, rather than detail optimization. It is probable that the focus on total sustainability performance will increase in construction projects in a near future. Furthermore, multi-objective constrained optimization with AI will be an essential tool in the pursuit of pareto-optimal sustainable designs and production methods.

The purpose of the pre-study is to identify, examine and describe knowledge gaps concerning the field, regarding turnkey contracts in Sweden. Best-practice as to how opportunities are analysed and searched for in the projects of today from a contractor viewpoint are also presented, together with an evaluation of the potential with AI. Moreover, how creative, and innovative tasks are managed in projects are also examined. For the most part, turnkey contracts are addressed from their intension of contractor influence and freedom, albeit transferable points can frequently be made, for other contract types.

By a literature review together with an interview study, the intention is to examine and evaluate the subject, as to the research front of AI-methods in design phases, together with the current position of the construction sector regarding project opportunities.

The results indicate that in order to successfully meet upcoming climate goals and demand for increased overall sustainability performance, further development of methods is necessary. The client requirements are extensive and will probably not decrease when more objectives in infrastructure projects are relevant. To successfully utilize and adapt, digital tools and automated methods, are essential if these demands are to be met. From the freedom provided by a client, a contractor has an unexploited potential in finding opportunities in projects, although the tender process needs to allow for more contractor freedom to ensure that the aim of turnkey contracts is met. Requirement documents are difficult to produce but need improvement so that contractors may utilize its expertise to the full extent. To find opportunities are important and comes down to experienced personnel. Increased support in this process, by multi-objective constrained optimization would enhance contractor in their pursuit of project opportunities. Several methods exist to perform such optimization together with AI, although none conclusive best practice regarding its implementation to design and production problems exists. To systematically evaluate a project by data-driven and objective means, will enhance contractor possibility in developing competitive tender offers. Organization is key and experienced personnel are essential in present workflow for finding opportunities. To add a new player, an AI, to this procedure could be much beneficial from providing new insights to a contractor.

In conclusion, clients need to enhance contractor freedom, enabling an improved search for opportunities from creative and innovative solutions. Today, this search is in large managed by experienced personnel with reference projects, discussing a few alternative solutions. From a data-driven approach, an AI may produce solution suggestions, in order to facilitate the search for opportunities and creative designs. Further method development is however necessary for a holistic multi-objective constrained optimization regarding sustainability to produce these suggestions.

Some specific conclusions are also made, which are presented in the list below.

- Both contractor and client have a journey ahead, in order to enhance digitalization in the construction sector to reap the potential of data-driven workflow.
- Requirement documents need to improve, and contractors need to increase their ability in pursuing opportunities.
- Alternative comparisons require advancement, both in numbers and resolution in order to better support contractors in finding opportunities.
- Several methods for multi-objective constrained optimization with AI exits, however none is implemented in present projects or tender processes.
- Set-based parametric design show potential in producing large model spaces which could be combined with optimization and AI.

Keywords: Digitalization; artificial intelligence; multi-objective optimization; automation.

ID-1236

Structural Performance Assessment of Post-Tensioned Concrete Beams by Embedded Continuous Fibre Optics

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ABSTRACT

Prestressed concrete structures have numerous advantages over conventionally reinforced concrete, though the usage of post-tensioned structures has declined over the last two decades. By distributed optical fibre sensors, key performance indicators of the post-tensioned concrete specimens were monitored and evaluated. Initial losses and long-term effects affecting prestressing force, deflections and cracks were tracked and compared to theoretical calculation methods. It was found that the theoretical calculation methods mostly agreed well with results from the distributed optic fibre sensors. The loss of prestressing force due to mechanical creep and relaxation was overestimated in theoretical calculation methods by approximately 6 %, while the loss due to friction was overestimated by 0.6 %. Regarding deflections, the relative error ranged from 0 % to 3.3 % and 0 % to 2.9 % for the reference specimen and post-tensioned beam, respectively.

Keywords: Post-tensioned concrete, Distributed optical fibre sensing, Prestressing force, Rayleigh backscattering, Crack monitoring, Performance indicators.

1 Introduction

At the beginning of the 1900th-century, the usage of concrete structures was commonly connected with issues such as creep and shrinkage. These effects were not well understood at this time [1] and to solve these issues and delay the cracking of the concrete, the development of prestressed concrete structures started to take place. Even though there are several benefits to using post-tensioning [2,3], in later years, the usage of this type of system in concrete bridges has decreased, see Figure 1.

2 Purpose and aim

The purpose of this study was to investigate the usability of fibre optics to monitor the performance of post-tensioned concrete beams. The following objectives defined the purpose:

- Assess suitable performance indicators during the initial relaxation shrinkage and creep of the beam.
- Assess distributed optic fibre sensors as a means to monitor the structural performance of a post-tensioned beam.

3 Method

The scientific approach included several steps. First, distributed optical fibre sensors (DOFS) were evaluated and critically selected. Second, a design and analysis of the experimental specimens, including the deployment of the DOFS, were assessed and performed. And finally, the post-

processing of data and material tests concluded the experimental work. In this section, each of these steps is explained further.

In the last decades, researchers have found out that Optic fibre sensors (OFS) of different types can be used to measure the behaviour of structures in real time. OFS has shown several benefits, such as high durability, low weight, good stability, and good resistance against corrosion, chemicals, and electromagnetic fields. There are several types of OFS and measuring techniques and they all have different benefits and drawbacks. The main drawback with one of the most common techniques, Fibre Bragg grating (FBG), is the limitation of the number of measuring points along the fibre length. This could result in uncertainties about the actual health of a structure since data from critical sections could fall out of the measuring scope. In later years, researchers developed DOFS, which takes advantage of the full fibre length and gives a spatial resolution and accuracy incomparable to the older developed systems with point measuring. The type used in this study was DOFS.

4 Results and discussion

In the initial phase, results are presented around the time when the post-tensioning was performed. The calculated deflection and curvature directly after post-tensioning is presented. The resulting strain curves are according to common assumptions. The prestressing force causes an axial force in the whole specimen, meaning that where the curvature is zero, i.e. where $\varepsilon_{top} \approx \varepsilon_{bottom}$, there is still a compressive strain. For the top fibre, due to the post-tensioning, tension was registered in the middle section of the length of the beam. There is some difference between the right and left fibre, which might be an effect of some rotation when tensioning the steel, but overall, the alignment is accurate. For the middle fibre, the ideal result would be a constant curve, but the tendency indicates a slightly parabolic shape, meaning that the true natural layer might be closer to the top edge of the specimen than expected.

By keeping the specimens in an enclosed environment over time, it was possible to measure the long-term effects of the two specimens. For both specimens, it can be interpreted that the compression is constantly increasing, which is an effect of the main shrinkage.

5 Conclusion

In conclusion, this project studies the usage of distributed optical fibre sensors for further possibilities of measuring behaviour and key performance indicators for a post-tensioned reinforced concrete beam. By using an additional reference beam, the effects of prestressing could be determined accurately by removing effects related to solely concrete, such as shrinkage and creep from self-weight. Regarding the strain from the DOFS, the quality of the output was successful. Previous research has solely tested the usage of DOFS for reinforced concrete specimens. The findings show that the usage of DOFS is feasible for post-tensioned reinforced concrete members. By comparing results from DOFS to theoretical calculation methods, some conclusions were made. Starting with the loss of prestressing force, shrinkage and creep from self-weight were removed and only mechanical creep and relaxation were considered. The results were verified by comparing them to theoretical creep and relaxation calculations. The theoretical result was on the safe side compared to the result from the DOFS and might be a reason for the overestimation.

Regarding the force loss along the specimen due to anchor slip and friction, the results were similar. By comparing the loss of prestressing force in the active end and middle section, a relation between the loss of prestressing force over the specimen could be assessed. It was seen that the anchor slip almost affected the whole length of the specimen.

ID-1244

Implementation of Controlled Flexibility as a Seismic Strategy Towards Building Sustainable Bridge Infrastructure in India

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Abstract

The growing need for safer bridges and structures is stimulating the concept of adapting smarter techniques in bearing supports, reducing seismic risk and structural costs. Advanced isolation devices offer engineers with various options. An appropriate solution include systems that provides desired flexibility, damping, and re-centering properties. Various projects of national importance are already implementing such smarter techniques, thereby laying the foundation of sustainable infrastructure.

Performance evaluation in simulated service and seismic conditions is of immense importance. Set up to support and supplement such demanding testing needs is now available in India already backing the projects as and when required.

Keywords: Isolation devices; flexibility; damping; re-centering; performance evaluation; dynamic testing

1 Introduction

Seismic events are a major concern, causing devastation, loss of life, property damage, and economic and psychological impacts. This paper introduces an integrated approach to seismic resilience, combining advanced engineering, innovative technologies, and quality control to mitigate earthquake damage. We explore core principles and practical strategies to strengthen communities and infrastructure against seismic forces, promoting sustainability.

2 Background

Traditional seismic bridge design in India used static methods, considering seismic zone, soil, and bridge mass. After the Bhuj earthquake, a shift to dynamic approaches and Response Spectrum Analysis occurred in the Indian Codes. IRC: SP: 114 and IRC: 83 (Part II) introduced Base Isolation and Energy Dissipation techniques, enhancing seismic resilience and resource efficiency.

3 A trendsetting shift: India's new seismic strategy

India's seismic design approach has transformed significantly in recent years, embracing Base Isolation and energy dissipation techniques. This shift has led to the use of continuous deck structures in bridges, which, while cost-effective, can pose challenges by concentrating forces at fixed points.

However, strategic integration of these techniques has not only reduced forces but also ensured controlled force distribution across the substructure, preventing plastic hinge formation during severe earthquakes.

This enables seismic design with a response reduction factor of 1.

4 Pioneering seismic strategies in India: Case studies

4.1 Dwarka Expressway: Extending structural resilience through Elastomeric bearings

One of the early milestone in seismic engineering is the Dwarka Expressway project in Delhi, a seismic-prone area. It featured the pioneering use of Base Isolation with standard Elastomeric Bearings as isolators.

4.2 Sahibganj Manihari Bypass: A Triumph of Lead rubber bearings

Integrating Lead Rubber Bearings in place of stereotype bearing solutions added isolation and damping, significantly reducing base shear during earthquakes. This approach improved substructure safety and set a precedent for seismic device use in Indian infrastructure.

4.3 Delhi Amritsar Katra: Elastic Flexibility of HDRB meets exceptional resilience

Despite some damping limitations, HDRBs are popular in India for their flexibility, resilience, and recentering capabilities. Proposing such solutions has played a vital role in Delhi-Amritsar-Katra project, isolating structures from seismic forces.

4.4 New Brahmaputra Bridge: Curved Surface Sliders (Friction Pendulum Bearings) a worldwide industry benchmark

An illustrative example can be found in the construction of a major bridge spanning the Brahmaputra River between Guwahati and North Guwahati. The Friction Pendulum Bearings, with an impressive load capacity of 79,000 kN and a displacement capacity of +/- 260mm, are clearly a worldwide industry benchmark.

4.5 New Ganga Bridge at Farakka: Dynamic Solution with FVDs for unforeseen Seismic Challenges

A remarkable application of FVDs can be witnessed in the new bridge under construction over the Ganga River near Farakka in West Bengal.

4.6 USBRL Project: A Multifaceted Approach using Pre-loaded spring dampers

Base Isolation design for a major railway bridge in the Udhampur Katra Section. Notably, India has begun producing these devices, further enhancing the nation's seismic engineering capabilities.

5 Dynamic testing machine – an industry mandated versatile equipment to understand dynamic behaviour

As isolators are likely to behave in dynamic condition, it is important to do rigorous testing. The first full scale Dynamic Test Machine for Isolators is now available in India.

It is also important to have international certifications for the Isolators e.g., CE certification as a proof of meeting international standards.

6 Conclusion

Earthquakes are inevitable and are here to stay. As engineers, we can work to make structures less vulnerable and more resilient. Bearing support systems are a vital component in the gamut of structural engineering, ensuring integrity and performance during seismic events. With careful planning, rigorous testing, and advanced engineering, we aim to create more sustainable and resilient structures.

7 References

[1] Mendez Carlos, Pakniat Parinaz, Moor Gianni – Seismic Isolation of short/medium span bridges in Canada using Lead Rubber Bearings. *10th International Conference on Short and Medium span Bridges*, Canada 2018

ID-1245

Performance Evaluation of Off-Site Construction Method for Mass Housing Projects using Building Information Modelling (BIM) Approach

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Abstract

Mass housing is typically constructed in large quantities using traditional methods. However, there has been limited research on the application of modern construction methods like Off-Site Construction (OSC) in mass housing projects. In this study, we used Building Information Modelling (BIM) to assess how well OSC performs in these projects. We created BIM models for both traditional base construction and OSC, and then evaluated their cost and time efficiency. Additionally, we considered the effects of the COVID-19 pandemic on these projects. The results of our investigation revealed that OSC is a cost-effective approach for mass housing projects, significantly reducing project time by 67% and saving costs by 23%. This study contributes valuable insights to the field and may provide guidance for housing policymakers and construction professionals interested in adopting OSC and leveraging BIM to streamline project timelines and optimize workforce utilization.

Keywords: Mass Housing; Off-site construction (OSC); Structural Behaviour; Schedule; Cost; Material Management and Building Information Modelling (BIM).

1 Introduction

Mass housing is a critical need in countries like India and other developing nations. To address this need, government housing ministries have initiated various mass housing schemes and initiatives. However, achieving these targets has proven challenging due to the lack of a structured development approach. To expedite project execution and address the issue of unorganized developments, it's crucial to replace the slow and traditional cast-in-situ construction method with more efficient techniques. One such promising approach is Off-Site Construction (OSC), which is better suited to meet the demands of mass housing projects. This study focuses on virtually implementing OSC using Building Information Modeling (BIM). BIM is a visualization platform that encompasses various aspects of building elements, including their characteristics, geometric constraints, parametric relations, quantities, material inventories, cost estimates, and project schedules.

By leveraging BIM in conjunction with OSC, we aim to streamline and optimize the construction process, making it more efficient and cost-effective. This approach holds great potential for achieving mass housing targets and addressing the housing needs of our communities.

2 Methodology

Case study adopts an approach to evaluate the time and cost of a construction project by developing an Off-Site Construction (OSC) Building Information Modeling (BIM) model. This model will be compared with the conventional construction method currently in use at the case study site. The case study approach provides insights into why OSC may be preferred over conventional cast-in-situ construction, using an interpretative BIM approach. The chosen case study involves repetitive construction work, where OSC is expected to efficiently complete the project within the agreed time and budget without compromising quality.

3 Results and Discussion

3.1 Evaluation of Time

The results reported potential savings in time of 67%, which follows the study conducted by Kim et al. (2020), who reported a reduction of up to 40% in duration with the adaptation of precast double wall panels.

3.2 Evaluation of Cost

In our current study, the adoption of Off-Site construction methods yielded significant cost savings. Material costs were reduced by up to 10%, consistent with the findings of a study by (Gupta and Mukherjee in 2017). Labor costs showed a remarkable 86% reduction compared to traditional construction methods, primarily due to smaller work crews and faster construction cycles. Additionally, we observed a 100% cost saving in scaffolding expenses, as the components did not require any scaffolding support. The precast wall panels also achieved 100% savings in finishing, both externally and internally, aligning with the results of a study conducted by (V. W. Y. Tam et al. in 2015). Overall, these findings indicate a 23% cost savings per dwelling, consistent (Kanyemba's study in 2001).

4 Conclusions

Based on the research findings, we can conclude the following:

- ✓ The OSC approach in this case study led to substantial cost savings: material costs decreased by 10%, labour costs by 86%, resulting in an overall 23% reduction in mass housing project expenses.
- ✓ Implementing Off-Site Construction significantly shortened the project duration, cutting it by up to 67% and yielding considerable time savings.
- ✓ Cloud-based platforms like Building Information Modeling (BIM) can establish the necessary database for offsite construction, facilitating the assessment of time and cost in mass housing projects.

5 Acknowledgement

The research funds provided by the Indian Institute of Technology (IIT) Dharwad and NIT Warangal are acknowledged."

6 References

[1] Abid Hasan, S. ., Elmualim, A., Rameezdeen, R., & Bassam Baroudi, P. D. (2013). Housing Affordability In India: Opportunities And Key Challenges Abid. *Urbanization Challenges In Emerging Economies*, *Quigley 2008*, 462–471.

[2] Ahn, S., Crouch, L., Kim, T. W., & Rameezdeen, R. (2020). Comparison Of Worker Safety Risks Between Onsite And Offsite Construction Methods: A Site Management Perspective. *Journal of Construction Engineering And Management*, *146*(9), 05020010.

[3] Kanyemba, J. (2001). Enhancing Housing Delivery Using A Simple Precast Construction Method. *Structural Engineering, Mechanics And Computation*, 1471–1479.

Session 25

Sustainability in Transportation Structures

ID-399

Structure as Symbolism: Pylons as Tools for Cultural Expression in the Asia-Pacific Region

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Abstract

In supporting both the deck and cable weight within suspension and cable-stayed bridges, the essential function of pylons provides architectural opportunity. Dissing+Weitling presents three case studies from China, the Philippines, and Australia to demonstrate how pylons can be transformed into design drivers of a bridge's aesthetic symbolism.

Recognizing the role infrastructure can play in engaging with local and indigenous user groups, this paper examines how design choices regarding colour, negative space, lighting design, and the physicality of pylons can reinforce cultural identity. In recognizing the symbolic potential of pylons – a structural necessity – mobility architecture can provide iconic, culturally responsive, and locally meaningful infrastructure.

Keywords: pylon; cable-stayed; suspension; illumination; cultural heritage; cultural expression; indigenous stakeholders; social cohesion; placemaking

1 Structure as Symbolism

Infrastructure is an investment in community. At its most reductive, a bridge is a safe crossing – and yet the potential for each individual infrastructure development to reflect and reinforce cultural values cannot be understated. Mobility architecture provides an opportunity to infuse infrastructure development with cultural iconography. Across scales and geographies, a bridge design can provide a physical and metaphorical platform of expression.

Key to achieving this is consideration of how structural necessities can expand in scope. This paper considers the role pylons can play in maximizing cultural responsiveness in infrastructure. In recognizing the architectural potential of pylons to broaden a bridge's visual impact – a project's overall aesthetic expression can directly engage with cultural iconography that speaks to its community and most frequent users.

Pylons are incredible tools for mobility architects to design culturally responsive infrastructure. They are an essential feature of a bridge – and hold immense potential for storytelling. As a Danish architecture firm with a robust mobility portfolio across the Asia-Pacific, Dissing+Weitling works in partnership with project stakeholderes to ensure bridge designs feel as if they emerge from the place they cross.

Pylons can therefore be viewed as design drivers – key to unlocking the aesthetic expression of entire structures.

2 Longmen Bridge

A major component of the Guangxi Binhai Expressway connecting the Beibu Gulf Economic Zone – the Longmen Bridge is the first mega bridge in Guangxi Province. The project scope asked the design team to consider was asked to consider how the bridge's visual impact could not only be a landmark – but a physical embodiment of regional

culture. This design constraint was met with an additional consideration: the client requested incorporation of painted colour and Chinese storytelling into the design concept.

Inspired by cultural visual and architectural traditions, the H-Pylons of Longmen are reimagined as two traditional Chinese gates. Placed on either side of the water crossing, they become striking points of entry and departure – providing a spatial connection for the user between bridge and landscape. Dissing+Weitling's architecture approach to Longmen combines a desire for an effective transportation solution with a transformation of bridge into destination.

3 Cebu-Cordova Link Expressway

Opened in April 2022, the Cebu-Cordova Link Expressway (CCLEX) is the longest and tallest bridge in the Philippines. Improving connectivity and reducing traffic congestion – the bridge connects the Mactan Island town of Cordova with the nation's second largest city, Cebu City and reduces travel time between the two islands by approximately forty minutes.

Embracing the pylons as tools for cultural and architectural expression, the architectural team engaged in an iterative process to arrive at a design that could directly pay homage to the history of Cebu. Working with the central concept of Magellan's Cross – and its historical evolution as a symbol of Filipino Catholicism, waymarking for Cebu City, and contemporary tourist destination – pylon design was a sculptural process.

CCLEX demonstrates how the bridge structure can reinforce cultural identity: no additional ornamentation is added to the pylon – the cross emerges from the manipulation of the structural design. While the pylon is certainly the signature of the infrastructure – the cross is not overbearing, even when illuminated.

4 Swan River Causeway

Swan River Causeway's development process has been intentionally structured to allow users to co-create the aesthetic expression alongside designers and Mainroads Western Australia. This is rooted in the recognition and acknowledgement of the site's importance to Aboriginal people – and a genuine, good faith desire by all project value chain participants to respect the cultural heritage, values, and symbolism the Traditional Owners and land stewards.

Dissing+Weitling's role as mobility architects within the project team has been to take each visual concept and integrate it into something architecturally cohesive and structurally buildable.

The symbolism of the snaking path, the wanna, and boomerang pylons, detailing on the bridge furniture, and views out into the riverway are all individually significant and collectively meaningful. Where the project design and engineering team has succeeded in ensuring Swan River Causeway's buildability – the bridge is a striking success story for how local and indigenous stakeholders can be active participants in co-creating their own cultural heritage.

5 Pylons as Cultural Heritage Drivers

A key opportunity in mobility architecture is ability to integrate cultural symbolism into the aesthetic expression of a bridge. Pylons emerge as powerful design drivers – with potential for abstract or literal sculpting to reflect visual identity for local users. Like their role as gathering point for cables – pylons can serve as the unifying force for an entire design theme.

Where engineering may view pylons as design parameters, architecture embraces them as design drivers. Together with clients, project stakeholders, and users – mobility architects can leverage the physicality of pylons and the centralizing role they play within the aesthetic expression of a bridge to ensure infrastructure developments are active contributors to the cultural heritage of the built environment

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ID-499

Use of Waste Plastic for Road Construction in Delhi NCR Region

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Abstract

Bitumen plays a vital role in binding the aggregates together by coating the aggregates thereby imparting strength to the road. However, the performance of these bituminous binders is questioned time and again, given that they are brittle and hard in cold environments and soft in hot environments. Use of waste plastic in bituminous mix has revealed improved performance, stability, strength and fatigue life, reduction in overall rutting. But this improvement in properties of bituminous mix depends a lot on the type of waste plastic used. Various factors like; size of shredded waste plastic, type of plastic, thickness of plastic, temperature of aggregates, addition method of waste plastic affects the performance properties of the bituminous mix. This paper discusses about the implementation of waste plastic technology in construction of roads in Delhi NCR region by adopting dry mixing process. Most of the roads under this project were constructed by following IRC SP 98:2013 and 8% (by weight of bitumen) of waste plastic was used whereas on one section in NCR region higher dosages of waste plastic was used (upto 3% by weight of the mix). After construction the performance evaluation of these roads was carried out. It was studied how the dosages of waste plastic affects the performance. The effect of type and size of waste plastic on asphalt mix was also studied.

Keywords: Plastic waste; modified asphalt mix; waste plastic road; plastic recycling

Internal roads in Delhi were to be constructed by using waste plastic for resurfacing of 20km roads. One stretch was constructed with 8% of waste plastic by weight of bitumen as per IRC SP 98. A small section of 500m was constructed as a trial with higher dose of waste plastic i.e. upto 3% of waste plastic by weight of mix. Properties of bitumen and aggregate were evaluated as per IS - 73 2013 and IS 2386 respectively. Upon investigation of materials it was found that the bitumen was as per IS 73 and aggregates were satisfying MoRTH 2013 specifications. The waste plastic samples were checked for its melting point. Mettler – Toledo DSC was used for the analysis. It was found that waste plastic sample has melting point of 122.2°C and would be able to melt and coat the aggregate at mixing temperature of 155-160° C.

Table 1 Properties of waste plastic

S.No	Description	Tm (1 & 2), °C	Tc (1 & 2), °C	Findings
1	Waste plastic	122.2	108.5	LLDPE/ LLDPE & LDPE

Tm: melting temperature, Tc: Crystallization temperature

The mix design was carried out as per Asphalt Institute Manual MS-2. Ministry of Road Transport, Vth revision and IRC 111-2009 specifications for Dense Bituminous Concrete Grade - II mix was followed in finalizing the mix design. Waste plastic mix was prepared in accordance to IRC SP 98 2013.

In one section dosage of waste plastic was 8% by weight of bitumen and Optimum binder content is

5.5 % by weight of Mix whereas another section as trial was constructed with waste plastic dosage of 3% by weight of mix. After finalizing the mix designs road construction work was carried out. In the batch mix plant, the total batch load, quantities of aggregate and bitumen was known as per job mix, total amount of waste plastic (WP) was calculated (as per 8% dose) and weighed and the total weighed amount was added manually. The aggregate is heated to 170 - 180°C in hot mix plant. The shredded plastic waste is then added in specified proportion. Immediately the hot bitumen VG-30 grade (160°C) is added. The mixture is then transferred to the road and the laying is carried out at 120°C.

To assess the overall condition of the project roads, visual inspection was carried out. Complete road section was covered during visual inspection and various surface distresses such as fracture (cracks), disintegration (raveling, potholes etc) and defor-mations were recorded. In order to obtaining/assigning the overall rating to different roads, collected pavement distresses are processed/compiled as per IRC:82-2015.

It was found that section with higher dose of waste plastic (more than 1% by wt of mix) shows early signs of distress whereas the section with 1% waste plastic (by wt of mix) and with 8% of waste plastic (by wt of bitumen have shown good condition after 1 year and no sign of distress.

To assess the structural condition of the project road Benkelman Beam rebound deflection test was done as per IRC: 81-1997. The cores from bituminous layers were extracted from various locations of the sections. Depth of cores was limited up to top bituminous layers only. The BBD deflection data shows that sections with 8% waste plastic by weight of bitumen gave least deflection and best performance. Core evaluation data also showed that if higher dose of waste plastic is added in bituminous mix then the Marshall strength of mix reduces. Higher doses of waste plastic makes the asphalt mix brittle.

It was also found that if the waste plastic is not shredded properly to specified size and high melting point material is used to construct bitumen roads then the waste plastic will remain un-melted and it will not coat the aggregates due to which reduced performance of the road will be observed.



Photo 1: Section with 3% WP Section with 2% WP Section with 1% WP



Photo 2: WP Road (8% waste plastic by weight of Bitumen)-Church road Delhi Cantt.

ID-682

Indian Institution of Bridge Engineers (IIBE) for Sustainable Construction of Bridges

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Abstract

IIBE (Indian Institution of Bridge Engineers) has been proactive in the field of promoting sustainable bridge engineering for the past 33 years in India. In fact, IIBE is the only professional body dedicated to bridge engineering only. Among the various knowledge dissemination events, it has been organizing webinars, conferences, panel discussions, workshops, technical visits, etcetera. One of the annual flagship events of IIBE is BRIDGExxx (Year no). First one of its series was started in 2018 in Lucknow (BRIDGE 2018) with over 300 participants. Later in Patna with over 400 participants in 2019 (BRIDGE 2020). In the years 2020 and 2021, they were organized as webinars. In 2022, it was organized in Pune (BRIDGE 2022) with about 300 participants. BRIDGE 2023 is held in Hyderabad. One of the main focuses is reduced construction time, reduced carbon footprint, conservation of natural resources, conservation of environment, etcetera all leading to sustainable construction of bridges.

Keywords: knowledge dissemination, sustainability, carbon footprint, speedy construction

1. IIBE Promotes Bridge Engineering Leading to Sustainable Construction

IIBE is the professional body dealing exclusively with bridges for promoting bridge engineering in the country. India being a large country needs variety of techniques to construct the large number of bridges. Established in 1989, IIBE has been organizing various conferences, seminars, exhibitions, lectures, panel discussions, etc. It celebrated its Silver Jubilee in the 2014 wherein the Chief Guest was Honorable Minister Road Transport & Highways Shri Nitin Gadkari ji. In order to encourage bridge engineers involved in pioneering works, IIBE organizes award functions from time to time. Even during the Covid period, IIBE continued with the trend of knowledge dissemination through digital platform. Even the annual flagship events BRIDGE 2020 and BRIDGE 2021 were held online which received excellent response from delegates, speakers and sponsors. In other words, **life never stops**. These annual flagship events were started in the year 2018, BRIDGE 2018 held in Lucknow, followed by BRIDGE 2019 in Patna. After BRIDGE 2020 online event, BRIDGE 2022 was held in Pune. And BRIDGE 2023 in Hyderabad.

2. IIBE's Contribution in Learning from Failures

It is well understood that numerous failures have been taking place in the country. IIBE recognizes these and trains professionals to deal with such cases and prevent them in first instance. For this purpose, workshops / conferences have been held.

3. IIBE Honors the Worthy

An awards event was held in July 2022 wherein Life Time Achievement awards were given.

4. IIBE's Knowledge Bank

With a base of 7000 members IIBE has a strong force of highly knowledgeable bridge engineers. The Executive Committee (EC) members of the IIBE Head Quarter (HQ) all a very selected lot with unique skillset. Similarly, the Chairpersons and EC members of the local centres are highly motivated and knowledgeable technocrats. Some of them are teaching faculty members. In addition, IIBE has contacts with several national & international technocrats. All the above knowledge bank is striving to make technical contribution to the growth of IIBE and share their knowledge. Hence, one can say that IIBE has no dearth of knowledge. It is proactively involved in teaching its professionals innovative ideas towards sustainable construction of bridges.

5. Concluding Remarks

It may be concluded that IIBE has immensely contributed towards the growth and sustainability of bridge engineering in the country. It has actively propagated the concepts of speed, economics, conservation of natural resources, reduction of carbon footprint (greenhouse effect), use of alternative materials, suitable techniques for design & construction of various types of bridges, etc. As a part of sustainability drive, IIBE has also focused on aesthetically pleasing structures in urban areas for masses' appreciation.

ID-116

Sustainable Solutions for Major River Crossings in Bangladesh

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Abstract

Bangladesh sits on the river delta formed as the Padma river enters the Bay of Bengal. Much of the country sits just above the water level and the topography is characterised by a vast network of rivers, some of which are several kilometres wide. In recent decades, the country has seen the need for development of its transport infrastructure to support, its economic growth. A major challenge has been the design and construction of river crossings which have encountered deep scour channels and poor ground. COWI has developed designs for several major bridge crossings in the south and east of Bangladesh. Along with this, COWI has developed designs for platforms to support high voltage transmission line towers which adopt the same engineering approach as applied to bridges.

Keywords: bridge; driven-piles; scour; braided river; river-delta; HV crossing; platform

1 Introduction

Bangladesh's GDP has grown by an average of 6% year on year over the last two decades. Over the same period, its population has grown from 130 Million to 170 Million and has shifted towards urbanisation. Together with an expansion of the manufacturing base, this has significantly increased the pressure on highway and railway transportation network .

Much of Bangladesh is low lying and located on a vast delta formed by the river system at the east end of the Himalayas. Dominating the delta is the Padma River, referred to as the Meghna River in its lower reaches, which is formed by the confluence of the Bramaputra River in Bangladesh and the Ganges from India.

Mean river flow at the Padma Bridge crossing is 30,000m3/s and peak flow is around 135,000m3/s (50 year return period).

2 Ground Conditions

Most of the southern and most populus part of Bangladesh sits on deep alluvial deposits. These are typically finer grain deposits with increasing silt content towards the south.

Coupled with this, scour channels on the Jamuna and Padma river can reach -47m PWD due to general scour alone, which are made even deeper by the effects of local scour. This has required piled foundations down to -122m PWD. Typically, piles consist of driven steel tubes up to 3m in diameter, utilising offshore construction techniques or large diameter bored cast in place piles. For the former, either the soil in the casings is removed and the pile concreted or, when driven open ended to full depth, the casing forms a partially plugged pile. For bored piles, the challenges revolve around concrete delivery to mid-river locations, cleaning the pile base and base grouting. Given the large capacities of the piles, static load testing is limited to smaller diameters.

3 Bridges

3.1 Span Configurations & Typologies

Economic bridge solutions are typically post tensioned concrete girders for spans up to 120m and extradosed options for spans up to 250m. Navigation on the Bangladesh river systems is typically limited to vessels of up to4000 DWT with little likelihood of this increasing in the longer term and therefore longer spans are not justified. Lack of steelwork fabrication capacity within Bangladesh has led to concrete being the dominant material.

COWI has recently completed feasibility studies for major bridge crossings of the Meghna, Paira, Bhola, Karkana and Bishkhali rivers. A range of foundation options, span and deck configurations were considered including cable stayed bridges. Generally, extradosed solutions were found to be favourable and COWI has further developed a design for the Meghna Crossing to enable construction to start imminently. Within this, a solution with a central plane of stays and a concrete box with a steel delta from to transfer the cable forces into the webs was found most favourable.

3.2 Bridge Deck Cross Sections



Typically, the functional cross section provided is no more than two highway lanes each way. Padma Bridge, opened in 2022, has an additional hard shoulder and also carries a single rail track on the lower deck whereas Jamuna Bridge, opened in 1997, has two narrow lanes each way and a narrow

Figure 89 Typical Deck Cross Section for Extradosed Bridge

guage railway. A dedicated rail crossing, adjacent to Jamuna Bridge, started construction just 20 years after Jamuna Bridge was opened, perhaps suggesting that a current day economic forecast would be very different.

4 High Voltage Power Line Crossings

COWI has prepared the detailed designed of two 400kV high voltage crossings of the Padma River, close to the Padma Bridge. These typically have spans of 800m although longer span options are feasible, Although the transmission towers rise around 180m above the scoured bed level, the vertical pile loads are somewhat lower than the loads experienced on some of the bridge foundations. As a consequence, the solutions adopted have consisted of vertical piles driven open ended, thus eliminating the expensive and time-consuming task of base grouting. Like the bridges, extensive dredging was required to permit access for construction.

5 River Training Works (RTW)



Figure 90 – Piling for 400kV Platform within dredged channel

The river morphology is particularly complex in the upper reaches where Jamuna Bridge is located, as evidenced by satellite images. Channels are highly dynamic and the banks prone to extensive erosion. Whilst the river bank is somewhat more stable at the Padma Bridge site, a fixed crossing requires extensive and costly river training works.

6 Market Capacity

International experience working in partnership with the local supply chain has been vital to transfer skills and technology and to manage risk. In this regard, the BBA has been at the forefront of importing international experience and expertise.

ID-122

Top-Down Construction in Railway Projects: A Sustainable Solution

Ankit Gupta

Abstract

This paper discusses an innovative construction approach that was implemented in the Western Dedicated Freight Corridor (WDFC) in India to facilitate the construction of viaducts over the depressed railway line in advance of earthworks. This approach helped to de-link earthwork and concreting activities, which would have otherwise affected the scheduled program. The structures were completed ahead of the earthworks team being mobilized; a practice not often used in the industry. This approach not only facilitated the program but also helped the Contractor to eliminate falsework and some parts of the formwork.

The paper highlights how design solutions evolved through the construction challenges and design innovations between construction and design. Design innovations drive the economy and positively impact the social and environmental fabric of the society within the built environment. The WDFC project is a part of the Indian government's commitment to low-carbon economic growth and energy-efficient transportation systems. To achieve this goal, a study was conducted to evaluate the effects of GHG emissions over a 30-year period under two different scenarios, with and without the implementation of the DFC. The study concluded that the DFC scenario would lead to significantly lower GHG emissions compared to the no-DFC scenario.

The paper also emphasizes the importance of sustainable construction practices in achieving a net-zero emission goal. The innovative construction approach used in the WDFC project is an example of sustainable construction practices that can help achieve this goal. The paper discusses the use of slender piles and concrete structures, which are both sustainable and eco-friendly.

In conclusion, the paper highlights the importance of design innovations and sustainable construction practices in achieving a low-carbon transportation system. The innovative construction approach used in the WDFC project is an example of such practices that can drive the economy while positively impacting the social and environmental fabric of the society within the built environment.

ID-392

Planning Zoji-La Tunnel for Sustainable Ecosystem

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Abstract

Mega infrastructure projects often pose a risk of damage to ecosystem in the form of loss to tree cover, soil and topography degradation, excavated muck disposal, and risks to human & Wildlife besides causing air and water pollution. Yet development of these projects are essential for socio-economic development of the region. The need is to have a careful planning keeping in view sustainable development with least damage to the ecosystem. The paper brings out a project study of Asia's longest Zoji-la tunnel of 14.15 km length connecting Kashmir to Leh as to how planning can bring out least damage to the ecosystem while addressing muck disposal problems by usage of excavated stuff, faster construction methods and ultimately bringing out huge saving in construction cost.

Keywords: Ecosystem, topography, degradation, planning, risk, pollution, muck, sustainable, development

7 Introduction

Zojila tunnel project was first conceived in 2005 to provide an all weather connectivity between Srinagar valley and Leh(ladakh plateau) on NH-1 and to bring about an all round economic and socio–cultural integration of Jammu & Kashmir(Now UT of J&K and Ladakh). It involves construction of a 14.15 Km long tunnel at an altitude of about 3000 m under Zojila pass (presently motorable only for 6 months in a year) on NH-1 connecting Srinagar and Leh through Dras & Kargil

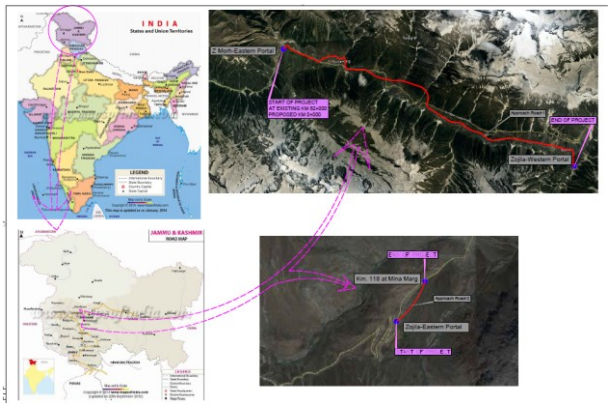


Figure1: key Plan

It is one of the most challenging stretch in the world to drive besides being geo-strategically sensitive.

Detailed Project Report was first prepared by BRO in year 2013. The project was earlier approved on BOT(Annuity) in Oct, 2013 at a total cost of Rs. 9240.27 crore.

Attempts to award the project four times weren't successful as the project was designed on BOT (Annuity) mode. Government took a decision to take up the project on EPC mode in Nov, 2016 by NHIDCL.

NHIDCL awarded the construction of 2-lane Bi-directional, 14.2 Kms long tunnel with a parallel escape (egress) tunnel after deleting the approaches to M/s ITNL at a cost of Rs4899.42cr($593million). Work commenced in May,2018, however owing to financial constraint at contractor's end, contract was terminated.

Consequent upon termination of contract agreement in 2019, NHIDCL revised the proposal to provide uni-directional twin tunnel, at a revised cost of tunnel projected by NHIDCL was Rs 8357.87cr. Further a separate proposl for approache of 20 km was also proposed at a cost of Rs2500cr. Thus total project cost worked out to Rs10857cr.

Government considering cost very high directed to call for a meeting of experts on tunnelling and referred the matter to the DG (RD) & SS on 26.2.2020 to firm up the modalities of project configuration and implementation, to achieve project completion in least possible time and cost.

Remodelling of project with Rational planning

A series of meetings were held with experts since 6th April, 2020 onwards to deliberate on various issue ie. Tunnelling Methodology, Tunnel configuration,Provision of vertical ventilation cum construction shaft, Risk Management during construction phase, Possibility of appointing more than one Contractor, Approaches & Tunnel to be implemented under single Contract. Cost estimate were also thouroughly examined and rationalised for EPC mode of contract.

It was opined that as per international norms and codes, either two single tube tunnel or one bi-directional tunnel with egress passage is required. It was deliberated that Zoji-La tunnel can considered for construction as single tube with bi-directional traffic with ventilation shaft at suitable place to be decided by the EPC Contractor along the length of tunnel and the appropriate equipment viz. air purifier (Electrostatic Precipitator) as the egress tunnel cannot be upgraded to another traffic tunnel with economy. It was also decided that Zojila Tunnel project shall be implemented as an integrated project under single Contract including its approaches.

4.6 Cost of Integrated Project

It was observed that Civil Cost of the Project also include a provision of Rs. 908 Cr for site facility and a time dependent cost of Rs. 229.61 Cr. Under the EPC /HAM contract, it is the responsibility of the Contractor to develop the site, being incidental to the main project and no separate payment is made for that. Furthermore, when a provision of escalation is made in the Estimate, the provision of time dependent cost is a duplicate provision and need to be deleted. Accordingly revised rationalised cost worked out.

On above recommendation govt approved the project and tender invited. Successful bid amount was Rs4509.5cr and project progressing very well. This received wide appreciation from Government.

The capital cost of approach road from Zozila Tunnel to Z-Morh tunnel (18.63 Km) to make the road all weather was worked out to be Rs.2335 Crores as per the DPR. The construction cost of Zozila tunnel was worked out at Rs. 6575.85 Crores after considering the escalation @ 5% per annum and the total capital cost of combined project of **Zozila tunnel and approaches upto Z- Morh tunnel worked out to Rs.10643 Crores**. Now comparing to the present cost of the integrated project, based on the tender received at Rs. 4509.5 Crs, the total capital cost of the project would be Rs. 6808.63. Thus, after re-modelling of the project & reaping the benefit of integrated project management by utilizing the excavated rock material generated from tunnel boring, in construction of approaches, resulted in an **anticipated saving of Rs. 3835 crore** besides resolving the issue of muck disposal to a great extent leading to environmentally sustainable development besides cost saving.

Proper planning of a project considering environmental sustainable methodology of construction saves cost of construction, ease of doing business and accelerated construction. This also saves avoidable environmental degradation. Therefore while planning a project, above points must be kept in mind.

Session 26

Case Studies in Sustainable Materials,

Technology and Practices

ID-520

Case Study on Re-Use of Dismantled Concrete Drain in A Highway Widening Project of India

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Abstract

The world needs a sustainable and climate resilient construction practices because of the desire to reduce environmental pollutions, save natural resources, reducing health hazards, minimize waste and save the project cost.

Environment scientists are saying that use of natural resources is one of the greatest sustainability challenges of the 21st century, means a commitment of finding and implementing efficient construction practices are to be developed by the engineers for a sustainable future.

One of such engineering initiative undertaken is narrated as case study of re-using the dismantled concrete drain in a highway widening project of India is thus undertaken to exemplify and motivate the engineers to adopt a smart and environmentally-conscious choice of saving the resources.

Keywords: Highway; Sustainable; Natural Resources; Environment; Health Hazard; Reuse

1 Introduction

India's focus on upgrading and expanding its road infrastructure is a significant step towards achieving world-class standards in transportation. With the second-largest road network in the world, road transportation plays a crucial role in the country's economy, accounting for 64.5% of all goods transported and serving almost 90% of total passenger traffic.

Under the Bharatmala Pariyojana Government of India with a target to convert 6500 km of existing 4-lane National Highways into 6-lane National Highways under Phase-V of National Highway Development project (NHDP).

Thus, it is evident that the existing 4-lane will generate huge construction and demolition (C&D) waste by concrete drains and at same location the widened 6-lane will need similar length of new longitudinal concrete drains for which materials are to be procured.

1.1 Objective of Study

At same location, highway widening generated incidences of material losses, C&D waste, incurring additional cost but no additional value. Thus, the case study in this paper aims to:

- Give significant attention on finding sustainable practice to Reduce and Reuse concrete waste that can be undertaken by the design consultant and the contractor for cost-effective environmental construction solution.
- Minimise the carbon emission by reducing the usage of cement in construction of highways.

Thus it is essential for engineers to implement sustainable practices for achieving the desired goal.

1.2 Importance of Reuse and Recycle

Concrete structures are a form of demolition waste that is in no way, shape or form biodegradable. The concrete that is disposed of today, while gradually crumble away but still be filling the land area which will be useless for years. The dumped concrete causes hindrances in the easy movement of local people. Recycling reduces the need for extracting (mining, quarrying and logging), refining and processing raw materials all of which create substantial air and water pollution.

1.3 Case Study: Reuse of existing concrete drain

The project from Etawah (km 323.475) to Chakeri (km 483.687) section of NH-2 (now NH-14) in the State of Uttar Pradesh falls in the Delhi-Kolkata arm of the Golden Quadrilateral. In existing 4-lane section, the RCC drains are located at a distance of 15m to 18m from centre line, and in 6-lane section they are proposed at a distance of 22m from the centre line. Thus, the necessity of relocating existing RCC Drain arose, due to change in the cross-section of the road from 4-lane to 6-lane.

There are three options available:

- Construct new drain at new location and dismantle existing drain;
- Relocate existing RCC Drain to new location
- Combination of above; relocating existing drain to new location wherever feasible and construct new drain at remaining locations.

The construction history from NHAI revealed that the existing RCC drains were constructed during 2001 to 2007, and it was found in very good structural and functional condition.

1.4 Impact of Relocation of U-Drain

The concrete recovered from dismantling of existing drain is in no way, shape or form is biodegradable. The concrete recovered that is disposed off today, shall gradually crumble away but still be filling the land area which will be useless for years. Further, the dumped concrete causes hindrances in the easy movement of local people. This leads to environmental degradation. It is estimated that 1km of existing RCC U-drain will require around 1000cum. of concrete dismantling and disposal.

The relocation of existing RCC U-Drain structures to new position is a small effort by concessionaire to reduce the overall carbon footprint of the project on the environment.

1.4.1 Cost Comparison

Calculating the bill of quantities for new concrete drain vis-a-vis the proposed construction involves the relocation of existing RCC U-Drain. The later option gave overall savings of approximately Rs. 70 Crore for 89 kM. of longitudinal Drain. Thus, the sustainable innovative construction practice gave overall savings over the traditional construction practice with tangible environmental benefits for the future.

2 Conclusion

The reuse and recycle of concrete structures can help alleviate the problem of raw material shortage and decrease environmental pollution and ecological footprint. By diverting concrete waste from landfills to reusing it in new construction, the industry can contribute to a more sustainable and circular economy.

It is absolutely essential to protect our environment so as to stop the causes leading towards many catastrophes and natural disasters. The challenge that confronts us are increasingly been measured in Global rather than National terms regarding the need for reutilization of Concrete Structures in effective manner. With this aim in view, it is appropriate to examine the various possibilities of reuse of waste materials, more so, in Civil Engineering construct.

ID-556

Design of Tall Railway Bridges in North Eastern States, India

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Abstract

Northeast Frontier railway (NFR) intends to connect Manipur, Mizoram and Nagaland with rest part of India. The railway lines pass through eastern trail of Himalaya resulting construction of large number of tunnels and bridges. The entire area is under seismic zone V. The heights of the piers vary from 20m to 141m with maximum length of bridges 700m. The configurations of the bridges were finalized taking into consideration of the parameters like span, location of the pier on the hill slope, constructability, maintainability, safety and economy. Multi modal analysis using site specific spectrum, spectrum compatible time history analysis and spatially varying time history analysis was performed to understand the behaviour of the structure under seismic and deformed shape of the continuous rail on the superstructure for safety of the train movement. Wind tunnel analysis was performed to understand the behaviour of bridge under wind force.

Keywords: Tall piers, High seismic zone, Slope stability, Site specific spectrum, Spectrum compatible time history analysis, Pushover curve, Spatially varying time history analysis, Track movement, Wind tunnel test.

1 Introduction

Indian Railway intends to connect the capitals of the four North-East states. The alignments of the railway lines pass through steep rolling hills of Patkai region, eastern trail of Himalaya, and as a result large number of tunnels and bridges need to be designed and constructed. While the high mountains are penetrated by tunnel, the deep gorges between the mountain ridges are connected by tall bridges. The tallest of such bridges spans over a gorge at about 140m above its bed level with an overall length about 700m at rail level. With extensive study and discussion on possible alternative span arrangement of the bridges, considering the parameters like the length of span, type of span, location of the piers, constructability, maintainability, safety and economy it was finally decided that main superstructures would be steel open web through type girders of span up to 103.5m (c./c bearing). The piers are of RCC hollow type with the tallest piers of 141m height. Other piers on the slope of the hills vary from 20m to 120m height. The foundations were designed with 1.5m diameter piles that penetrate into rock layers with maximum length of 30m. The critical issues of analysis and design involve preparation of site-specific spectrum for seismic design of the bridge, spectrum compatible time history analysis and spatially varying time history analysis in order to check the track movement in transverse direction for safe movement of train, rigorous slope stability analysis of the hill slopes on which the tall piers are standing, wind tunnel analysis to ascertain the actual behaviour of the structure in wind, fatigue analysis of superstructure with the latest provision of fatigue. A considerable length of track in Manipur has been opened for traffic in which the tallest pier of the bridge is 100m. Apart from Indian Railway Standard, other codes like IS Indian Standard, Indian Road Congress, American Railway Engineering and Maintenance-of-way Association, International Union of Railway and Euro code

provisions have been considered. The paper presents the steps followed for making these bridges as sustainable structures in a highly seismic zone at optimum cost.

2 Critical design issues

2.1 Construction material

Due to the remoteness of the area high grade of concrete has been avoided. The presence of hilly winding road governed the length of chords of superstructure.

2.2 Slope stability

Extensive slope stability analysis has been performed using software STED. PLXIS software has also bene used to get the deformation of ground. Soil parameters have been considered judiciously by using various available methods.

2.3 Site Specific Acceleration Spectrum

The site-specific seismic acceleration spectrum was generated and was found that the PGA was very close to the value suggested by IS 1893 while the spectrum is considerably higher than that of suggested in code.

2.4 Spectrum compatible time history analysis

El Centro time history has been used for the time history analysis after it was properly scaled to make compatible with site specific spectrum.

2.5 Spatially varying time history analysis

Asynchronous motion for each pier has been generated using the El Centro time history and was used for checking the track movement to ascertain safe movement of train.

2.6 Pushover curve

Pushover curve was generated for the pier sections to estimate response reduction value R. Mander's stress strain curve has been considered for this purpose. It was found that the available R value is to the tune if 3.5. However as suggested by the code the value has been considered as 1.



Figure 1. One of the tall bridges in Manipur – span arrangement 1x28.5+4x103.5+1x69+1x28.5 with maximum pier height 100m

2.7 Wind Analysis & Wind Tunnel Test

Wind tunnel test has been done at National wind tunnel facility at IIT Kanpur. It was found that the responses obtained in the test corroborates with the analytical response values.



Figure 2. Wind tunnel test

2.8 Inspection, Maintenance, Illumination, Ventilation

Elaborate steel ladder inside the hollow piers has been erected for inspection and maintenance. Separate illumination and ventilation arrangement have also been envisaged.

3 Conclusions

The different aspects as discussed have been taken in to consideration with due importance to achieve safe and sound structures with optimum cost.

4 Acknowledgement

NF Railway Engineers, TAG, IIT Guwahati, IIT Kharagpur, IIT Kanpur

ID-559

Residual Fatigue Strength Assessment & Rehabilitation of Rajendra Setu, Mokama, India-Case Study

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Abstract

Rajendra Setu (Rail Cum Road Mokama Bridge) was constructed in 1959 over river Ganga on NH-31 is of Span 3 x18,30m + 2 x 30,50m +14 x 121m + 2x30,5 m + 3x18,3m. The bridge was originally designed for BGML loading at railway level and 2-Lane Class A or 1-Lane Class AA at roadway level. East Central Railway intends to use the train for 25T – 2008 loading which is of higher loading standard than it was originally designed for and wanted to check the residual fatigue strength and to do the necessary modification for this purpose. This paper presents the steps followed for assessing the residual fatigue strength of the truss members and the railway & roadway floor system, i.e. the railway stringers & its connections and roadway stringers. The reason for the damage of the connection of the railway central stringers with rail cross are also assessed and presented in the paper along with its remedial measures.

Keywords: Fatigue Strength, Fatigue Load, Cumulative Damage, Detail Category, Residual Fatigue Strength, Railway Stringers, Roadway Stringers, Superstructure.

1 Introduction

The Road cum Rail Bridge, popularly known as Rajendra Setu, is a bridge across the Ganges near Hathidah in Patna district and Simaria in Begusarai district. The rail traffic is located below the road level over the bridge. This was the first bridge constructed post-independence, to link the northern and southern portions of the state of Bihar. Construction of the bridge started in October 1955 and the bridge was inaugurated in 1959 by the then prime minister of India, Pt. Jawaharlal Nehru & the then Chief Minister of Bihar. The location was about 7,5 Km from Mokameh junction and about 94 Km downstream of Patna (by road).

2 Salient Details of the Bridge

Overall length of the Rail cum Road Bridge is 1852,464 m. Span arrangement comprise of 14 main spans of length 122,95m each with 2 short shore spans of 32,512m and 33,2m on either side of the main span. The spans are all simply supported open web trusses. The main superstructure is a parallel chord double-intersection warren truss structure, with half-depth verticals. The truss depth between neutral axis of top and bottom chord is kept as 18,29m. The distance between centres of truss is kept as 8,84m. The bridge caters to 2 lanes of highway on top while it carries a single BG rail track below.

3 Fatigue Assessment

3.1 Fatigue

Fatigue refers to the phenomenon of progressive and localized structural damage that occurs when a material is subjected to repeated cyclic loading over an extended period of time.

3.2 Fatigue Methodology Adopted

In this paper, we describe the methodology used to assess the fatigue life of a 63-year-old rail cum road bridge. The damage accumulated due to these constant amplitude blocks can be calculated individually and summed using Palmgren Miner's rule. The two mostly commonly employed methods for cycle counting are the "Reservoir method" and the "Rain flow method".

3.3 Fatigue Strength (S-N Curves)

The fatigue strength of the members depending upon the detail category are considered based on the S-N curves.

3.4 Partial Safety Factors

Partial Safety Factors for fatigue Assessment as per cl. 11.4 of IRS Steel Bridge Code.

$\gamma_{Ff} = 1{,}0 \quad \ldots\ldots\ldots Fatigue\ Load$

$\gamma_{Mf} = 1{,}15 \quad \ldots\ldots Fatigue\ Strength$

3.5 Traffic Models for 25t Fatigue Loading

Table 1. Fatigue load vehicles

Train	Total Load (Kn)	Train Length (m)	Load (Kn/m)
Type 1	9300	348	26,7
Type 2	14440	524	27,5
Type 3	19900	613	32,4

Similarly, Fatigue Type 6,7 & 8.

3.6 Cumulative damage factor by "Reservoir method"

The graphical plot of the stress history, in this method, is imagined as a cross section of a reservoir filled with water. The water is drained from each of the lowest points successively till the entire reservoir is drained.

3.7 Cumulative damage factor by "Rain flow method"

The rain flow counting technique is based on the visualization of flow of rain over a sequence of pagoda roofs and essentially counts half cycles. The MATLAB programmes are enabled with rain flow methodology. And we used this programme for cumulative damage calculations.

3.7.1 Fatigue Assessment for Railway Stringer

Step 1: Flexure Stress history at centre of the railway stringer due to passage of all fatigue vehicles described in table 1 is evaluated.

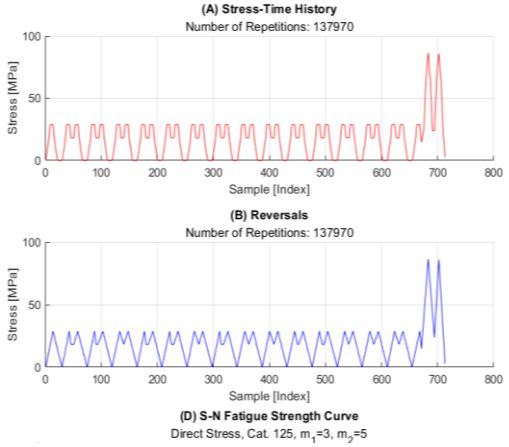


Figure 1. Flexure Stress History for Fatigue Train-1

Step 2: Cumulative damage due to each fatigue train is separately calculated in MATLAB.

Step 3: Damages at centre due to flexure due to all Fatigue trains are cumulated.

4 Remedial Measures

The Welded connection of Central Stringers with face plate at cross girder location found inadequate. To address this issue, we proposed a seating arrangement as remedial measure.

5 Conclusions

Findings highlight the importance of conducting thorough fatigue assessments of bridge components to identify potential vulnerabilities and ensure the long-term safety and reliability of the structure.

ID-571

Design and construction staging of a 300m steel bridge renovation

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Keywords: steel bridge; arch bridge; renovation; refurbishment; assessment; re-use;

1 Introduction

The van Brienenoord Bridge (VBB) consists of two steel arch bridges of 300m span, the east was built in 1965 and the west in 1990. They carry the A16 highway, a vital part of Dutch infrastructure near Rotterdam. The west arch has been suffering from fatigue in the orthotropic deck and Arup (in JV with RHDHV) was assigned by Rijkswaterstaat (Dutch highway authority), to develop a renovation for the west arch. A solution was required for the fatigue problems in the orthotropic deck and the main load carrying structure required strengthening.



Figure 38: Side view of VBB

Instead of renovating the bridge with traffic, it was proposed that a renovation outside traffic on a wharf had benefits in achievable quality and hindrance. The main objectives of this renovation where: maximizing remaining service life (100 years) in combination with re-using the maximum amount of existing steel. The paper focusses solely on the western 2nd VBB. The existing structure consists of an orthotropic deck, inverted T cross girders, two box girders as main girders, two box girders as arches, wind bracings between arches and inclined hangers.

2 Renovation scope 2nd VBB

A detailed assessment was undertaken on static strength and fatigue performance. The analysis work was combined with a full inspection. The found conclusions form the renovation scope, to extent the bridge's design life with 100 years.

- The deck should be replaced completely.
- The parallel wire hangers must be replaced.
- The arch requires strengthening over its complete length.
- The main girder needs local strengthening.
- Cross girders can be re-used with minor adjustments. The connection with the main girder needs strengthening.

Since the renovated bridge will be placed on the eastern location, a bicycle and inspection path should be placed on either side of the bridge.

3 Renovation design

An improved version of the existing orthotropic deck is installed during renovation. The increase of plate thicknesses (24mm deck plate with 8mm troughs) greatly reduces the stresses, providing a design life of 100 years.

The following design decisions were taken to ensure the static capacity of the arch cross-sections:

1. Moving the bearing position: this reduces the large bending moments near the springing point.

2. Adding strengthening plates above the hangers: causing favourable local eccentricities that counteracts the bending moment.

3. Increasing the cross-sectional area: adding steel strips to the web plates.

4. Reducing the cross-sectional reduction due to local instability: placing the strips at $^1/_{5^{th}}$ of the web height to increase stiffness for the web.

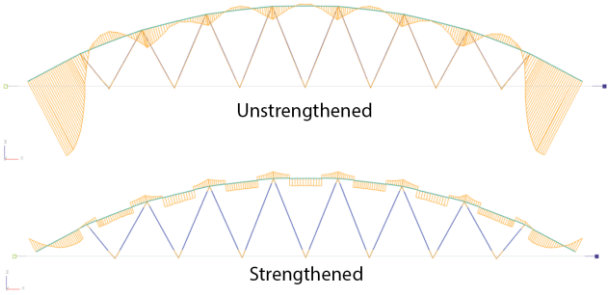


Figure 39: Moment distribution before and after renovation

The cross and main girder benefitted immensely from the new thick orthotropic deck. The main girders only need local strengthening underneath the bottom flange. For static strength the cross girders do not need strengthening at all, only local adjustments were necessary to cope with the high fatigue demand.

Parallel strand system (PSS) was chosen as a replacement for the hangers, providing a doubling of cross-sectional area and additional functionality in replacement per strand. The anchorages of the PSS are significantly larger than the current system. For reasons of safe access and minimizing changes to the existing boxes, the anchorages were placed outside the boxes of the main girder and arches.

4 Construction staging

How and when strengthening is added, impacts the stress distribution and geometry, in the different construction stages, but also in the persistent design situation. The construction staging and strengthening design are developed as one as the dependency is strong. Based on the above the main aims of the developed construction staging are the following:

- Current alignment = alignment after renovation.
- Reducing locked-in stresses; making the strengthening plates more effective, thus minimizing the additional material.
- Limit uncertainties in geometry and locked in stresses; Start renovation with a defined geometry.

The above was met by a step-by-step analysis of all historic and future construction stages. The influence of the original sequence was quantified and a reference stage, the start of the renovation, was defined to limit the uncertainties in stress state. Temporary supports underneath the main girders and arches are added, displacements were applied to relieve the stresses in the structure, before installing the strengthening plates, making them more efficient. Because the renovated bridge is much stiffer than the current construction, the main girder is lowered by approximately 200mm before the deck is installed. This is necessary to achieve the same alignment in the end condition. Tolerances in hanger forces and lengths were included in the design to make sure that there is enough room for adjustments when unforeseen hanger forces occur, to meet the strength and alignment requirements.

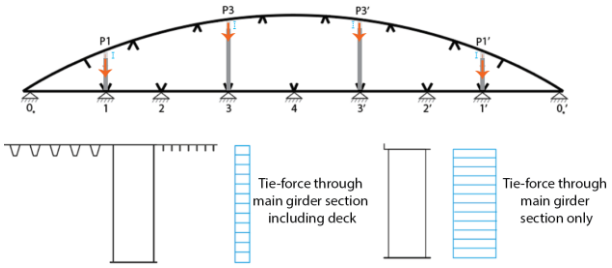


Figure 40: Releasing of self weight tie-force

5 Conclusion

The combination of detailed assessment, inspections, strengthening options and tailor-made construction phasing ensured a design that copes with all new loads to extend the lifetime with 100 years, while maintaining an identical profile to the existing situation.

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Mumbai Trans-harbour Link - A leap over Sea

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Abstract

The new Sea link Bridge over Main land Sewri on Mumbai side to Ulwe on Navi Mumbai side is characterized by some aesthetically appealing elevations of the Bridge and large spans. This paper gives an insight to the design adopted and focuses on innovative execution ideas developed to overcome challenges faced during construction of the Trans-Harbour Link Package-1 starting from Sewri end. It details out use of lean construction method followed without causing any disturbance to the surrounding environment.

Keywords: intertidal zone; temporary access bridge; reverse circulation drilling; precast shell; pre-cast segmental; orthotropic steel deck; full span marine erection; strand jack lifting.

1 Introduction

Rising traffic levels and development demands led to an old idea becoming reality with Mumbai Trans-harbour link. The project shall provide new connectivity between City of Mumbai and satellite city of Navi Mumbai besides two existing connections.

2 Overview of the project

The mega bridge is 21.8 km long six lanes wide connecting Sewri (main land) on the west to Chirle (Navi Mumbai side) on the east. About 16.3 km of the viaduct is over sea and about 0.5 km is land viaduct on Sewri side and 4.9 km is land viaduct on Navi Mumbai side. The MTHL alignment is divided in three packages as per contract. This paper shall cover only salient features and challenges faced during MTHL Package I (MTHL-1) construction.

2.1 Bridge structure

MTHL -1 includes Sewri interchange on land and adjoining 10.38 km sea bridge. There are many important under sea utilities and port facilities which required obligatory horizontal and vertical clearances to be maintained during design and even construction. Due to this MTHL-1 has special Navigational spans totalling up to 2.33 km with maximum span up to 180 m. The main bridge concrete viaduct has 6 to 7 span continuous arrangement, and the interchange and merging areas ramps have 5 span continuous arrangement.

2.2 Superstructure Deck

The Main bridge has two separate carriageways separated by a clear gap of 500 mm but are having common foundations. Majorly the Main bridge comprises of PSC box girders with Precast segments and at obligatory navigational spans of Orthotropic Steel box girder deck. The concrete bridge has internal tendons of epoxy coated (flow fill type) seven wire low relaxation strands and external tendons of seven wire low relaxation Zinc coated with co-extruded HDPE sheathing strands. The Bridge deck has a polymer waterproofing membrane beneath the riding surfacing of mastic asphalt layer. The bridge has Elastomeric bearings of mainly 2 types. Type one at intermediate Piers is and other at Expansion joint Piers is of anchored type. There is also provision of access from one

carriageway to the other under special/emergency situations through Moveable Steel Barriers (MSBs).

2.3 Foundations and substructure

The bridge foundation concept consists of large diameter bored rock socketed piles with different sizes of steel casing having inner diameters viz. 1.5 m, 1.8 m, 2.0 m and 2.2 m. Pile foundations are resting on rock strata at a depth ranging from 20 m to 40 m from sea bed level. The side friction capacity of overlaying soil is completely ignored.

The proximity to ecologically sensitive surrounding has resulted in the interesting dumble shaped design of typical pile cap, which has minimal impression on ground in mangrove zone. The navigational span foundations are designed for barge impact.

3 Construction challenges

The entire length of the bridge was categorized in two zones viz. Intertidal and Marine zone. During low tide period in intertidal zone to facilitate equipment, material, and workforce movement a Temporary Access Bridge (TAB) was constructed along the bridge.

3.1 Access Bridge construction

A self-moving Cantilever type Piling Gantry (CPG) was designed to construct 8 m wide Temporary bridge (Figure 1). An innovative self-jacking up Bridge arrangement was made to provide larger



Figure 1. Cantilever Piling Gantry (CPG)

span clearances demand of local fisherman crossing the TAB. The TAB had to face tropical storm for 2 consecutive years. Tauktae cyclone led to large amount of damage to the TAB and affected construction activities for more than a month.

3.2 Construction of Substructure

Reverse Circulation Drilling machine (RCD) was using for construction of piles in main bridge. Extensive system for water supply, sludge collection & disposal was planned for RCD operation. Jack up barge was used as platform for piling works in deep waters.

Being eco sensitive zone a lean method of construction was adopted, wherein steel brackets were welded to pile liner, over which hydraulic jacks supported the formwork system. Use of Controlled permeability form liner was made on formwork surface to improve finishing and concrete durability.

The OSD pile cap was lying in intertidal heights. It also had protection rings around the pile to protect the pile from barge or vessel impact. An innovative self-supporting system for loading precast rings and precast shell along with slabs and walls on the piles was developed (Figure 2). For concreting Marine (floating) batching plants (MBP) (2 nos.) of 60 cum cap each were used.



Figure 2. OSD pile cap soffit slab

The Main bridge has twin piers resting on common pile cap. The tall height and size of Pier caps posed a challenge during construction near vicinity of utilities and obligatory spans crossing at various structures in sea. A skill-full positioning of Crane barges and material barge was important to

overcome wave forces due to constantly changing directions of cross tidal currents at mid sea.

3.3 Construction of Superstructure

3.3.1 Precast concrete Erection method

Due to space constraint 3-tier stacking of Main bridge segments was adopted. In intertidal zone TAB and feeding portal were used to shift segments to launching machines. For segment transportation to Marine erection fronts, a round the clock barge load out facility was built in TAB. Feeding of segments and uninterrupted supply of resources was a real time challenge due to tidal conditions and suddenly changing sea weather conditions.

3.3.2 OSD Erection methods

OSD superstructure weighing maximum up-to 23000 KN were pre-assembled in assembly yard and transported on self-propelled multi-axle vehicles to especially built skid track jetty for loading onto OSD barge. Once loaded it was manoeuvred to the span erection location using heavy duty tugboats. Then OSD was precisely moved in position and using strand jack lifting towers lowered onto the pier cap (Figure 3). Due to shallow water depth and limited manoeuvring space availability few OSD spans were assembled in situ on platform supported on towers.



Figure 3. OSD span under erection

4 Discussion

The project of this kind is highly equipment and machinery oriented. Such mega job throws a challenge to the strength of design, planning and control teams. The design team in conjunction with the construction team could develop holistic solution to overcome extremely difficult conditions and take a leap over the sea. Also, meticulous resource planning, and project control played an important role in success of the project.

5 Conclusions

Critical review of site conditions and innovative construction techniques suiting to specific needs of various elements developed during the project lead to optimistic productivity. Inarguably the Project has set a bench mark and can contribute to the accomplishment of future long bridge project construction techniques in India.

6 Acknowledgement

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7 References

[1] Theodoros T., and Evgenia G. Planning Design and construction challenges of Major Bridges in the Egnatia Motorway, Greece. *Structural Engineering International.* Vol. 20. February 2010:41-48.

[2] Kashima S., Kitagawa M, Mortitani T, and Yamada K. Design and construction of foundation for Akashi Kaikyo bridges. *ING-ABSE colloquium.* New Delhi; 1999:265-270.

ID-1069

Construction of New Brahmaputra Bridge & Road Works Near Tezpur- an Insight.....

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Introduction

This Project comprises of 4-Laning of highway (NH-37A) of total length 17.30 km, from Kaliabor Tiniali (at Nagaon District) to Dolabari Junction (at Sonitpur District) in the state of Assam, including construction of New Brahmaputra Bridge of 3.040 Km length , with the aim to create 4-lane connectivity to Itanagar, the capital of Arunachal Pradesh. Bridging the mighty & ferocious river Brahmaputra is a great challenge in itself.

Technical Details:

New Brahmaputra Bridge - Total Length = 3.015 Km + 0.025 Km (additional span) = 3.040 Km
- Span Length - 120 m
- Total No of Span - 27
- Foundation - Well Foundation/ Pile Foundation
- Super Structure – Balance Cantilever Box Girder (RCC) Comprising of 9 Module
- End Module = 67.5+120+60
- Other Module = 60+120+120+60

Highway = 14.285 Km

The bridge is meant for two lanes of traffic with footpath on one side having a total deck width of 12m. Variable Depth (7.5m to 2.5m) cast-in-situ, single cell, PSC, box girder Superstructure is constructed by cantilever construction technique. Expansion joint & central hinge are provided between two continuous modules i.e.360m apart. Superstructure is integrally connected with substructure (without bearings) at piers and supported through pot/PTFE bearings on abutment locations. All piers and abutments are resting on 55m deep well foundations. Due to presence of rocky strata, foundations at P24, P25 and A2 are provided over 2.0m dia bored cast-in-situ pile foundation. For imparting higher flexibility to the system, twin leaf piers having height of 15m are adopted as substructure. For navigation purpose, 100m horizontal and 10m vertical clearance is provided. Due to non-availability of appropriate sub-strata at A2, another 25m span is provided and earth is retained by independent Gabion system. South Bank (Tezpur side) of Bridge is protected by guide bund whereas North Bank is naturally protected by hillock. The construction work has been completed & the bridge is now open for traffic.

In this paper, regarding construction of New Brahmaputra Bridge, the technical features, methodology of construction of foundations/ piers/Superstructure, major quantities, challenges encountered & engineering solutions adopted like, seasonal change in the course of river and water depth at different locations resulted in change in construction methodology and materials / plant & machineries movements to desired locations, hindrances encountered during the execution of well foundations & innovativeness in design concept were discussed.

There has been substantial difficulty in planning of Construction Methodology. Transportation of

concrete to locations in Brahmaputra river was challenging considering change in river course / island configuration in every working season. One of the most challenging tasks was the construction of 9 Nos caisson foundation for Well P15, P16, P17, P18, P19, P20, P21, P22 and P23 in one season. The Superstructure is being constructed by Cast-in-situ Segmental Construction method with 13 sets of CLC Gantry at a time for fast track construction. Hindrances encountered during the execution of Well Foundation at P18 & P19 also. These were also discussed in this paper.

It is worth mentioning that, the Project comprises of one of the kind 2m dia. Piles driven in the Brahmaputra River at P24, P25, A2 & A2/1 locations. Total of 08 nos. at P24 & 06 nos. at P25 locations were driven using the most sophisticated machineries. The depths of these piles vary from 46.90m to 20.22m. The other innovation is the use of 16 nos of Central Hinge Bearings at eight hinge locations of New Brahmaputra Bridge. The superstructure consists of eight continuous parts, 360m apart separated by TENSA®MODULAR expansion joints.

Conclusion:

The completion of this bridge ushered, in an era of prosperity and development to Assam and Arunachal Pradesh in particular. This had further strengthened the national security of North eastern region of India. This bridge is of strategic importance as well.

ALL CONSTRUCTION BOTTLE NECKS CAN BE WON BY ENGINEERING SOLUTIONS

Session 27

Analysis, Research and Standardisation

ID-424

Seismic Isolation Design for Achieving Post-Earthquake Functionality

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Abstract

Functionality is an important consideration while designing critical buildings, bridges, and industrial structures in earthquake prone regions of the world. This is necessary for minimizing post-earthquake disruption to society. Major earthquakes that have occurred every year in the world are a constant reminder that critical structures must remain functional and operational post- earthquake, so that community needs are met. Hospitals need to remain functional and operational in order to treat injured people and save lives. Bridges classified as lifeline structures also need to remain functional so that rescue and recovery operations can be performed. Code provisions (ductility based) for seismic design of structures all over the world have focused primarily on achieving "Collapse Prevention" within acceptable limits, at the expense of inflicting damage to structural, non-structural, architectural elements, and contents, resulting in loss of function.

For over 60 years the code seismic performance objective has been to prevent structure collapse. Code compliance is the performance criteria used for 99% of structural component design. Building and bridge engineers typically implement prescriptive design procedures to comply with minimum building code requirements at the lowest construction cost. These prescriptive code design procedures based on "ductility" concept have allowed structures to get damaged during an earthquake, but largely intended to avoid "collapse" so that human lives would be protected. However, avoiding facility damage is not the intent of the building codes. Over the years this approach was refined with new design/analysis, construction materials and methods. However, till date the basic code objective for earthquake design all over the world has remain unchanged; i.e. "Collapse Prevention". The 2010 Mag. 8.8 earthquake in Chile and the 2011 Mag. 6.3 earthquake in New Zealand have demonstrated that Engineers have accomplished the basic objective of "Collapse Prevention" as only 22 buildings collapsed amongst thousands. Earthquake damage of over US $ 60 billion has nevertheless, left communities devastated.

The Building Code objectives should now change from "Collapse Prevention" to "Damage Prevention". The world of automotive industry has already started shifting from "Occupant Safety" to "Collision Prevention" with the integration of smart sensors and advanced braking technology.

In the US both the Building Code requirements and Building Industry practices are shifting towards resiliency in design and construction to minimize earthquake damage. The American Society of Civil Engineers (ASCE) latest Building Code Standard ASCE 7-22 Section 1.3.3 on Functionality requires Essential Facilities (Risk Category IV Structures) to remain functional and operational after a design level earthquake.

Seismic isolation design provisions in the code offers opportunities to reduce total construction costs, but it is a new construction method that requires special expertise in the implementation. Building codes allow isolation bearings to be damaged during earthquakes, and some collapses of newly built isolated structures are expected to occur. For code compliant structural systems, the seismic performance criteria specified in ASCE 7-22, Table C.1.3.1b, is a 10% probability of collapse during the Maximum Considered Earthquake (MCE) shaking. The conventional structural

systems that are qualified for severe seismic zones are specifically developed, designed and detailed to distribute lateral seismic deformations throughout the height of the structural frame. Most structure collapses occur when seismic deformations accidentally concentrate in limited portions of a structure. Isolated structures intentionally concentrate the seismic displacements in the bearings, making the bearings the safety critical structural components.

To have safe seismically isolated structures, codes should require isolation bearings to be manufactured and tested to have the strength necessary to withstand the simultaneous lateral and vertical shaking effects, without structural damage. Reserve strength and displacement capacities beyond those calculated for the MCE load case should also be required since code requires displacement capacity only for the average of either 7 or 11 pairs of spectrally compatible ground motions. Most collapses of structures have occurred during ground shaking stronger than the maximum strength earthquakes considered by codes. High quality seismic isolation bearings can achieve these prudent design criteria, but these criteria are not yet requirements for isolation bearings under structural design codes.

There are no industry standard equivalents to ASTM, AISC, or ACI, which have been developed for seismic isolation bearings. There are no industry standards for rated bearing load capacities, displacement capacities, factors of safety, property variations; aging or temperature effects, material longevity, manufacture methods, or testing methods, other than the Seismic Isolation Standard (SIS) https://bit.ly/3xbui7C.

Constructing for post-earthquake functionality according to the SIS is a proven, practical, and economical alternative to designing and constructing ductile structures for only collapse avoidance.

Seismic isolation was invented to minimize earthquake damage for maintaining post-earthquake functionality. The seismic performance for achieving functionality is a result of the design criteria and the isolator standard implemented. Just using an isolator does not automatically achieve functionality. The proven performance of isolated structures designed in accordance with the Seismic Isolation Standard demonstrates the importance of the design criteria and isolator standard for maintaining post-earthquake functionality.

The February 6th Magnitudes 7+ earthquakes have clearly shown that seismic isolation when implemented correctly can maintain post-earthquake functionality for saving human lives. The Adana Hospital performed as designed and as expected remained fully functional and treated thousands of people injured during the recent Turkey earthquakes.

Structural engineers are society's guardians for minimizing earthquake deaths, loss of use, and economic losses. As a profession we need to go beyond providing designs for minimum cost for minimum code compliance, and protect our clients and society by minimizing earthquake damage and deaths. Implementing functionality designs with seismic isolation not only achieves owner's expectations, but also satisfies our professional and social responsibilities.

ID-435

Flexural Behavior of Perforated Steel Beams with Multiple Web-Corrugations and Openings

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Abstract

Web perforations in corrugated web beams (CWBs) are essential in buildings for easy installation of services, etc. However, web openings lead to frequent instability and new failure modes compared to solid flat-web beams. Providing web corrugations in steel beams improves flexural behavior with higher out-of-plane web stiffness and reduces web thickness requirements for stability issues. The behavior of CWBs with web perforations has scarcely received research attention. With a better understanding of the behavior of corrugated-web steel beams and their benefits, there is definite research need to examine the structural behavior of perforated CWBs for their increased utility with the advantage of a high-strength-to-weight ratio. This study primarily focussed on the flexural behavior of CWBs with and without perforated webs. A detailed nonlinear finite element (FE) methodology was adopted to generate numerical models. The FE modeling was first validated against documented flexural-test results on five perforated flat-web and seven solid corrugated-web steel beams available in the literature. Nonlinear theoretical analysis was additionally performed on flat-web beams to validate the modeling methodology further. The study parameters for investigating the flexural behavior of CWBs were web-corrugation profiles, i.e., rectangular versus triangular corrugations, and web-perforation shapes (hexagonal versus octagonal openings). Detailed nonlinear FE analyses were performed on 16 CWBs, and results extracted from the numerical models for flexural behavior included load-deformation characteristics, von Mises stress distributions, etc. A detailed discussion is presented on the validation study and performance of CWBs for (1) rectangular corrugations with hexagonal web openings, (2) rectangular corrugations with octagonal web openings, (3) triangular corrugations with hexagonal web openings and (4) triangular corrugations with octagonal web openings. A comparison of the load-carrying capacity of CWB versus flat-web beams with web perforations is also provided. The parametric study results showed that a rectangular CWB with hexagonal openings is the most efficient, with a maximum of about 24% reduced web thickness seen in the present study for a load-carrying capacity similar to that of tested flat-web specimens. Compared to triangular corrugations, CWBs with rectangular folded webs depicted about 48% average increase in load-carrying capacity with perforated webs. The shape of web openings for similar aspect ratios was seen to have less influence on flexural behavior of CWBs compared to the corrugation profile.

Keywords: Corrugated web; finite element analysis; hexagonal and octagonal openings; load-carrying capacity; steel beams; web perforations.

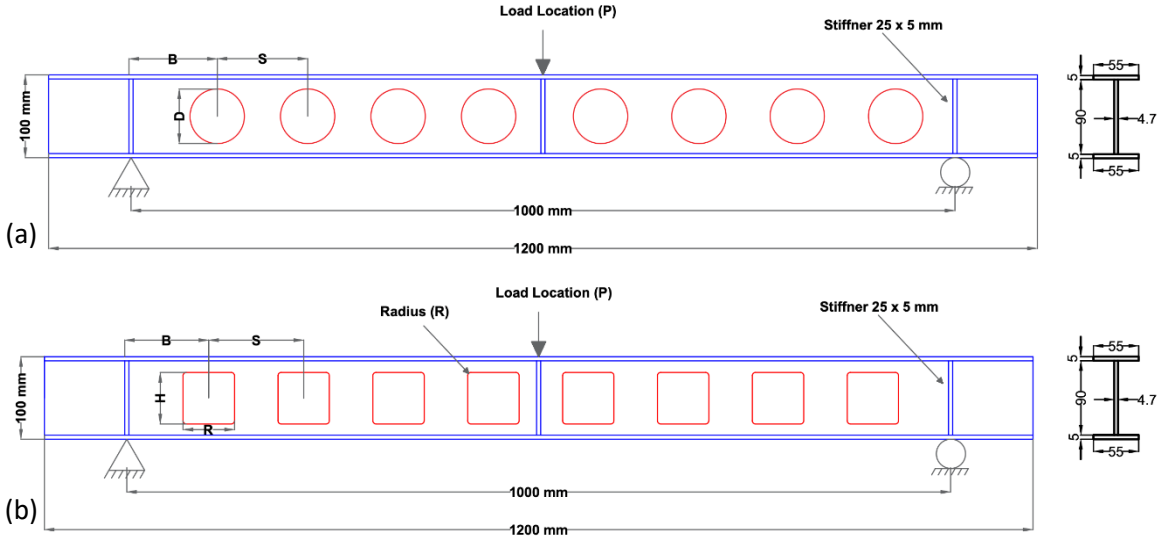


Figure 1: Geometry details of flat-web beam specimens with web openings [2]: (a) circular (SBWO1, SBWO2 and SBWO4); (b) rectangular openings (SBWO6 and SBWO7).

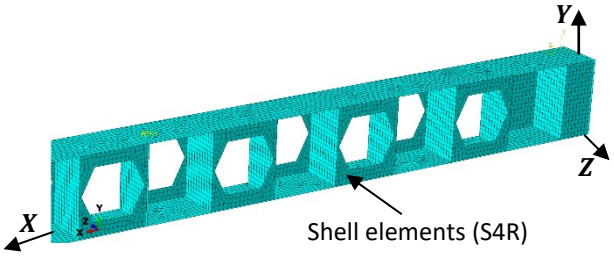


Figure 2: Typical FE modeling of perforated CWB.

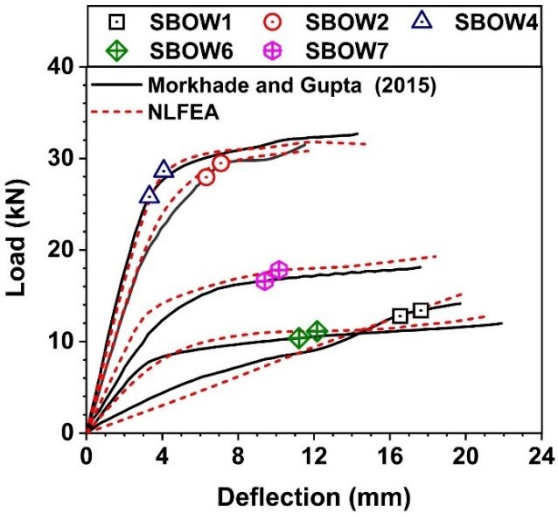


Figure 3: Comparison of NLFEA vesus. Experimental load-deflection characteristics.

ID-527

Effects of Polyvinyl Alcohol Fiber on Bond Behavior Between Concrete and Steel Rebar

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Abstract

The effects of Polyvinyl alcohol (PVA) fibers on the bonding behavior between reinforcement and concrete is studied by experiments. The effects of PVA fibers, rebar diameter and cover depth on bond behavior are clarified. Results show that PVA fibers affect negatively on bonding in ascending branches both for the pull-out and splitting cases, but improve the bonding in descending branches after peak stress for splitting case. In the present test, the maximum decrement of bond strength is about 16.2% with PVA fiber less than 0.6%. PVA fibers restricts both the macro-cracking and micro-cracking for splitting case, the former one seems much more significant than later one. The effects of rebar diameter and cover depth on bonding become slight and significant with increment content of PVA fibers, respectively.

Keywords: polyvinyl alcohol fiber; bond behavior; mechanical performance; experimental study.

1 Introduction

The material properties and the mechanism of single PVA fibers is much different with that of steel fiber or hybrid fibers, resulting in difference in bonding mechanism. The effects of single PVA fibers on the bond behavior between the concrete and steel rebar is still not well understood.

In this paper, an experimental test is proposed to study the effects of PVA fibers on bond behavior between rebar and concrete. 20 pull-out specimens are prepared and subjected to bonding test. The effects of PVA fibers, rebar diameter and cover depth on bond behavior are clarified. Several conclusions were drawn based on the study.

2 Experiment process

Twenty pull-out specimens were prepared in the present test. The factors considered in the present tests included four fiber volume contents (0%, 0.2%, 0.4% and 0.6%), three rebar diameters (12 mm, 14 mm and 16 mm), and three concrete cover thicknesses (30 mm, 50 mm and 70 mm). Experimental data including tensile force, relative slip and crack width were collected to obtain the required bond stress and slip values.

3 Bond behavior between rebar and PVA fiber reinforced concrete

3.1.1 Failure of pull-out specimens

Three different failure modes are observed in the present test: pull-out failure, splitting failure and splitting-pull-out failure. The failure of bonding specimens depends mainly on the ratio of cover depth to steel rebar diameter.

3.1.2 Effects of PVA fibers

The bond stress - slip curves of samples with different PVA fiber content were obtained. The slope of the ascending branch and the bond strength decrease with the increment of PVA fibers.

Bond strength of specimens with different content of PVA fibers were obtained. All the specimens show a descending trend in bond strength with the increase of PVA fiber except the d16-c70 series specimens.

the propagation of splitting cracks for d12-c30 series specimens were obtained. For plain specimen, the splitting crack appears at a low load stress and propagates gradually with the increase of applied load stress. There is a suddenly widening in cracking and the width increase quickly to a greater value after the peak load stress. After then, the splitting crack keeps almost unchange during the further load procedure. The propagation of splitting crack in specimens with 0.2% PVA fibers is similar to that of the plain specimen, but with a narrow crack at finally. For specimens with 0.4% and 0.6% PVA fibers, the load stresses corresponding to the appearance of splitting cracks increase significantly. And, there is no suddenly widening in cracking after the peak load stress. The finally crack width become much narrower than that on the plain specimen.

Effects of PVA fibers on splitting cracks were obtained. 0.2%, 0.4% and 0.6% of the PVA fibers increase the cracking load stress about 8.37%, 31.44% and 42.43%, respectively, and decrease the finally crack width about 36.23%, 59.02% and 65.08%.

3.1.3 Effects of rebar diameter

Details about the comparison of bond strength, slip corresponding to bond strength and the bond stress at onset slip of free end for specimens with different rebars are summarized . Almost all of the bond strength, slip corresponding to bond strength and the bond stress at onset slip of free end are decrease with the increase of rebar diameter. The negative effects of large rebar on bond behavior between concrete and rebar becomes slightly with the increase of PVA fibers.

3.1.4 Effects of cover depth

Details about the comparison of bond strength, slip corresponding to bond strength and the bond stress at onset slip of free end for specimens with different cover depth are summarized .The bond strength and the corresponding slip of specimens decrease with the decrement of cover depth, while the bond stress at onset slip of free end increase significantly with the decrement of cover depth.

4 Conclusion

（1）The failure of bonding specimens depends mainly on the ratio of cover depth to steel rebar diameter. Specimen trend to pull-out failure as the ratio of cover depth to rebar diameter greater than 4.5-5.0. For specimens with small ratio of cover depth to rebar diameter, the splitting of concrete is affected more significantly by rebar diameter rather than cover depth. PVA fibers can restrict the splitting cracking and improve the failure of specimen in a more ductile way.

（2）PVA fiber show generally a negative effect on bond behavior, but a positive effect on the descending branches for the case with splitting failure. In the present test, PVA fibers decrease the initial bond stiffness and bond strength both for the cases with pull-out and splitting failures. The maximum decrement of bond strength is about 16.2% with PVA fiber less than 0.6%. PVA fibers restricts both the macro-cracking and micro-cracking for splitting cases, the former one seems much more significant than later one.

（3）Specimens with small rebars have usually greater initial bonding stiffness and bond strength than specimens with large rebars. The difference in bond behavior caused by rebar diameter become smaller with the increase of PVA fibers. Thin cover decreases bond strength of specimens, but increase somewhat the initial bond stiffness of specimens. The more the PVA fibers, the greater the difference of initial bond stiffness caused by cover depth.

ID-534

Studies on The Microstructure of Carbon Dioxide-Sequestered Cement Paste.

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The current article focuses on CO_2 sequestration in concrete using the method of mineral carbonation. Mineral carbonation technology has advantages because carbonates are products generated by the reaction of CO_2, are thermodynamically stable and insoluble, allowing for permanent CO_2 fixation. Carbonation can occur naturally during concrete production and aid in absorbing CO_2 emissions, but the process is too slow. It may take hundreds of years to absorb all emissions fully. It can also lead to the corrosion of steel reinforcements, ultimately harming the structure. While early-age cement carbonation using CO_2 can strengthen concrete and decrease porosity. Following are the basic chemical reactions (Eqn. (1-3)) occurring in early-age carbonation for permanent CO_2 fixation in concrete [3,4].

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

$$C3S + (3\text{-}x)CO_2 + yH_2O \rightarrow CxSHy + (3\text{-}x)CaCO_3 \quad (2)$$

$$C2S + (2\text{-}x)CO_2 + yH_2O \rightarrow CxSHy + (2\text{-}x)CaCO_3 \quad (3)$$

Various studies have examined the effects of CO_2 on cement and concrete, such as the use of CO_2 gas to treat cement mortar and recycled concrete aggregates exposed to CO_2 gas pressurized curing, as well as the performance of cement slurry under the influence of sodium bicarbonate. However, there are still uncertainties surrounding the amount of CO_2 captured and its impact on hardened cement paste's chemical properties and microstructure. Research on CO_2 sequestration in fresh cement paste is lacking and warrants further investigation.

The current study focuses on the comparative evaluation of the effects of varying water-to-cement (w/c) ratios on microstructure, chemical characteristics, and mechanical properties of modified carbonated cement pastes prepared using dry ice and CO_2 gas bubbling. The dry ice percentage was fixed to 4% by the weight of the cement.

Batches of cement pastes weighing 3 kilograms have been prepared with a water-to-cement ratio of 0,3, 0,35, 0,4, and 0,45, following ASTM C305. To prepare the paste, cement, and water were weighed and crushed dry ice was immediately added to prevent sublimation losses. The dry ice was slowly mixed and sublimated to form a homogeneous paste. For CO_2 bubbling, cement and water were mixed for 5 minutes to form a smooth paste. CO_2 gas was injected for 15 minutes using a 6mm diameter pipe, and slow stirring was employed for proper mixing. Cubic samples measuring 50 mm × 50 mm × 50 mm were cast.

After standard curing, hydration was terminated with anhydrous ethanol, and samples were dried in a vacuum drying oven at 40 °C, just before the compressive strength test. Microstructure characterization has been done by grinding samples taken from the edge of the crushed cubes with a stone grinder and passing powdered samples through a 75 mm sieve.

Current experimental studies involve the dissolution of CO_2 in the cement paste using physiochemical processes such as:

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(l) \quad (6)$$

$$H_2CO_3(l) + Ca(OH)_2 \rightarrow CaCO_3(s) + H_2O(l) \quad (7)$$

The intermediate product H_2CO_3 so formed is acidic. Thus, to ensure that the above method is not harmful to reinforcing steel during upscaling. pH measurement has been performed on samples using pH paper. It has been observed that the pH of

all the paste samples was above 11, including samples of different water-to-cement ratios, tested just after carbonation. Thereafter the pH value was observed to increase for carbonated specimens. The results were in accordance with the amount of calcium hydroxide observed in the TGA analysis.

It has been observed that specimens manufactured with bubbled CO_2 gas showed an average increase of 10,8% in the initial setting time compared to control specimens. The initial setting time for specimens made with dry ice decreased by 12% compared to the control specimen. This decrease in setting time can be attributed to the change in temperature caused by dry ice addition.

The setting time for carbonated specimens with varying water-to-cement ratios also showed a similar trend as that of the control specimens of respective w/c ratios. The initial setting time for dry ice mixed samples corresponding to different w/c ratios showed a decreasing trend, that is setting time for dry ice mixed specimen with a w/c ratio of 0,3 was the lowest, and the setting time for dry ice mixed specimen with w/c ratio 0,45 was highest, but lower than that of control specimen of respective w/c ratio.

The compressive strength of bubbled CO_2 gas specimen was 8-10% higher than the control specimen, whereas the dry ice specimen was 6-8% higher than the control specimen of respective w/c ratio at the end of 28 days. The 1-day compressive strength of the bubbled specimen was higher than the control specimen. The dry ice gave a comparable strength to that of the control specimens at the end of day 1. With the increase in the w/c ratio, both bubbled and dry ice specimens showed a similar decrease in compressive strength as the control specimen.

FTIR test's peaks were identified and assigned to various bond stretching and vibrations in accordance with Portland Cement Associations (PCA) library. Higher calcite peaks observed in FTIR were attributed to early calcite ion precipitation in carbonated specimens, which also act as deposition sites for hydration products. These results have also been confirmed through SEM imaging.

The mass loss in TGA analysis in the range of 400 °C - 540°C can be attributed to the dehydroxylation of calcium hydroxide, which is an indirect measure of the degree of hydration and has been calculated using eqn. (1)

$$CHloss(\%) = \frac{(W_{540} - W_{400})}{W_{105}} \quad (1)$$

Where,

W_{540} = mass loss in TGA at 540 °C,

W_{400} = mass loss in TGA at 400 °C, and

W_{105} = mass loss in TGA at 105 °C

The mass loss in the range of 550 °C - 950 °C is attributed to the decomposition of calcium carbonate, which can be directly attributed to CO_2 captured and has been calculated by eqn. (2)

$$CCloss(\%) = \frac{(W_{950} - W_{550})}{W_{105}} \quad (2)$$

Where,

W_{950} = mass loss in TGA at 950 °C, and

W_{550} = mass loss in TGA at 550 °C.

The highest mass loss due to calcium carbonate decomposition was observed in dry ice specimens for all w/c ratios. Thus, indicating that the maximum amount of CO_2 sequestered was using dry ice. The TGA analysis of bubbled CO_2 gas specimen also showed a higher amount of carbonate loss compared to the control specimen, indicating that both methods can be used to sequester CO_2 in cement paste.

The mass loss due to carbonate increased with an increase in the w/c ratio, indicating that increasing the water content helps dissolve more CO_2 into the paste, eventually leading to higher CO_2 sequestration.

ID-574

Image Analysis of Concrete Surface for Investigating the Influence of Aggregate Distribution and Load Induced Damage on The Chloride Permeability of Concrete Measured Using RCPT (ASTM-C1202)

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Abstract

The durability of concrete structures such as bridges, buildings, highways, ports, etc. are controlled by deteriorating mechanism in their service environment. Corrosion of steel in reinforced concrete (RC) structure is one of the major concerns for premature deterioration of RC structures. The chloride ions (from sea water or salts used in thawing application) damage the protective layer (or passive layer) of rebar resulting in the corrosion initiation. The penetration ability of chloride ions through concrete is the major component in service life models (SLM). Numerous instances of early deterioration in concrete structures questions the reliability of concrete's resistance against chloride ion penetration which is considered an input in SLM. The erroneous predictions of concrete durability could arise from random distribution of aggregates in the matrix and load induced damages under service conditions. The aggregates play an important role in migration of ions through concrete. The thin layer referred as Interfacial Transition Zone (ITZ) surrounds the aggregate and facilitates the penetration of ions. Aggregate blocks the penetrating agent's path (dilution effect), but the ITZ accelerates it with comparatively high permeability than matrix (ITZ effect). Hence, the bulk response would be governed by localised aggregate distribution in the mortar matrix. Similarly, the concrete structures are supposed to carry structural loads. These loads cause micro cracks in concrete creating the additional paths for the movement of chloride ions.

The present study explores the utility of using image analysis for investigating the influence of non-uniform aggregate distribution and load induced damages on the concrete's permeability. The concrete disc specimen of 100 mm dia. and 50 mm thick, extracted from the concrete cylinder (dia. 100 mm and height 200 mm) is considered. Two concrete mixes of grade M40 (M1) and M30 (M2) were designed in the present study. For analyzing the influence of aggregate distribution on chloride permeability, the concrete was modeled to be composed of three phases- aggregate, mortar, and Interfacial Transition Zone (ITZ). The linear flow (normal to the direction of surface) of ions is assumed. Hence, the surface is considered as the representative of aggregate distribution in bulk. While deriving the equation, the aggregate parameters were identified and evaluated from digital image of concrete surface. Parameters were estimated at both the concrete surface and the

average was calculated using ImageJ program which is java-based image analysis program utilized for such purposes. The ratio of conductivity of ITZ and mortar (β) is considered as 29.8 and 34 and ITZ thickness was assumed as 40 µm and 50 µm for M1 and M2 respectively. The predictions of concrete permeability were made for 60 specimens (30 of M1 and 30 of M2) regarding the chloride permeability in terms of RCPT value (charge passed in 6 hours). The results showed that that about 83% (of M1) and 90% data points (of M2) are within 10% error which ensures the authenticity of the three-phase model.

In the next objective, the pristine specimens were subjected to load induced damage introduced by applying 1) compressive and 2) split tensile stress. RCPT of damaged specimens were carried out for investigating the influence of loading and resulting cracks. Different cracking patterns were observed for specimen under compression and splitting tensile action. The former being irregular in shape and more tortuous cracking while the later were clear and along the diameter path. The reason is the difference in the distribution of stresses for both the loading. In case of compression of disc, the failure path is not pre-defined, and the load takes path through weak links i.e., ITZ. However, there exists a predefine failure plane in split tensile stress. These damages were quantified by capturing the cracks using wand tool (in ImageJ) and calculating the crack area using color threshold approach which is based on the concept that cracks appear darker compared to adjacent areas due to inability of light reflecting from cracks. The results of cracked specimen under compression showed a correlation of increment Factor (I.F.) with the percentage crack area. The I.F. is defined as the ratio of RCPT charge of damaged and pristine specimen. In case of tension damaged specimen, the results showed an interesting trend. The crack did not initiate for loading level below 75% of split tensile strength. The reason could be due to the existence of predefined failure path and inability of load to transfer through weakest path unlike compression failure. Splitting failure is brittle hence damage evolution is not as gradual as with the compressive stresses. The I.F. was found to be less than 1, at loading level below the critical load showing the change in concrete microstructure. The change is caused by reduced porosity due to compression at the top and bottom of concrete cylinder under splitting load. It was also observed also that chloride permeability can be correlated with the percentage crack area and not the loading level. The reason is the non homogeneity of concrete associated with the distribution of aggregates which influence the load path and resulting failure. At about the specific crack area of 10%, the increase in discharge was found up to 3 times.

The study concluded that digital image analysis of concrete surface can be utilized for predicting the in-situ durability of concrete and the influence of non-uniform aggregate distribution and load induced damages on it. The image analysis could provide a quick and economical way to assess the variation in the concrete quality at different locations in RC structures to assist planning in advance for maintenance/repair activities which can optimise the resources. Drones can be used to take images at inaccessible regions. The improvement in monitoring could prevent early degradation that uses more resources and energy, which would have an impact on sustainability. Overall, this method aids in improving the health of concrete infrastructure and helps in achieving sustainability. UN-SDGs are considered as globally accepted goals for achieving the sustainability. The present work is related with SDGs 9, 11, 12, and 13.

Session 28

Climate Change Adaptation and Disaster Resilience

ID–82

Failure Analysis: Shallow and Deep Causes Assessment Methodology

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Abstract

The ability to identify the underlying cause(s) of a structural failure is of essence for the improvement of structural civil engineering practice, and for the structural performance and its resiliency against extreme load and climate conditions. This ability requires forensic expertise along with rigorous and systematic approach due to multiple nature of the potential causes. This paper presents two (2) complementary forensic investigation approaches that will allow engineers to identify the shallow and deep causes and the triggering effect of a structural failure. While being approaches that are complementary, each of them will be best suited for specific failure analysis scenarios that will depend on the severity (extent versus intensity) of the observed damage/pathology.

The first approach is Top-Down Approach, which is based on a rigorous and systematic engineering investigation, which sets to trace back the structure´s lifetime through the gathering of technical information across the different design stages of the structure, from Governance to Inspection and Maintenance stages, with the corresponding key decisions. The second approach is Bottom-Up Approach that sets the investigation strategy from the observed damage/failure and lays down a series of hypothesis, correlated and/or uncorrelated, that are to be validated during the engineering investigation.

As a first step in the process of defining the Failure Analysis Methodology, it was important to identify the most comment structural failure pathologies observed in bridges and roads in Bangladesh. The analysis of the inspection and maintenance records of LGED's infrastructure portfolio was performed, and the observed pathologies were grouped and agreed as follows, for both bridge and road infrastructures:

Bridge Infrastructures:

- Mechanical Decay (MD): cracking (MD1), deformations (MD2), and structural failure (MD3);
- Surface Decay (SD): spalling (SD1), corrosion (SD2), honeycombs (SD3), and scour and erosion (SD4);
- Structural Components Behaviour (SCB): bearing malfunctioning (SCB1), movement joints malfunctioning (SCB2), and lack of continuity (SCB3);

Road Infrastructures:

- Embankments Material (EM): scour and wash-out (EM1), and excessive deformations (EM2);
- Flexible pavement (FP): surface cracking (FP1), potholes (FP2), and rutting (FP3);

The present FA Methodology is overarched by the Fault Tree Method (FTM), which is analytically implemented using the following two (2) analytical techniques: Fault Tree Analysis (FTA) and the Analytical-Hierarchical Process (AHP), corresponding to the Top-Down and Bottom-Up forensic investigation approach, respectively. The overarched FTM is defined by as a two (2) way tree, where the observed structural failure, which constitutes the tangible evidence of the failure mechanism, it can be placed either at the beginning or at the end of the tree, but which analytical procedure would vary, between a Top Down and Bottom-Up Approach.

The Top-Down Approach will follow a road map based on the live-cycle of the structure, from Governance to Operation and Maintenance, including Planning, Design, Procurement and Construction, and the key decisions made at the mentioned stages.

The Bottom-Up Approach starts from the observed structural pathology and unleash the potential root causes of the pathology based on a technical assessment of the structure (design vs observed behavior) and material (design specifications vs. handling and construction).

The presented methodology allows to switch form one investigation journey to the other in function of the quality of the data set or from obtained preliminary results of the investigation.

This paper presents in detail both approaches, their best suitability in function of the project investigation process and available data, and the development of a supporting tool as an aid to the forensic engineer.

Keywords: failure analysis; forensic structural engineering; forensic structural assessment.

ID-267

Climate Change Induced Carbonation of Reinforced Concrete Buildings in European Cities

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Abstract

The European Green Deal aims at making Europe the world's first climate neutral continent by 2050, fully adapted to the unavoidable impacts of climate change. A new EU Adaptation Strategy to Climate Change was adopted in 2021 to improve the adaptive capacity of the Member States and the Union, strengthen resilience and reduce vulnerability, in line with the Paris Agreement. This Strategy recognises the importance of increasing the preparedness Europe's building stock to withstand the impacts of climate change, investing in climate-proof infrastructures, and updating standards governing the safety and performance of buildings and infrastructure in a changing climate (Mandate M/526).

Hence, this paper aims to quantitatively estimate the impact of climate change on the corrosion of reinforced concrete buildings in European major cities, and to provide insight on the formulation of adaptation strategies for existing buildings in Europe, namely the adaptation of standards to climate change. The quantitative assessment is a first step to advise the formulation of effective adaptation strategies for existing buildings in the EU. It can inform the extent to which design standards and safety provisions need to be revised to cope with a changing climate, so that European building stock maintains acceptable levels of safety, maintenance and durability.

Hence, a simplified model was adopted to estimate climate change induced carbonation of the European reinforced concrete (RC) building stock for a baseline (or reference) and future scenarios accounting for climate change conditions. This model requires as input only two atmospheric forcing variables: the atmospheric CO_2 concentration and the mean air temperature.

In this regard, temperature values are provided by 11 bias-adjusted climate projections where the raw climate simulation chains are included in the ensemble of Regional Climate Models (RCMs) made available within the European branch of the Coordinated Downscaling Experiment (EURO-CORDEX) initiative. Historical runs, forced by observed natural and anthropogenic atmospheric forcing, cover the period from 1765 to 2005; the projections (2006–2100) are forced by two Representative Concentration Pathways (RCP), namely, RCP4.5 and RCP8.5. RCMs' outputs have been bias adjusted following the procedure suggested by Piani (2010) using the observational data set EOBSv10 (released in April 2014; Cornes et al., 2018).

On the other hand, the inventory of the European building stock was based on a database produced for a European pilot project led by the Joint Research Centre (JRC) (Gkatzogias et al., 2022). The database is georeferenced and encompasses the number of residential and commercial buildings for the 27-EU countries, grouped in classes established to describe the seismic performance of buildings. The buildings were grouped into two major groups, called "old" and "recent". In each group, the durability of concrete buildings is characterized in terms of recommendations of construction standards, literature review and expert knowledge. The group "old buildings" aggregates reinforced concrete buildings built before 2000, while, the group "new buildings" collects the remaining buildings where aging effects start to be considered in 2000.

The impact of climate change on the carbonation damage of the European building stock is determined by the difference of future climate scenarios against baseline or reference scenarios. The calculation is carried out for the 27 capital cities of the EU Member States, for climate change scenarios forced by RCP4.5 and RCP8.5.

The analysis indicates that increases in carbonation depth are mainly function of time horizons and severity of RCPs scenarios. Results show that the percentage of increase in 60 years (2085) of carbonation depth in European capital cities, due to climate change, varies between 27% and 47%, and between 31% and 55%, respectively, for an intermediate and an unlikely high-risk future scenario. Furthermore, a cluster of factors affecting the durability of concrete was identified in the north-eastern Europe, which is the region most affected by climate change-induced carbonation.

In the near future, it is planned to estimate corrosion costs for all countries of the European Union.

Keywords: carbonation damage, climate change, European cities, reinforced concrete buildings.

References

Cornes, R.; van der Schrier, G.; van den Besselaar, E.J.M.; Jones, P.D. (2018). An ensemble version of the E-OBS temperature and precipitation datasets. J. Geophys. Res. Atmos., 123, 9391–9409, doi: 10.1029/2017JD028200.

Gkatzogias, K., Crowley, H., Veljkovic, A., Pohoryles, D., Norlén, H., Tsionis, G. and Bournas, D., Prioritising EU regions for building renovation: seismic risk, energy efficiency, socioeconomic vulnerability (2022). REEBUILD: Integrated techniques for the seismic strengthening and energy efficiency of existing buildings, edited by K. Gkatzogias, G., Tsionis, Publications Office of the EU, Luxembourg, doi:10.2760/263803, JRC128988.

Piani, C.; Weedon G.P.; Best, M.; Gomes, S.M.; Viterbo, P.; Hagemann, S.; Haerter, J.O. (2010). Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models. J. Hydrol., 395(3–4), 199–215, doi: 10.1016/j.jhydrol.2010.10.024.

ID-316

Embodied Energy and Urban Infrastructure: Mitigating Impact of Climate Change

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Abstract

Urban growth demands sustainable residential, commercial, heritage, and transit infrastructure. Urban planning requires local knowledge, data, horizon year selection, and land use flexibility. Urban designers prioritise architecture, local resources, public input, and affordability. From extraction and refinement to marketing and disposal, embodied energy is defined as the sum of energy inputs (fuels/power, materials, human resources, etc.). Better amenities use more energy, whereas sustainability lowers embodied energy. Green development would never get 'Greener', rather go less red. Brownfield development revitalises abandoned factories, military locations, transportation infrastructure, Go-Downs, etc.

Keywords: sustainable brownfield development, built environment, embodied energy, cumulative energy demand, embodied carbon, net zero, green infrastructure

1 Introduction

According to the International Energy Agency's (IEA) latest study, World Energy Outlook, "Green" initiatives are obligatory. Unless we act now, we will be doomed forever. This paper aims to provide a qualitative viewpoint on the notion, although one that is supported by variable quantification.

2 Infrastructure development

It is well known that poor infrastructure prevents developing nations from progressing. Embodied energy is defined as energy used to make building materials and components. Energy audits begin with raw material mining. It is transported, processed, and incorporated into infrastructure, such as a road, railway line, airport, irrigation work, industrial facility, commercial enterprise like a mall, or residential house.

3 Embodied carbon

It covers any CO_2 produced during the fabrication of building materials (material extraction, transfer to manufacturer, manufacturing), transportation of those materials to the job site, and construction procedures. Embodied carbon is separate from operational carbon, which is carbon derived through energy, heat, lighting, and so on. Recent data from the World Green Building Council show that embodied carbon is becoming a larger component of a building's overall carbon footprint, thanks to developments in lowering operational carbon. By 2060, the number of buildings on Earth is projected to have doubled. The concrete industry can rejoice at this development. It's awful news for global warming if

we don't alter our methods of concrete production. One of the major contributors to carbon dioxide emissions from man-made sources is cement, the primary component responsible for concrete's durability. Cement production is the largest contributor to embodied carbon in the built environment, and as concrete is the most widely used man-made material, this makes sense. As some building materials and products are more carbon-intensive than others, such as concrete, aluminium, and steel, it is not recommended to determine the absolute total carbon footprint of a project, as many components will have a minor impact and offer extremely limited mitigation potential. Initial emphasis should be placed on high-impact materials ('carbon hotspots'), which allow for very straightforward carbon calculations and account for around 80% of the total embodied carbon footprint.

3.1 Net zero embodied carbon

This definition makes net zero embodied carbon part of a lifecycle decarbonization approach. As we extract and manufacture construction materials and goods, it recognises the significance of tackling upfront emissions. The concept uses international lifecycle assessment standards for buildings and infrastructure.

4 The “Green” initiative

India, like most developing nations (South Africa, Brazil, even China with its rural-urban migration restrictions), is rapidly urbanising. It implies increased embodied energy due to a demand for better amenities. "Green" design counteracts these environmental issues. “We shall consume, but it will be ‘Green’” is acceptable. Green building follows these main principles: Siting and Structure Design Efficiency, Energy, Water, Materials, Indoor Environmental Quality, Operations and Maintenance Optimization, Waste and Toxics Reduction. India created GRIHA (Green Rating for Integrated Habitat Assessment) grades for "Green" design. These ratings match US Green Building Council LEED ratings. Though young, India's "Green" movement is growing fast. Few Examples are as under:

- Rajiv Gandhi International Airport, Hyderabad
- Suzlon One Earth Campus, Pune
- Infinity Benchmark, Kolkata
- The ITC Green Centre, Gurgaon
- T-ZED Homes, Bengaluru
- Kolkata East-West Metro: Central Park Depot

5 Brownfield projects

The term "brownfield development" refers to the economic redevelopment of properties whose original use has been lost, such as an abandoned factory or unused military land or traffic infrastructure elements or abandoned Go-Downs and so on, in an effective use of land, having market demand, and in an economically viable manner. Climate-centric brownfield revitalisation improves access and health, helping communities adapt and reduce climate change. Green investors see better economic circumstances and bigger profits after revitalisation.

6 Conclusions

The study expands on "Green" design and its structural engineer requirements. It has focused on "Green" buildings within the rapid infrastructure development programme in India and most developing countries.

7 References

[1] Steps towards “Green” Design – Embodied Energy: Roy, B C; IABSE Proceedings, Cairo, Dec 2011.

[2] Methodology to Calculate Embodied Carbon of Materials: Royal Institution of Chartered Surveyors (RICS) July 2012 ISBN 978 1 84219 795 0, www.ricsbooks.com

[3] Misc. Papers from the lead author on this topic.

ID-463

Seismic Resilience Assessment of Aging Highway Bridge Considering Climate Change Effects

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Abstract

Highway bridges are the major component of the transportation network and play an important role in the sustained economic growth and social development of any country. Building and maintaining existing bridges are gaining importance among bridge owners and stakeholders. The effect of climate change due to increasing global warming may adversely affect the performance of reinforced concrete (RC) bridges. The Intergovernmental Panel on Climate Change (IPCC) report state that the global temperature will continue to rise over the coming decades, primarily due to greenhouse emissions caused by human activities. The increase in temperature will accelerate the corrosion rate and may have a detrimental impact on the lifetime performance of bridges in India. Along with continuous exposure to adverse climate conditions, bridges in India are also susceptible to damage induced by earthquakes. However, there are no studies currently available in the literature that evaluate the combined effect of climate change and corrosion deterioration on the lifetime seismic resilience of older bridges in India.

Addressing the drawbacks, this study presents a framework for evaluating the lifetime seismic resilience of bridges considering the influence of climate change-induced corrosion deterioration. This framework is demonstrated using a case-study two-span semi-integral bridge obtained from the work of Shekhar et al. [1]. **Error! Reference source not found.** (a) shows the general layout and analytical modeling of the s emi-integral bridge consisting of a deck, a pier in the middle, and abutment at two ends. **Error! Reference source not found.** (b) depicts the time-dependent rebar area loss ratio considering the corrosion deterioration model with and without climate change effects. At 75 years, the reduction in mean steel rebar area is observed to have increased from 7.7% to 51% after considering climate change and cracking effects in the deterioration model. A detailed finite-element model of the bridge is developed in OpenSees by incorporating the nonlinear behaviour and time-dependent climate change-induced corrosion deterioration effects. Nonlinear time-history analyses are performed to obtain time-dependent seismic fragility curves. **Error! Reference source not found.** (c) shows the seismic fragility c omparison of the bridge at as-built and 75-year. The percentage reduction in median fragility estimates for the bridge at 75-year without and with climate change effects is 23% and 51%, respectively, compared to as-built conditions. These results are used to calculate the post-earthquake direct and indirect losses that are then paired with recovery models to evaluate the functionality and lifetime

resilience of the bridge. **Error! Reference source not found.** (d) illustrates the seismic resilience of the b ridge corresponding to as-built and 75-year corroded bridge for varying *PGA*s. As the *PGA* increases from 0.1 to 0.8g, the resilience reduces up to 50%, 51%, and 52%, respectively, for as-built and 75-year-old bridge without and with climate change effects. The results show a degrading trend in the resilience of the bridge after considering the effect of climate change, highlighting the importance of considering the influence of climate change on the lifetime seismic resilience assessment of older bridges.

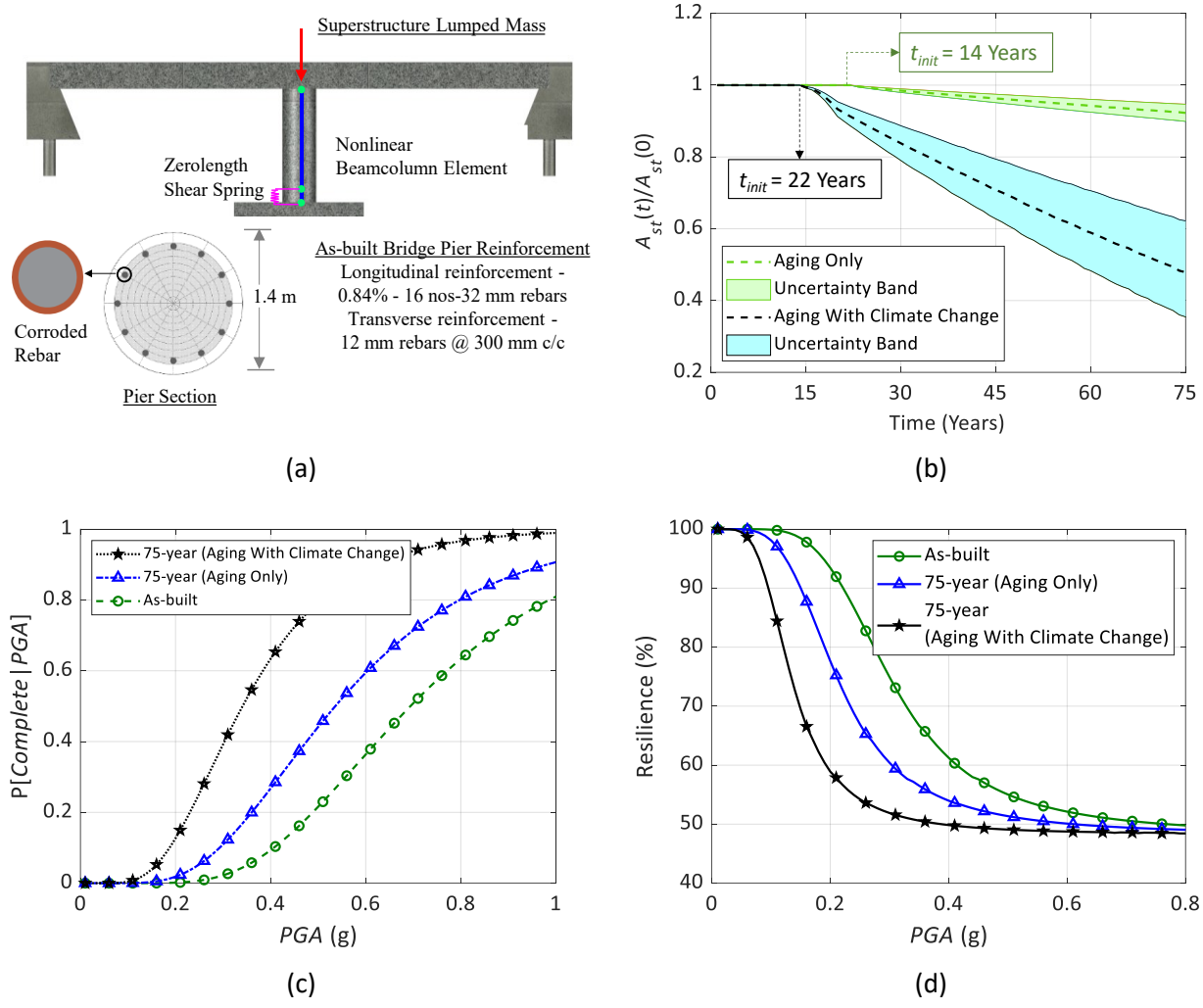


Figure 41. (a) Layout of the case-study bridge showing details and FE modeling of as-built bridge pier, (b) Time-dependent cross-sectional rebar area loss ratio using corrosion deterioration model with and without climate change effects, (c) Seismic fragility and (d) Seismic resilience comparison for case-sudy bridge at as-built and 75-year condition (with and without climate change effects).

References

[1] Shekhar S, Ghosh J, Ghosh S. Impact of Design Code Evolution on Failure Mechanism and Seismic Fragility of Highway Bridge Piers. *Journal of Bridge Engineering* 2020; 25: 04019140.

ID-558

Seismic Hazard Evaluation and Damage Assessment of Bridges

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Abstract

One of the most frequent natural catastrophes that cause the loss of life and property is earthquake. The fragility assessment carried out by a structural analyst of a current structure is a technique for minimizing damage, loss of life, and cost. Because it is a simple and flexible analytical and design tool, fragility analysis has gained popularity all over the world. It is used to forecast how much structures will move to the side when subjected to seismic stresses. The fragility curve provides critical information for decision-makers, such as engineers, policymakers, and emergency managers, to assess the vulnerability of bridges and prioritize mitigation measures. Fragility damage assessment of bridges is a process of evaluating the potential damage to a bridge under different levels of seismic or other types of hazards. The assessment involves the development of a fragility curve, which describes the probability of a bridge reaching or exceeding a particular damage state for a given level of hazard intensity. By analyzing the fragility curves, they can identify the critical bridge infrastructure that is likely to suffer severe damage during an earthquake or other natural disasters and allocate resources to retrofit or replace those structures. One can identify how much a structure is susceptible to earthquakes. Bridges are classified as lifeline structures as they need to be functional in an earthquake event. Failing to satisfy working conditions can result in the shutdown of damaged bridges, possibly causing negative consequences on daily traffic. The proposed study in Surat investigates the seismic risk possessed by bridges. The second-largest city in Gujarat falling within the third seismic zone has 118 bridges located throughout the city. In this study, the deformation of the structure has been examined using nonlinear static pushover analysis in midas interface. Midas Pushover Analysis is a structural analysis method used to evaluate the performance of a building under seismic loads. The method is commonly used in structural engineering to assess the potential collapse of a building during an earthquake. It is based on the concept of capacity curves, which represent the relationship between the lateral force applied to the structure and the corresponding displacement. The damage to bridges of various spans, material quality, Indian seismic provisions, and so on have been estimated using the fragility function. The chance of going above a threshold and the spectral displacement have been connected by the fragility function. This inquiry is capable of keeping track of the likelihood of pre-defined damage conditions. HAZUS methodology has been utilized to carry out a probability damage assessment. Hazus (Hazards US) is a methodology and software tool developed by the Federal Emergency Management Agency (FEMA) in the United States to estimate the

potential losses from natural hazards, including earthquakes, floods, and hurricanes. The Hazus methodology is based on a combination of geographic information systems (GIS), engineering, and social science data to estimate the impact of natural disasters on buildings, infrastructure, and populations. The methodology uses a combination of statistical models, vulnerability functions, and hazard data to simulate the potential damage and losses from a natural disaster. The likelihood, magnitude, and severity of bridges in Surat can be examined using ArcGIS software. The management and reduction of risk may be aided by these results.

Keywords: fragility curve; pushover analysis; performance point; midas civil; hazus methodology

ID-1246

Sustainable and Green Construction Technologies in India

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Abstract

India has taken up an ambitious Road Development Programme thereby planning Construction/Up-gradation of about 50000 km of National Highways in the next five years. This implies huge construction work in the road sector. As transport sector is responsible for about 14% of total energy related CO_2 emissions and share of road transport in CO_2 emissions is about 88% in India, these large-scale emissions endanger the environment sustainability and is closely linked with global warming and climate change challenges.

Many a times, this development comes at the cost of disturbance to ecological balance. Loss of vegetation is an inevitable consequence of road development. Further, all stages of highway project i.e., construction, maintenance and operation require energy intensive inputs which are derived from burning of fossil fuels. This results in the release of massive amounts of greenhouse gases and other ambient air pollutants. The share of road transport in overall CO2 emissions of India stands at 12.32 %(approximately 457 million tonnes) which is expected to reach 966 million tons by 2030. Within the road transport, emissions from National Highways are significantly higher and presently stands at 140 million tonnes.

With the global focus shifting to low carbon transport and Government of India has committed to net zero carbon by 2070, the highways sector offers a significant opportunity of reducing the carbon footprint of road transport. Therefore, efforts should be made to take up the highway projects having the minimum carbon emission. There is huge scope to reduce CO_2 emissions generated during construction by deploying low carbon measures. Carbon footprint is a commonly used term to describe the total amount of carbon dioxide and other greenhouse gas (GHG) emissions released during the life cycle of project / activity or an event. Generally, carbon emissions are calculated at a national level, often using methodologies and default values suggested by the Intergovernmental Panel on Climate Change (IPCC) and Indian Roads Congress.

Construction and maintenance phase of highway projects involve several activities such as extraction of raw materials, transportation of men, materials, plant and equipment, processing of material, laying of pavement and construction of structures each of which requires large scale energy consumption in the operation of plant and equipment. The energy needs are met by burning fossil fuels. In addition, the embodied carbon of the raw and value-added products adds up to the carbon emission tally. However, as construction and maintenance constitute only 5 – 13 % of the total emissions, bulk of the emissions (87 – 95 %) are caused predominantly by burning of petrol and diesel in the running of vehicles.

Reducing carbon emissions to a minimum during the life cycle of any bridge is one of the major aspects of sustainability. The bridges are designed for 100 years' service life as per IRC specifications. The major carbon intensive construction material used in the bridges are concrete and steel. In India it is estimated that on an average 0.236 t CO_2 eq carbon emission takes place for producing 1 GJ of energy out of non-renewable fossil fuels.

Mainstreaming of Sustainable and green construction technology included various measures including preparation of National Standards and Guidelines for construction materials & methods and developing green rating systems for Indian road sectors. Indian Roads Congress is an apex body of highway engineers with the mandate to prepare National Standards for entire road sector in India. Recently, IRC has prepared several codes and guidelines for promoting sustainable and green construction technologies. This paper discusses recent IRC codes on Sustainable and green solutions for reducing the carbon footprints of construction and maintenance works in road sector. The important codes are IRC SP: 108 – Guidelines on Preparation and Implementation of Environment Management Plan: IRC: 113:2013 Guidelines for the Design and Construction of Geo-synthetic Reinforced Embankments on Soft sub-soils: IRC: 120:2015 Recommended Practice for Recycling of Bituminous Pavements: IRC: SP:101-2014 Guidelines for Warm Mix Asphalt: IRC: SP:121: 2018 Guidelines for Use of Iron, Steel and Copper Slag in Construction of Rural Roads: IRC: SP: 122:2019 Guidelines for Green Rating of Highways: IRC: SP:132- 2022 Guidelines on use of Industrial Wastes for Road Embankment and Subgrade Construction and IRC: SP: 133:2022 Guidelines on Reducing Carbon Footprint of Road Projects.

This paper has been divided in four sections. In the introductory section, the current and future statistics on CO2 emissions released during different stages of highway projects i.e Construction, Maintenance and Operations have been presented. In the second section carbon emission estimation methodology developed by Intergovernmental Panel on Climate Change (IPCC) and IRC have been explained. In the third section most of the globally recognized carbon efficient technologies relevant to construction and maintenance of highways have been documented. It has been estimated that adoption of carbon efficient technologies during highway constructions and maintenance phases can bring down their emission intensity by almost 20 - 40% from the business as usual scenario. Technical and administrative recommendations which may be considered by the road authorities have also been covered in the last section. The paper also discusses the challenges in the use of green and sustainable technology in India and their possible solutions.

Keywords: -Sustainable, carbon footprint, Life Cycle Assessment, Climate change, GHG emission. Recycling, Industrial Wastes, Geosynthetics, Copper slag and Green rating

Session 29

Case Studies in Sustainable Materials,

Technology and Practices

ID-227

Characterization of the Site-Effects on the Local Seismic Hazard Assessment for A Long-Span Suspended Bridge in Southern Chile

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Abstract

The upcoming Chacao Channel Bridge that will be located at X region in southern Chile, is undoubtedly one of the most important civil engineering projects in Chile and the world. The location of this mega structure is framed and confined by several hazard sources, from which the seismic hazard, uniform and local, is one of the most important to consider. The area where the bridge will be located corresponds to a seismically active zone, where the famous Mw=9,5 1960 Valdivia, the strongest earthquake ever recorded in the world, generated extensive subsidence and uplift (1). Convergence between the Nazca and South American plates conditions the development of N-S trending morpho structural units, which affect the seismic characteristics of the area, where the main seismogenic sources are identified: thrust, intraplate of intermediate depth and crustal superficial intraplate earthquakes (2).

One of the basic hazard variables is the evaluation of the site-effects, due to dynamic amplification of soil. Those effects can increase the seismic demand on specific areas, and mainly for long span bridges, in which this aspect is considered as part of the spatial variability effects. In order to complement the studies carried out, and aiming mainly to quantify the site-effects and local amplifications, seismic micro zonation surveys and determination of shear wave velocity profiles (Vs) were performed. The campaigns were concentrated on the north and south approaches to the bridge, focusing on the areas where the towers and anchoring blocks will be located. Therefore, it is intended to verify the relationship between the amplification factors obtained from the seismic micro zonation, the geological and geotechnical background of the soils, and the parameters that quantify the stiffness. The definition of micro vibration points was made based on the technical feasibility in the field and considering the future location of the main structures of the bridge. Additionally, measurements were concentrated in areas where seismological recording stations were previously installed, which in a future stage of evaluation, will make possible to obtain correlations between micro vibration records and real earthquake records. 21 points were surveyed in the northern access and 17 points in the southern access.

This paper describes the methodology, field campaigns and the main results related with the evaluation of site-effects in the area associated with the location of the mega-structure. The geophysical surveys performed applying seismic arrays as well as ambient micro-vibration analysis are explained and detailed. Predominant periods of soils, soil stiffness and dynamic amplification are exposed.

Results for the north and south access are presented as the basis for the evaluation of the local seismic demand of the structural system. The local amplification detected in the upper area of the southern access, in principle, does not directly affect the seismic behavior of the superstructure, however, can affect the seismic design of rigid structures, such as the anchor blocks and the access structures to the bridge. Because

eventually the fundamental periods of these rigid structures could match the predominant soil response, these structures could be affected by dynamic amplifications.

Keywords: Site-effects, seismic hazard, long span suspended bridge, Chile.

References

[1] Plafker, G. and J.C. Savage (1970). Mechanism of the Chilean Earthquakes of May 21 and 22, 1960. Geological Society of America Bulletin, V. 81, p. 1001-1030

[2] Consorcio Icuatro-Cowi (2001). Informe Fase 7, Pre-Informe Final. Volumen 5D: Ingeniería Básica del Emplazamiento del Puente. Estudios Sísmicos. Santiago, Chile.

ID-617

Case Study: Implementation of UHPFRC Technology in India - Pilot Bridge Project.

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Abstract

This paper briefly presents the current state of practice in the development of ultra-high-performance concrete (UHPC) bridge construction technology in Indian Sub-continent. Since the early 2000's, research in the optimal uses of UHPC in bridge construction through its Sustainable Bridge Construction Initiative has been taken up on large scale. World is currently exploring new materials and faster construction methods to keep up with demand of better infrastructure.

This paper highlights a case study of Pilot bridge project constructed at Latur, Maharashtra, India (herein referred to as Latur Bridge). The case study sets forth design aspects, quality control, constructability, and of how UHPC has helped to make the bridge more affordable, sustainable, easier, and economical. Latur Bridge, is a 16 m wide bridge with 11 m carriageway with 1.5 m footpath on both sides and 2 x 56m long concrete road bridge that was constructed by Ministry of Road Transport and highways (MoRT&H) through Maharashtra State Road development corporation (MSRDC) in the state of Maharashtra. The bridge was constructed at the downstream of Masalga dam, crossing Sole Nalla, (with GPS coordinate of 18.25692N, 76.724605E). To date, this is the only bridge is the India to be constructed using UHPC Technology. This paper presents the feature of this UHPC segmental box girder (SBG); brief in-sight of the manufacturing of the girder; the construction sequence of the bridge; the design method and lastly the environmental impact calculation.

The collected field midspan deflections of the bridge during the load test were compared against the analytical data and it showed that the calculated values generally agree well with the field data.

Keywords: UHPFRC; Segmental Girders; Bridge Girders; French Codes; UHPC; Age Adjusted Effective Modulus Method;

ID-618

Design of 102.6 m span Bridge using Ultra High Performance fiber reinforced Concrete (UHPFRC)

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Abstract

Ultra-high-performance concrete (UHPC) is an advanced cementitious-based composite material that offers new opportunities for current or future infrastructure development in both urban-suburban regions and rural developments. UHPC in its present form has become commercially available in many countries such as Australia and New Zealand (Rebentrost, and Wight, 2011), Austria (Freytag et al., 2012), Canada (Blaise, 1999), Germany (Schmidt, 2012), Italy (Meda, 2003), Japan (JSCE, 2006), Malaysia (Voo et al., 2014), Netherlands (Kaptijn et al., 2004), Slovenia (Šajna et al., 2012), South Korea (Ricciotti, 2002), the United States (Graybeal, 2011) and other countries. A complete search of the literature has identified more than 100 completed bridges (pedestrian and motorway bridges combined) constructed using UHPC in one or more components. Both private and governmental bodies are directing increasing attention and initiative towards exploiting UHPC as the future construction material, in the belief that UHPC technology embraces the complete solution for sustainable constructions (Ng et al., 2012; Voo and Foster, 2010).

In 2016, AFNOR (Association Française de Normalisation) has published the world's first and only design standard for UHPFRC Technology and is National addition to Eurocode 2 for concrete structure design. In addition to these standards, other guidelines available are French Interim Recommendations, German & Japanese Recommendations.

Similar type of standardisation is also being adopted in Switzerland, China, Canada, Malaysia, and Japan. Now India has also made strides in the implementation of UHPFRC Structures. Till date almost 10 nos of bridges are completed.

This paper highlights a case study of bridge project being constructed near Pune, Maharashtra, India. The case study sets forth design aspects, quality control, constructability, and of how UHPC has helped to make the bridge more sustainable, easier, and faster to Construct. Bridge, is a 16 m wide bridge with 13 m carriageway with 1.5 m footpath on both sides and 1 x 102.6 m long SINGLE SPAN. The bridge is being constructed across Nira River Canal with 70 deg skew. To date, this is the only bridge is the India with simple supported span of more than 102.6 m in concrete.

Keywords: UHPFRC; Segmental Girders; Bridge Girders; French Codes; UHPC; Age Adjusted Effective Modulus Method;

ID-1189

Construction of Underpass by Box Pushing across NH-48 near Aerocity, Delhi.

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Abstract

Construction of a 2 x 3 Lane wide Underpass, 135m long (60m below NH by box pushing and remaining by cut and cover method) below National Highway-48 was required to improve access to the Indira Gandhi International Airport (IGIA) in Delhi and reduce congestion of traffic in the adjoining area of Mahipalpur as per the plan of Govt. of India.

Key words - Underpass; Box Pushing; Thrust Bed; Rocky Strata

1 1 Introduction

It was taken up on recommendation of a High-Powered Committee headed by the Secretary (Urban Development), Govt of India.

2 2. Planning

It was planned to create a crossing near Hanuman Mandir as an additional entry to the Airport area. Flyover was ruled out due to closeness to funnel of airport.

3 3. Design

The Underpass was 60m long across NH-48 as per the width of the highway. Two sets of parallel boxes were planned. Each box was of 11m x 5.9m inside dimensions with 1m thickness all around. The weight of one box was around 900 MT and therefore adequate arrangement for placing of Jacks was made during casting of Boxes.

4 4. Pushing of Boxes

Air pushing was done till the box touched the toe of embankment of NH-48. Cutting of earth in front of cutting shield was started with the help of Excavator. In one go, 400 to 500mm earth in front of the Box was cut. The box was pushed using Jacks of 200 MT capacity (Ram dia of the Jacks was 160 mm).

For the first Box, 20 Number Jacks were used. 4 Jacks were fixed in the Top Slab, 4 on the side walls and remaining 12 jacks were fixed in the Bottom slab. For remaining Boxes, 12 to 16 Jacks were used. It was observed that for Air pushing, average time of 25 minutes was required for pushing by 500mm. For pushing in Earth/rock, time varied according to strata.

Pushing remained smooth for the first 25m length. After 25 m, rocky strata started to appear. Huge quantity of rock cutting was involved; therefore, two breakers were deployed.

The rocky strata was inclined from IGIA side to Mahipalpur side and increased with every inch of pushing and by the time 1st Box crossed the Jaipur Bound Carriageway of NH, the height of Rocky strata reached to around 7m from bottom of the box. The Earth portion between rock and crust of the carriageway was hardly 2.5-3m at this location. It was very challenging to cut rocks beyond this location as there was every possibility of collapse of the NH carriageway. Hence the remaining work in a length of about 10m was carried out with cut and cover methodology.

When pushing was being carried out below National Highway, it was observed that there was a tendency of the soil layer above the box to get pushed along with the box which would have damaged the road. CRRI was consulted for suggestions regarding better protection of Highway embankment. Based on the suggestions of CRRI, nailing with 25mm dia bars in embankment above box level was carried out.

5 5. Challenges faced during execution

The underpass was to be constructed by pushing boxes below a major traffic artery, NH-48 without stopping traffic.

The boxes had to be pushed through rocky strata which made the pushing work difficult. Controlling alignment of the boxes was a major challenge.

Though efforts were made to match all Boxes vertically and horizontally but due the presence of rocky strata, few gaps between Boxes were left after final pushing which were filled with Light weight concrete.

The tunnel of Airport Express Line Metro was running just below the space identified for casting of Thrust Bed. Hence, close coordination was maintained with DMRC so as not to cause any damage to the tunnel.

The work was executed during monsoons to meet deadlines.

The limited clear gap of 2m available within the two rows of boxes and limited overburden of 2m over the boxes mandated that the boxes had to be pushed very slowly.

6 6. Sustainability features of Project

6.1 Environmental considerations: Measures were taken to make the project environment friendly. Rainwater harvesting arrangement, extensive tree plantation and use of rocks obtained during excavation for making toe walls.

6.2 Social considerations: About 28,000 people travelling through the influence area have benefitted from this project directly. This has led to saving of about 14000-man hours daily and a saving of 30 lakh litres of fuel each year.

6.3 Economic considerations: The project was completed with a saving of approx. 26 Crores, did not cause any disruption in traffic during construction and caused a saving of approx. 30 lakh litres of fuel each year.

7 Conclusions:

i. Proper identification of congested corridors is important.
ii. Selection of the most appropriate technology for construction as per site and sustainability considerations.
iii. The construction should be economical. The project under construction was completed with about 15% savings in the approved cost.
iv. Least disturbance to the environment and make life easier for the people at large.
v. Quality assurance measures should be adopted to ensure delivery of a quality project.

Acknowledgement

The authors express gratitude to Director General, CPWD, NHAI, CRRI, Delhi Traffic Police and DTU .

References

1. Report of High-Powered Committee on “How to decongest Delhi”.

ID-1238

Precast PSC Segmental Girders – An overview of failures during construction based on some case studies

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Abstract

Considering faster pace of development, consistent increase in the volume of traffic in developing country like India and limitation of land availability especially in built up or urban areas, lateral expansion in transport facilities has become more challenging. Under such circumstances vertical expansion through construction of long flyover or elevated structures is most viable solution to meet the traffic demand. However, desired quality management, skilled human resources are not keeping pace to meet the requirement of rapid expansion in the field of bridge construction. Road and Railway Bridges are complex in nature w.r.to their design and construction which require a high level of knowledge expertise and experience. Hence, some failures are taking place even during construction of bridges due to some material quality issue as well as human error. Recently failures of some under construction railway and Road Bridge in India have rocked the civil engineering profession apart from public sentiment. This paper mainly covers the issues relating to risk sharing among stakeholders for different mode of Road and Bridge Construction, Role and Responsibilities of Contractor, Engineer & Client, reasons leading to failures of some Precast PSC segmental Box girders and few suggestive preventive measures.

Keywords: Lateral Expansion, Vertical Expansion, Role and Responsibilities, Human Error, Risk Sharing, Precast PSC Segmental Girders.

1 Introduction

Bridge structures consist of different parts which require different expertise as well as proper coordination among all stakeholders from conception to completion stage. In respect of bridge construction under FIDIC condition, the design risk was fully shared by the client as well as financial risk for funding the project. But on account of change of mode of Road and Bridge Construction to BOT (Toll) BOT (Annuity) Engineering Procurement (EPC) and Hybrid Annuity Modal (HAM), the entire design risk is shared by the contractor or concessionaire. In this process the contractors are adopting the analysis and design of the bridges with utmost factor of safety and going for adopting the sleek design modal of the structure in the light of available national as well as international code of practices for bridge engineering. On the other hand, in order to meet the fast pace of bridge construction there is a lack in total quality management aspect with respect to use of Imperfect Materials as well as Standard Operating Procedures and human errors. These are some vital reasons for causing failures in bridges during construction. Due to implementation of various mode of bridge construction, wherein risk sharing are mainly done by the contractor, a proper coordination on regular basis are desirable among contractor's designer, proof checker, safety consultant and engineer to bring improvement in quality management and minimizing or avoidance of bridge failures during construction.

2 Risk Allocation

Considering the limitation of public funding for infrastructure development in Road and Bridge projects, different mode of implementation of the project by involving private fundings are

undertaken. Accordingly, there are different risk allocation to stakeholders for different mode of implementation.

3 Roles & Responsibilities of Contractor, Engineer and Client

Roles and Responsibilities of all stakeholders are vital with respect to DPR, Design Basis Report (DBR), Quality Assurance Plan (QAP), Project Specific Quality Assurance Manual (QAM), specification for Road and bridge works issued from Ministry of Road Transport and Highways, Standard Operating Procedure (SOP) for all the bridge construction activities.

4 Case Study on Failure of Precast Segmental PSC Box Girder Bridge

4.1 Collapse of two spans of 8 Lane Elevated (spine cum wing) Flyover

Collapse of two spans with launching girder happened due to crushing of segments with poor concrete in span P108-P109. Failure of this span triggered the failure of 2nd span P107-P108 and along with falling of Launching Girder.

4.2 Collapse of a span of 6- Lane Elevated (spine cum wing) Flyover

Crushing of concrete at segment S-5 (location from pier P10) caused sagging of the span, resulting into overloading of pre-stressing cables causing slippages of PT wages and lose of pre-stress which further resulted into sagging and fall of the span. The span was resting of the temporary steel stools at the time of collapse.

4.3 4-Lane Precast PSC Segmental Box Girder Bridge (2x12.50m)

The launching girder and segmental box girder A1-P42 Collapsed due to change in sequencing of pre-stressing process. In spite of pre-stressing 21 cables, only 17 cables were pre-stressed before auto launching of LG. This was deviation from the approved SOP of Good for construction drawing and movement of launching girder. It was clearly mentioned to do pre-stressing of all the 21 cables before movement of LG.

5. Conclusions

In spite of advanced level of knowledge and vast experience and availability of design codes and guidelines which are applied during bridge design and construction, engineering mistakes are always possible which can all lead to structural failure. However, based on the above case studies following steps shall be helpful to preventive such type of failure in future.

- Design/Drawing be checked and approved as designated with proper seal and date. Designer and proof checker to visit site on regular basis.
- Level of Approval of Good for Construction Drawing (GFC) - Design Director - Safety Consultant - Proof Check Consultant - Authority Engineer
- SOP for each and every activity at site should be prepared by the contractor and got vetted or approved by the AE.
- Any deviation in the construction activity from the approved Good for Construction (GFC) Drawing should be brought to the notice of designer.

6. Acknowledgements

In preparing this paper, necessary help and the support have been taken from the construction site Project Manager and other field officers in obtaining the requisite details relating to failures of the segments and the spans of the Precast PSC Segmental Box Girder Bridge.

Session 30

Analysis, Research and Standardisation

ID-155

Verification of reinforced concrete D-regions designed with Strut-and-Tie models by nonlinear FE-Methods

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Abstract

In this Paper the ultimate load capabilities of Strut-and-Tie Models (STM) are examined with the help of nonlinear FEM simulations. These were performed with the software Abaqus and Ansys, with their Concrete-Damaged-Plasticity (CDPM) and Coupled-Damage-Plasticity-Microplane (MPM) material models respectively. This paper provides an overview of all the relevant aspects regarding modelling the material nonlinearities and provides an example on how to use both material models. The conclusions of this work shall pave the way for further studies, especially for D-Regions with non-metallic reinforcement such as Glass Fibre Reinforced Polymer (GFRP) rebars.

Keywords: Deep beam; D-regions; strut-and-tie models; reinforced concrete simulation; finite-element-method; nonlinear FEM; microplane; concrete material models; design; fracture energy.

1 Introduction

Structural discontinuities (D-regions), such as openings and dapped ends, are still a demanding task for the practical design. These D-regions are practically designed with Strut-and-Tie Models (STM). Alternatively, software based on the Finite Element Method (FEM) can be used. The proper use of these, however, requires deep understanding of the theoretical background. Especially when trying to simulate nonlinear material behaviour.

This paper provides an overview of all the relevant aspects, regarding the consideration of material nonlinearities. A well-known design example from literature, which was solved with the use of the STM-method, has been simulated by FEM-Software. The FEM simulations were performed with the material models called the Concrete-Damaged-Plasticity (CDPM) in Abaqus and the Coupled-Damage-Plasticity-Microplane (MPM) in Ansys. A comparison of the FEM simulation results, obtained with the two different material models is given. The comparison is focused on the ultimate load capabilities. This study shows, that the STM is a good tool for ultimate load design. The conclusions of this work shall pave the way for further studies, especially for D-Regions with non-metallic reinforcement such as Glass Fibre Reinforced Polymer (GFRP) rebars.

2 Design of a deep beam with opening

For the FE-Calculation of a deep beam with an opening the well-known example from Schlaich and Schäfer has been chosen. The suggested STM for this case is presented in Figure 42. The reinforcement distribution was chosen as shown in Figure 43.

3 Results

A summary of the obtained results is presented in Figure 44 and Table 11. For the Abaqus calculations different mesh sizes were analysed. For the Ansys calculations this was not necessary. Calculations were done for characteristic and design material values.

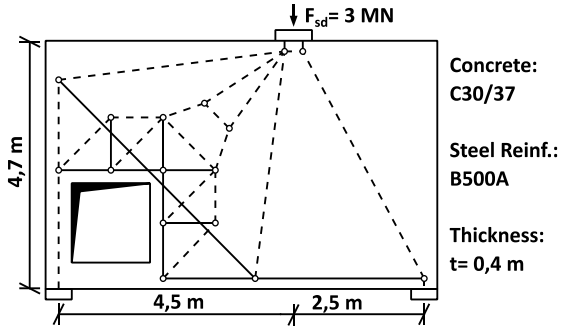


Figure 42. Strut-and-tie model

4 Conclusions

A comparison of ultimate loads from STM design and FE-design showed only little differences. Thus, the STM is considered still as an economical and reliable method for design of structural concrete. Both sophisticated material models used in FE-software have shown reasonable prediction of the nonlinear behaviour of structural concrete. Although FE-calculations can be useful to predict and showcase crack patterns and investigate failure causes, a lot of expertise is needed and achieving reliable results is very time consuming.

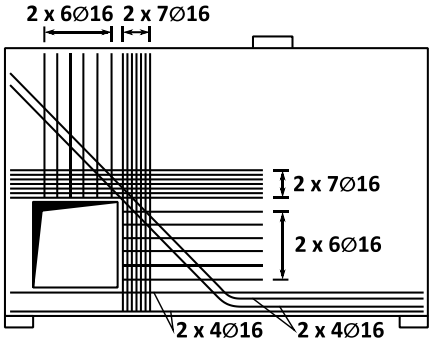
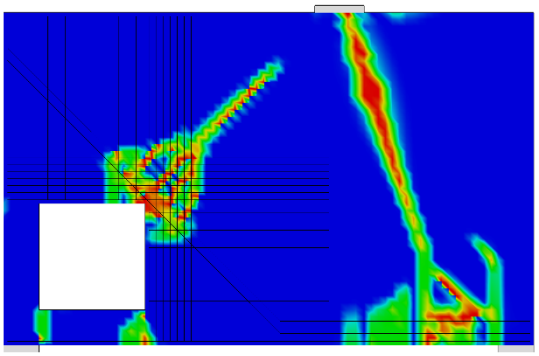


Figure 43. Statically necessary reinforcement

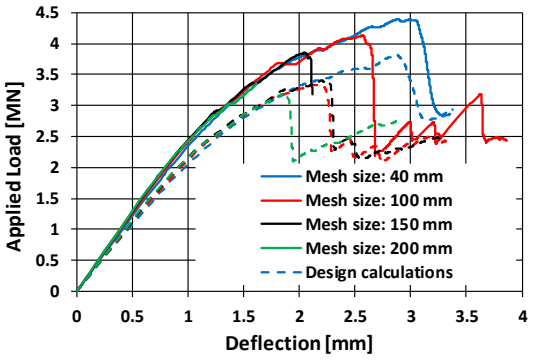
Table 11. Load Results [MN]

	Ansys MPM	Abaqus CDPM
Characteristic	4,328	4,391
		4,131
		3,848
	STM	**FEM**
Design	3,000	3,812
		3,339
		3,399

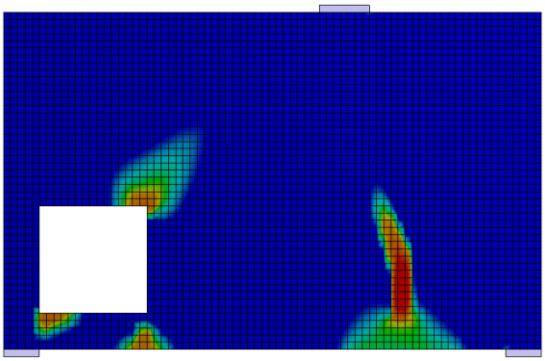
Abaqus CDPM (Mesh size: 100 mm)



Load deflection response Abaqus (CDPM)



Ansys MPM (Mesh size: 100 mm)



Load deflection response Ansys (MPM)

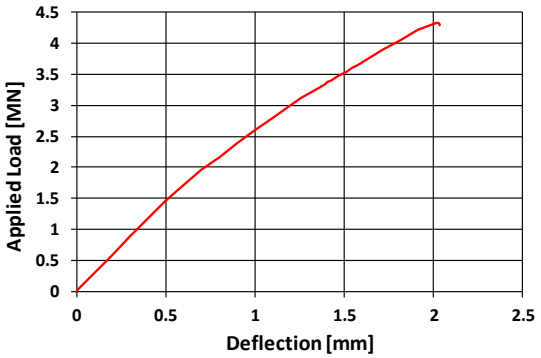


Figure 44. Summary of results containing damage plots and load deflection response

ID-602

Seismic Retrofitting of Multi-Storey RCC Building using Fluid Viscous Dampers and Comparing the Results Before and After the Retrofitting

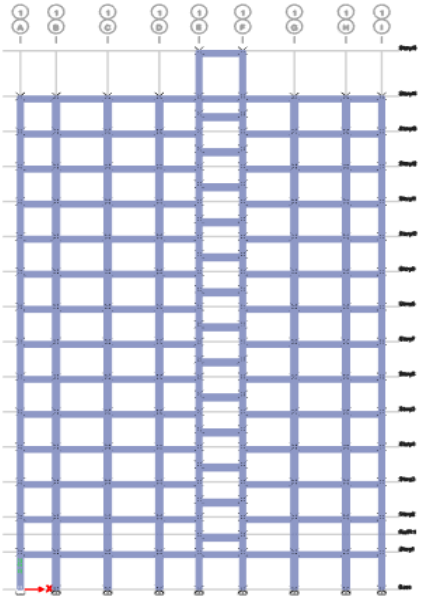
Arup Saha Chaudhuri, Md. Toshif Alam

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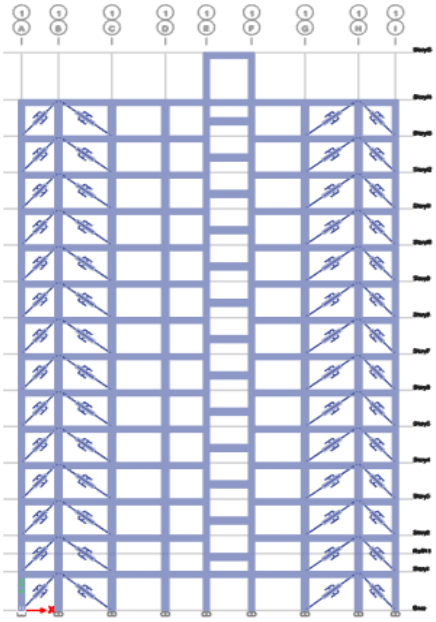
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Abstract

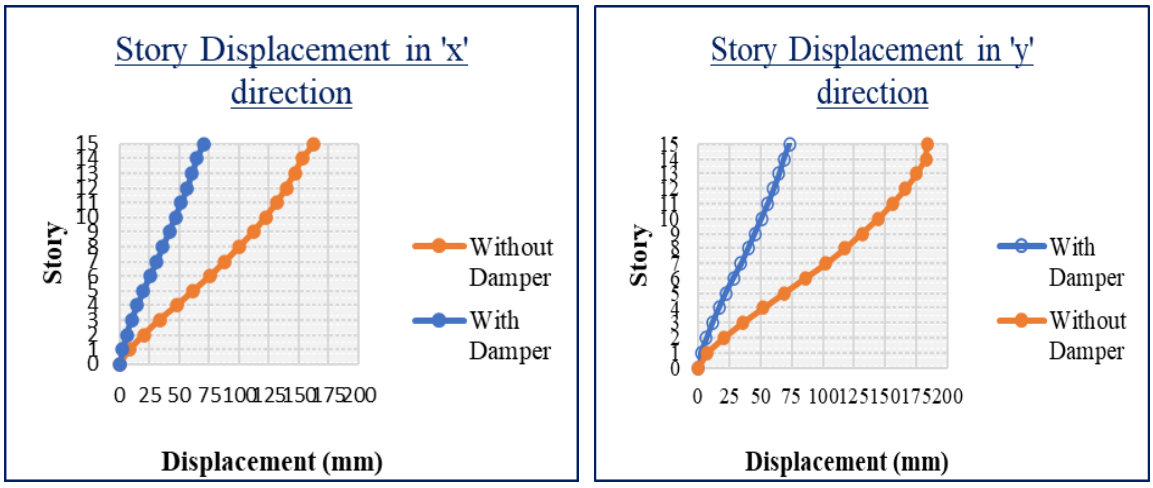
In the past, a large number of building structures in India have been damaged by earthquakes and some of these structures have been repaired and strengthened. The strengthening of existing structures is required in cases where the buildings are constructed according to the old regulations, and they do not fulfil any more the requirements of the recent regulations. Most of the buildings in India are normally constructed to resist static loads without considering seismic action. However, this leads to deficiencies in the design of the structures. In our case, one newly built 15 storey RCC framed building which have experienced a strong earthquake and during that time the seismic vibration of the building was much high which settled a fear among the tenants about the safety of the structure. After the earthquake the structure was carefully observed but no cracks or any sorts of damages to the frame members were found except the wall on which hair cracks were developed. But for the safety against the future earthquakes and most importantly safety of the structure, the building is to be retrofitted with Fluid Viscous Dampers. Here we will analyze the changes in the storey displacement, storey drift, modal period and frequencies, storey stiffness, critical column and beam forces before and after retrofitting the structure with the dampers using ETABS. This will help to provide extra safety precaution to the joints of the structures also.



Front Elevation View without

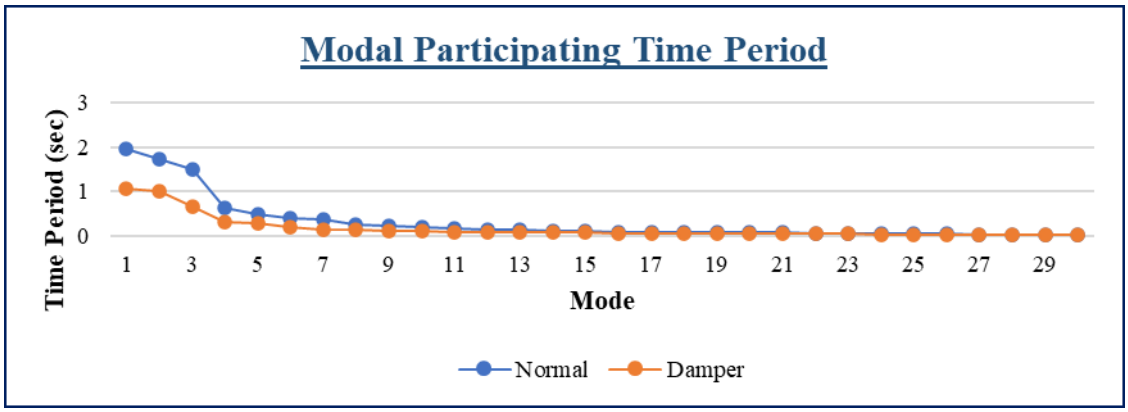


Front Elevation View with Damper



Comparison of storey displacements between Original and Retrofitted Buildings

Modal Periods and Frequencies					
Case	Mode	Period sec	Period sec	Frequency cyc/sec	Frequency cyc/sec
		Normal	With Damper	Normal	With Damper
Modal	1	1.95	1.065	0.513	0.939
Modal	2	1.742	1.02	0.574	0.98
Modal	3	1.487	0.662	0.672	1.51
Modal	4	0.63	0.3	1.586	3.335
Modal	5	0.486	0.282	2.058	3.548
Modal	6	0.399	0.208	2.507	4.803



Comparison of Modal Periods and Time Periods between Original and Retrofitted Buildings

Keywords: Seismic hazard, RCC building, Fluid viscous dampers, Safety precaution.

ID-606

Ultrasonic Pulse Velocity Testing for Evaluation Of Stabilized Soil in Pavement Structures

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Abstract

On the clayey soil, Ultrasonic pulse velocity tests were conducted in order to investigate the relationship between pulse velocity, dry density, water content, and bulk density experimentally. In a Proctor mould (100 mm dia.) and a split mould, laboratory test specimens were created using the compaction method (38 mm diameter). Then, using the direct transmission method, the wave velocity of each compressed specimen was measured. Unconfined compression tests on compacted materials with a diameter of 38 mm were also performed to determine the relationship between compressive strength and pulse velocity. All soils tested exhibited an increasing pulse velocity with increase in dry density until the optimum water content. A rapid drop in pulse velocity was observed subsequently with decrease in density. This observation is in conformity with the findings of earlier various investigators. The parameters investigated were water content, soil type, dry density, compressive strength. The relation between velocity and density is linear for the soils tested. Unconfined compressive strength of the soil sample was correlated with velocity and is found to vary polynomial with velocity. The empirical equations proposed in this study for predicting density, water content, compressive strength is encouraging.

Keywords: Ultrasonic pulse velocity; Dry density; unconfined compression; compressive strength; water content.

ID-1008

Mechanical Performance of Ultra-High Performance Concrete for Bridge Applications

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National Council for Cement & Building Materials, India

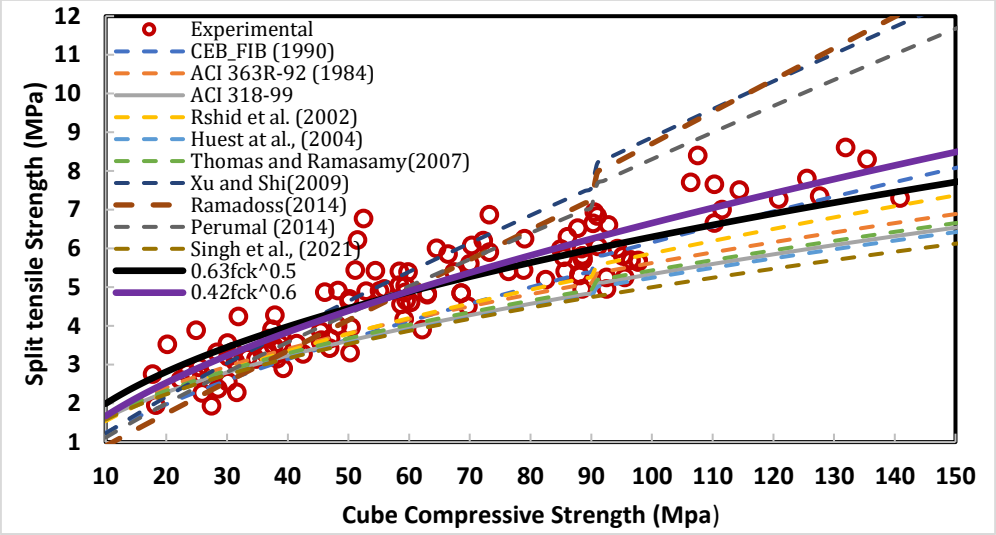
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Abstract

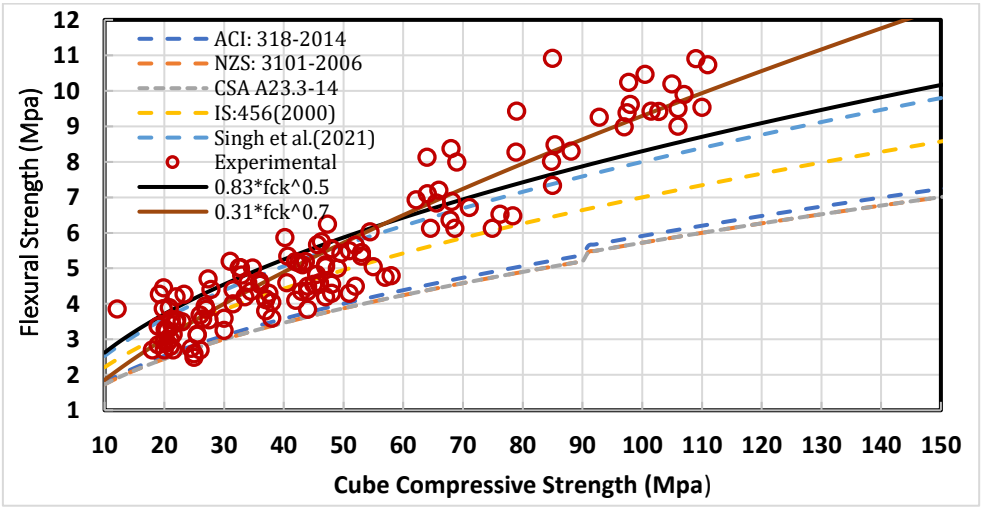
With adoption of Ultra-High Performance Concrete (UHPC) now a days in construction, there is need to develop equation and relationship which can predict modulus of elasticity, flexural and split tensile strength of UHPC using indigenous materials. Study is done by analysing experimentally obtained results of a total 120 specimens each for flexural & split tensile strength and 100 specimens for modulus of elasticity of UHPC. Ordinary Portland Cement-OPC 53 grade, flyash, ultrafine GGBS and silica fume meeting requirements of IS: 269, IS: 3812, IS: 16714 & IS 15388 respectively were used in concrete. Granite type coarse aggregate and fine aggregate as per IS: 383 is used for strength up to 90 MPa. To obtain better packing density of concrete, three types of aggregates namely (a) Fine Quartz Sand, (b) Ground Quartz and (c) River sand for strength between 90 MPa to 150 MPa were used. Ten mix proportions from w/b ratio of 0.60 to 0.16 were adopted to achieve compressive strength range of 15 to 150 MPa. Mix proportion for UHPC of individual cementitious material was decided using Modified Andreasen and Andersen equation. Split tensile strength and modulus of elasticity of concrete was carried out on cylinders of 150x300 mm as per IS: 5816 & IS: 516 respectively. The flexural strength of concrete was determined on beams of size 150x150x700 mm as per IS: 516. Based on the experimental results an empirical equation is proposed for prediction of modulus of elasticity, flexural and split tensile strength for strength range of 15 to 150 MPa and is compared with equations in International standards.

The proposed equation for estimating split tensile strength and flexural Strength of concrete for compressive strength ranging from 15 to 150 MPa can be 0.63 $fck^{0.5}$ where Fck is cube compressive strength of concrete. Most of the previous equations are reasonably predicting estimated split tensile strength of concrete upto 90 MPa except equations proposed by Perumal (2014), Ramadoss (2014) and Xu & Shi (2014). But for compressive strength between 90 to 120 MPa, proposed equations by Perumal (2014), Ramadoss (2014) and Xu & Shi (2014) are closer and slightly higher to experimental results. The proposed equation for estimating flexural strength of concrete for compressive strength ranging from 15 to 150 MPa can be 0.83 $fck^{0.5}$ where Fck is cube compressive strength of concrete. Comparison of codes and literature indicated that ACI: 318, New Zealand code (NZS: 3101), Canadian code CSA: A23.3-14 (2014) and IS-456-2000 estimates flexural strength value on lower side than actual experimental values for normal and high strength concrete. The proposed equation for estimating modulus of elasticity (MOE) of concrete for compressive strength from 15 to 150 MPa can be 10000 $fck^{0.3}$ where Fck is cube compressive strength of concrete. Predictions by ACI 318-14 indicated that MOE values are lower than experimental values for normal strength concrete and higher than experimental values for high strength concrete. Predictions by EC2 showed a clear conservative values as test values are above experimental trend line but they are not far from experimental results. New Zealand code predicts lower MOE value than experimental values for normal strength concrete while predicted values comes closer to experimental values for high strength concrete. IS: 456 equation predicts MOE values more or less equal to the experimental values for normal strength concrete while predicts

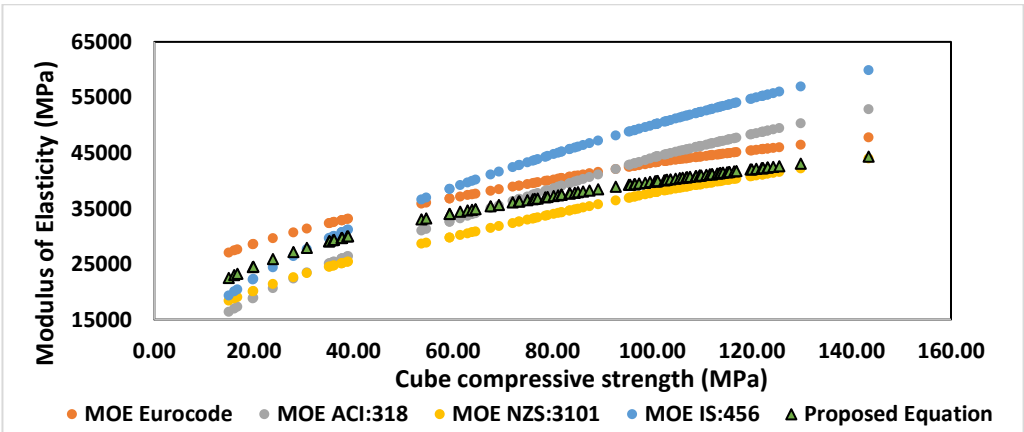
higher MOE value than experimental values above 40 MPa.



Comparison of Proposed Equation for spilt tensile strength of concrete with literature



Comparison of Proposed Equation for flexural strength of concrete with literature



Comparison of Proposed Equation for modulus of elasticity of concrete with literature

ID-1106

Effect of Pedestrians on Vehicular Speed and Capacity of Hilly Roads

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Abstract

Roads and transportation are essential necessities for everyone in the today's world. Two-lane highways make up the majority of the Indian National and State Highway System. More than half of State Highways and National Highways are still two-lane roadways. The considerable amount of two lanes highways lies in hilly regions especially in the Himalayan region of Indian peninsula. Very few studies have been conducted on hills roads due to the geological and environmental conditions in such regions. This study attempts to analyze the effect of various geometric features on the capacity and speed of two lane hilly roads. The geometric features such as width of the lanes, the gradient, the lateral clearance, pedestrian crossings and the type and condition of the shoulders are among the major elements that affect the capacity of a two-lane roads. Realizing that the pedestrian crossing and longitudinal gradient are some of the significant factors affecting Indian roads, this study examines the capacity and speed of vehicles under varying roadway and traffic conditions.

The study utilized the video graphic method to collect field data on two lane highway (NH-7) of Srinagar city of Uttarakhand. Among the selected sites, two sites had pedestrian movements and other two sites were free of pedestrians. The survey was conducted during two periods of high traffic volume: in the morning from 8:00 to 10:00 AM, and in the evening from 4:00 to 6:00 PM. The sites were selected with varying magnitude of gradient, i.e., two sites with gradient less than 2% and the remaining two sites with gradient greater than 2%. The recorded video was played on Kinovea software, which is a video annotation tool designed for movement analysis. The primary goal of this study is to evaluate vehicle flow, density, and speed in order to calculate roadway capacity. The study also establishes the relationship between speed, flow and density using Greenshield's model. Another objective is to observe the effect of gradient and pedestrian movements on capacity of the road for different gradient ranges.

The conclusions of the study are as follows:

I. The results suggested In this study we observed speed reduces at pedestrian site as compare to non-pedestrian site by 23.28 km/hr when gradient is greater than 2 and reduce by 7.3 (km/hr) when gradient is less than 2.
II. The capacity at pedestrian site reduces with respect to non-pedestrian site by 344 (pcu/hr) when the gradient is greater than 2 and reduces by 663 (pcu/hr) when gradient is less than 2 because of pedestrian crossing.
III. When we increase the gradient in pedestrian site the speed is reduced by 16.49 km/hr. and in non- pedestrian site the speed is reduced by 0.51 km/hr.

IV. When we increase the gradient in pedestrian site the capacity reduced by 14pcu/hr and in non- pedestrian site capacity reduced by 333 pcu/hr.

The study's findings can be used by transportation engineers and planners to develop a comprehensive understanding of the traffic on hill roads. The outcome is anticipated to be extremely helpful for practitioners and ongoing attempts to develop the Indian Highway Capacity Manual (Indo-HCM).

Keywords: hilly regions; gradient; pedestrian; two-lane highways; speed; capacity.

ID-1219

Seismic protection of built environment. The Revision of the European Standard EN 15129 on Anti-Seismic Devices

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BOLINA Ingegneria, Venice, ITALY

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Abstract

CEN officially created the TC 340: Anti-seismic Devices in 1993 with the task to proceed with the standardization of the seismic hardware for use in structures erected in seismic areas and designed in accordance with EUROCODE 8, with the aim of modifying their response to seismic action. This European Standard specifies functional requirements and general design rules thereof, material characteristics, manufacturing and testing requirements, as well as acceptance, installation and maintenance criteria. This Standard covers all types of Seismic Hardware in existence and leaves a door open to future progress. Also, the paper elucidates the criteria adopted for the pending revision of the EN 15129 that began in December 2015. In conclusion, this document summarizes the experience gained in Europe over the past 40 years in the field of Anti-seismic devices, which is dealt with through the application of very advanced criteria. This favours pro-gress inasmuch as it promotes loyal competition through clear and fair rules that protect the interests of the community.

Keywords: Comité Européen de Standardalisation; CEN; European Standards; Standardization; Antiseismic devices; seismic protecion.

1 Introduction

An increasing number of Congresses and Symposia - as well as other professional meetings - give testimony to the significant strides made by Earthquake Engineering during the last forty years. Progress has been the result of a better understanding of the seismic behaviour of structures as well as improved knowledge of the characteristics of seismic actions. In relation to these two aspects [Dolce (1991)], newly developed design strategies have been devised and implemented entailing the use of special mechanical devices to be included in the structural system in order to substantially:

- change its overall behaviour (e.g. seismic

isolators);

- dissipate most of any input energy (e.g. energy dissipating braces, hydraulic dampers);
- provide a different behaviour under service and seismic actions (e.g. shock transmission units).

2 Structure of the Standard

The structure of the European Standard on Antiseismic Devices has been modified several times. Its definitive version, subdivided in "Parts" is arranged as follows:

- Part 1: Terms and definitions, symbols and abbreviations - General Design Rules; - Part 2: Rigid Connection Devices;
- Part 3: Displacement Dependent Devices;
- Part 4: Velocity Dependent Devices;
- Part 5. Elastomeric Isolators;
- Part 6: Curved and flat surface sliders.

Informative Annexes accompany the various Parts of the Standard, in order to give useful comments and explanations to the reader. Much attention has been focused on the definition of the various types of devices. In effect, the CEN rules require that "the definitions shall be unambiguous and as concise as possible". As an example, let's examine the case of clause "Scope". "This European standard covers the design of devices that are provided in structures with the aim of modifying their response to the seismic action. It specifies functional requirements and general design rules in the seismic situation, material characteristics, manufacturing and testing requirements, as well as acceptance, installation and maintenance criteria".

3 The revision process

The objectives of the ongoing revision work of the EN 15129 revision are (in ascending order of importance) to:

1. divide the Standard into 6 different Parts according to different types of devices in order to make it more modern and usable;
2. edit and update the text;
3. correct possible technical mistakes;
4. remove reported interpretation difficulties;
5. conform with Eurocode EN 1998: Design of structures for earthquake resistance;
6. address environmental issues, as requested by the CEN Guide 4;
7. update the content to the present State-of-the- Art.

4 Conclusions

The European Standard on Anti-seismic Devices represents the most complete and up-to-date document presently available to Seismic design Engineers and Seismic Hardware Manufacturers. In effect, the Standard aims to cover all types of Seismic Hardware in existence and leaves a door open to future progress. This principally derives from the fact that the Standard is highly performance-oriented and this feature also constitutes a guarantee of equity between the various systems that may be used as alternatives. The main input to revise the EN 15129 derived from several factors like the surging seismic engineering market, the expiration of international industrial patents on important types of devices, the development of new technologies and the need for new high-performance, durable and reliable materials. The revision of EN 15129: Anti-seismic Devices is expected to be completed by the end of 2024.

5 Acknowledgments

Authors are pleased to acknowledge the Expert involved on the drafting and revision of the European Standard EN15129 "Anti Seismic Devices". Among other names, a special thank to Mauro Dolce, Philippe Bisch, Samuele Infanti, Felix Weber and Keith Fuller. A special praise to WG5 for the incredible effort and support.

6 References

References are listed in the Full version of this Paper.

Session 31

Special Session: New Indian Guidelines on Cable-Stayed Bridges and Extradosed Bridges

ID-164

A New IRC Guideline for Design, Construction and Maintenance of Extradosed Bridges in India

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Abstract

Initiated by the Indian Roads Congress (IRC), the official body that is responsible for developing standards and codes for Roads and Bridges in India and an institution which represents the think-tank on the subject, IRC constituted a body of experts under the aegis of the B-9 Committee 'Specialised Bridge Structure including Sea-Link', to formulate a guideline for the design, construction, and maintenance of extradosed bridges. Currently, there are more than 30 extradosed bridges existing or under construction in India. Many more are in the pipeline, in bidding stage. This paper highlights the salient features of the provisions in the guideline that is recently published by IRC.

Keywords: Extradosed Bridges, Stay Cables, Pylon, deck, Anchorage, fatigue, corrosion protection.

1 Introduction

The extradosed bridge form is eminently suited to spans in the range of 100m to 250m. In India, the maximum individual span length achieved to date is 234m for an extradosed bridge. India holds the record for the world's longest multi-span extradosed bridge, which is a bridge over river Ganga at Bihar. The length of the navigable portion of this mighty river, which is covered by extradosed spans is 1920m.

The concept of an extradosed bridge (EDB) dates back to 1988, when Jaques Mathivat presented the concept. The first extradosed bridge was the Odawara Blueway Bridge, completed in Japan in 1994. Today there are more than 200 bridges of this type around the world. In India, nearly 30 bridges are constructed/are under construction, with this concept.

Extradosed bridges are often described as mix of a conventional prestressed concrete girder bridge and a traditional cable-stayed bridge. From a morphological point of view, extradosed bridges are well-known as intermediate bridges between cable-stayed bridges and prestressed box-girder bridges. The salient difference between these bridge types are highlighted in the main paper.

Though extradosed bridges have gained popularity worldwide, there are hardly any national/ international codes and guidelines, which cover the subject in its entirety. The first comprehensive publication on the subject was made by IABSE. A state-of-the-art report on extradosed bridges was published in the year 2019.

2 Background

Initiated by Indian Roads Congress under the B-9 Committee 'Specialised Bridge Structure including Sea-Link', a sub-committee was formed five years ago (2018) under the chairmanship of the author to prepare a guideline for the design of extradosed bridges. A group of 20 eminent members, all of them having varied experience in the field of research, design, and construction of cable-supported bridges were inducted into the sub-committee. This guideline is the outcome of 5 years of intense discussion and deliberations. This guideline is perhaps the only operational guideline on extradosed bridges worldwide, covering all aspects of design,

detailing, and construction aspects. This paper will highlight some of the salient features of the guideline on extradosed bridges.

3 Broad Content of the Guideline

The following sections describe the content of various chapters.

1. Scope
2. Introduction
3. Definitions & Symbols
4. Planning Considerations
5. Preliminary Design
6. Construction Considerations
7. Loads & Load Combinations
8. Extradosed Cable System & Technology
9. Structural Modelling & Analysis
10. Design & Detailing Aspects
11. Maintenance & Performance Monitoring

Chapter 1 relates to Scope of the document. The scope is restricted to the concrete highway or pedestrian bridges with either cast-in-situ or segmental decks, having a maximum main span length of 200m only. Bridges with a design life of 100 years is only covered. Chapter 2 titled 'Introduction' covers a brief history of the evolution of extradosed bridges. The chapter also covers salient structural forms, proportions of various structural elements of ED bridges, and a comparison with cable-stayed bridges and girder bridges. Typical deck cross-sections, pylon configurations, and aesthetic details which are generally used for highway bridges are covered for guidance. Chapter 4 deals with planning considerations for EDB. Chapter 5 discusses the structural action and concept design of Extradosed Bridges. The main components of the bridge types, viz, the deck, the stay cables, and the pylon have been addressed. The methodology of Preliminary dimensioning and estimation of quantities have been given. Chapter 6 deals with construction techniques and methodologies for various components of ED bridges (i,e. Lower and Upper Pylon, Deck). Chapter 7 of this guideline summarises the loads, load combinations, and design requirements. Reference is made to IRC 6 and fib bulletin 89 while finalizing the provision of this chapter. IRC:6 for most of the loads and load combinations, which are common to all bridge types, and fib 89 for extradosed cable characteristics. Chapter 8 deals with stay cable system & Technology. Structural Modelling & Analysis is dealt with in Chapter 9. The major components discussed in chapter 10 relate to a) the interface between the deck and the pylon, b) the design of the interface between the cable and the deck and c) the connection between the pylon and the extradosed cables. Last chapter deals with maintenance and performance monitoring, which is an extremely important consideration for longevity of the bridges.

4 Conclusions

The proposed guideline in the making on EDBs is going to be a useful document in the toolbox of Bridge Engineers since it is going to provide a rational method for the design of extradosed bridges. While the authors and the Committee recognize that standards alone do not eliminate all problems associated with design and construction, this standard is intended to provide minimum criteria for safety and performance.

Acknowledgments

Thankfully acknowledge the support from the following :

a) Mr. G Sharan, Convenor of the B-9 Committee of IRC.
b) The Chapter heads who led the development of the document are Mr. Alok Bhowmick (Chair, Chapters 1 & 2), Mr. V N Heggade (Chapter 4), Prof. Mahesh Tandon (Chapter 5), Mr. C S Sankaralingam& Mr. Inki Choi(Chapter 6), Mr. U K Rajeshirke & Mr. Nirav Modi (Chapter 7), Mr. V N Heggade & Mr. J S Pahuja (Chapter 8), Mr. J S Pahuja (Chapter 9), Mr. P G Venkataram (Chapter 10) and Dr. Lakshmy Parameswaran (Chapter 11).

Other members of the sub-committee are Dr. B C Roy, Dr. Harshavardhan Subbarao, Mr. Vinay Gupta, Mr. T Viswanathan, Prof. Yogendra Singh, Mr. Aditya Sharma & Prof. Prem Krishna

ID-1240

The New IRC Guidelines for Cable Stayed Bridges in India

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Abstract

The Indian Roads Congress (IRC), the official body that is responsible for Roads and Bridges in the country and represents the think tank on the subject constituted a body of experts to formulate Guidelines for the design and construction of Cable-Stayed Bridges. This paper summarizes the contents of the Guidelines. Currently, there are some 38 Cable-Stayed Bridges existing or under construction in India and most of them feature one way or the other in the Guidelines. Brief details of these bridges appear in the Appendix of the Guidelines.

Keywords: *Cable-Stayed bridges, deck, pylon (tower), stay cables, aerodynamic, seismic, design, construction technology.*

1. INTRODUCTION

The Indian Roads Congress (IRC), the official body that is responsible for formulating codes of practice for Roads and Bridges in the country constituted a team of experts to make new guidelines for Cable-Stayed Bridges. The work covered various aspects of design, construction and maintenance, and was carried out under the overall supervision of the B9 Committee dealing with Special Bridges and are currently in print.

This paper gives an overview of the contents of the Guidelines. As on date, there are some 38 Cable-Stayed Bridges existing or under construction in India and many of them feature in one way or the other in the Guidelines. Brief details of these bridges appear in the Appendix of the Guidelines.

2. SCOPE

The Cable-Stayed Bridges is well suited for span range of 200m to 1200m (main span) from the economical point of view. However, examples of small to medium spans in the range of 27m to 150m exist.

The scope of the Guidelines shall be applicable for cable stayed bridges with maximum main span lengths as follows:

Concrete……. upto 350m

Composite Steel-Concrete and Steel…upto 500m,

The Design Life of the Cable-Stayed Bridges will be taken as 100 years to be in sync with other current IRC codes. However, in case it is desired to have a greater design life of the Cable-Stayed Bridge, additional considerations come into play, which relate to durability, waterway discharge (and scour), seismic effects, and wind effects.

3. MAIN CONTENTS

Considerable effort was put into the structural action of Cable-Stayed Bridges. The structural concepts were explained through bridges that have been constructed in India. This is invaluable from the point of view of getting to know and understand about the cable stayed bridges in our own country.

Preliminary estimation of quantities for the deck and stay cables derived from data of previous bridges have also been indicated in the Guidelines.

The more frequently used construction techniques for cable stayed bridges have been given exposure. The cable-stayed bridges differ from conventional girder bridges due to the presence of stay cables and the upper part of the pylon. The installation and anchoring of the stay cables during the construction stages of the deck and their tensioning along with the construction method and construction sequence, all have a significant effect on the service stage performance of the bridge as well as the resulting stresses and deformations.

The selection of the construction technique and other details must take into consideration aspects such as environmental exposure, construction safety, cost and period of construction, which are based on the purpose, type, scale and local conditions relating to the project.

In general, the provisions of relevant codes for Concrete Bridges (IRC112), Steel Bridges (IRC 21) and Steel- Concrete Composite Bridges (IRC22) are applicable for structural design.

Although the Load Combinations for SLS and ULS checks must be carried out in accordance with IRC 6, the load factors and load combinations applicable for the Stay Cables have been tabulated separately. The design requirements of the stay cables include the Ultimate limit state (ULS), Fatigue limit state (FLS) and Serviceability limit state (SLS). Based on fib 89 for ULS conditions, the strength shall be checked for UTS of the stay cable with a material factor of safety of 1.35. The fatigue consideration will be based on the Wohlers Curve of the stay cable. The allowable stresses under SLS conditions shall be limited to 0.5 UTS. Testing of stay cable systems has also been covered.

Lateral forces due to wind and earthquake have been given special attention. The slenderness of the cable stayed deck introduces some complications in aerodynamic design because of the excitation of higher modes of vibrations and the coupling thereof. On the other hand, the light weight of the deck is of some advantage from seismic considerations. Vibration control in cable stays due to various effects and mitigation by use of different types of damping systems have been elaborated.

Inspection, Maintenance, and Structural Health Monitoring of cable stayed bridges is an important provision in the Guidelines. The monitoring essentially deals with four aspects during service conditions, viz,. environmental monitoring around the bridge, deck loads monitoring, structural response monitoring under different loadings, and durability inspection monitoring.

Cable Stayed Bridges are almost always of ‘landmark’ and ‘signature’ status. A discussion on their aesthetics has been included in the Guidelines.

4. Acknowledgements

The Guidelines has 15 Chapters and each has one or more lead author and a reviewer as summarised below:

	B9.4 Guidelines on Design and Construction of Cable stayed Bridges		
Chapter No	**TITLE**	**LEAD AUTHORS**	**REVIEWERS**
1	Preface	Prof Mahesh Tandon	Mr. G. Sharan, Prof Prem Krishna
2	Scope	Prof Mahesh Tandon	Mr. G. Sharan, Prof Prem Krishna
3	Introduction	Mr. Vinay Gupta Dr Harshavardhan	Prof Prem Krishna
4	Structural Form	Mr. Alok Bhowmick	Dr. B C Roy, Prof Prem Krishna
5	Conceptual Design	Prof Mahesh Tandon	Mr. V. N. Heggade, Dr Harshavardhan, Mr. Alok Bhowmick
6	Construction	Mr V.N. Heggade	Mr Sankaralingam, Dr. B C Roy, Mr. Mohan Jatkar
7	Loads And Load Combinations	Mr. U.K. Rajeshirke Mr. Nirav Mody	Mr. J S Pahuja, Mr. Alok Bhowmick
8	Analysis and Design	Mr. U.K. Rajeshirke Mr. Nirav Mody	Mr. J S Pahuja, Mr. Alok Bhowmick
9	Seismic Effects	Prof. S.K. Thakkar Prof Yogendra Singh	Prof Mahesh Tandon, Prof. Prem Krishna, Mr Alok Bhowmick
10	Wind Effects and Aerodynamic Design Considerations	Prof. Prem Krishna Dr P. Lakshmy	Dr. Suresh Kumaresan, Mr. Alok Bhowmick, Dr. Arunachalam
11	Stay Cable System, Materials and Quality Assurance	Mr. J.S. Pahuja	Prof Mahesh Tandon, Mr. Alok Bhowmick
12	Bearings, Expansion Joints and Seismic Protection Devices	Mr. Vinay Gupta, Mr. Jitendra Rathore	Mr. V.N. Heggade
13	Geometry Control	Mr. V.N. Heggade	Mr. Sankaralingam, Mr. Inki Choi
14	Inspection, Maintenance and Structural Health Monitoring	Dr. P Lakshmy	Mr. Rajshirke, Mr. T. Vishwanathan, Mr. Saha
15	Aesthetics and Sustainability Considerations	Prof Mahesh Tandon	Mr. V. N. Heggade, Dr. Lakshmy

ID-1243

Features of the New Indian Guidelines for the Design of Cable Supported Bridges to Resist Wind & Seismicity

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Abstract

The paper brings out the features of guidelines on the design of Extradosed Bridges and Cable Stayed Bridges as related to wind loads and effects as well as seismic forces. The subject area being addressed herein represents a subset of Guidelines on planning, design and construction for the these two types of bridges, which are highlighted in separate papers entitled, "The New IRC Guidelines for Cable Stayed Bridges in India" by Mahesh Tandon and "A new IRC Guideline for Design, Construction and Maintenance of Extradosed Bridges in India" by Alok Bhowmick. The purpose of the guidelines being addressed in this paper is to enable the designer to reach at least the advanced preliminary stage in his work.

The first part of the paper focusses on wind loading and effects and this is followed by seismic issues.

Introduction

Wind being a dynamic phenomenon, it essentially evokes a dynamic response from any structure obstructing its flow. The degree of dynamics however varies. For stocky structures the dynamic component of response is low enough to be neglected and a quasi-static approach can be adopted for their design. However, as structure spans, heights, and thus flexibility increase, in most cases their wind-sensitivity enhances. The aerodynamic effects become more important

The basics of wind and its effect on a bridge as it interacts with the wind are explained. It has been pointed out that bridges of moderate spans can be designed for wind on a quasi-static basis, for which the loading can be assessed from relevant Standards. For longer spans, essentially the aerodynamic approach has to be pursued. The various kinds of related phenomena that can occur in such bridges are briefly described. Based on the aforesaid information a preliminary design can be prepared, for the wind-sensitive bridges, it will require to be proved through further investigation.

Dynamic Characteristics

It has been highlighted that Cable bridges tend to have very closely spaced natural frequencies and often significant coupling of flexural and torsional modes of vibration occurs due to

separation of mass center and stiffness center of the deck. The frequencies are mainly affected by the physical properties of the deck, though towers and cables also play a part. These can differ substantially as the bridge progresses from construction stages to completion. Often the bridge may be more vulnerable during the construction stages, in comparison to the completed bridge.

Wind Effects

The aerodynamic wind effects on the bridge deck such as the limited amplitude oscillations and divergent amplitude oscillations, and, those for the towers are briefly touched upon. Cable vibrations, such as due to wake effects and the rain-wind interaction are explained along with measures to control these.

Wind actions that shall be considered for the design of cable bridges in general, are, equivalent static wind load, vortex induced oscillation buffeting, flutter, galloping, and, these may produce, excessive forces, stresses or deformation or repeated dynamic stress or deformation causing fatigue of bridge or its elements; aerodynamic instability; excessive dynamic movement causing discomfort to the users.

Principles for Wind Resistant Design

The wind resistant design principles for cable stayed bridges consist of the following:

- Designed for wind loading and other actions, the bridge shall meet the requirements of strength, rigidity and static stability.
- During the service life of a bridge, it shall not be prone to divergent amplitude oscillations such as flutter and galloping
- The low amplitude of oscillations due to vortices/ buffeting shall meet the requirements of traffic safety, structural fatigue and comfort of road users.
- The wind resistant design shall be achieved by considering geometrical, structural or mechanical measures, which could include wind tunnel testing.

Preliminary Design & Checks for Aerodynamic Stability

This essentially is not a straightforward process and iterations are more often needed than not. The guidelines move through different steps such as,

- Conceptual Design. Related to forms and geometrical proportions so as to achieve appropriate aerodynamic performance .
- Desktop Study for checking the Aerodynamic Susceptibility. Guides the user to get the structural and wind characteristics, apply checks for assessing susceptibility of the bridge deck against buffeting, flutter, divergent oscillations, (vortex-excited oscillations), wind action on pylons (similar to tall building towers), cables, where vortex-induced vibration, wake effects and rain-wind vibrations may occur.
- Desktop study for predicting aerodynamic Susceptibility. Whereas the previous stipulations were to check for stability, this is mainly to predict whether aerodynamic investigations are required. If the answer is in the affirmative, the following section gives in detail the steps for the same.

Data Required for Aerodynamic Design

This covers geometric details, material properties, damping ratio for bridge deck and tower, wind characteristics at bridge site, quasi-static design wind loads**,** buffeting analysis**,** evaluation of the Strouhal Number and Flutter derivatives, Investigations for Design Parameters through numerical simulation studies and/or wind tunnel studies.

Mitigation Measures for Improving Aerodynamic Performance

This is a detailed section giving guidance about measures that can be adopted for deck, tower and cables in case their aerodynamic performance requires to be improved. Examples of bridges where such measures have been used are also given

Seismic Considerations

Cable stayed bridges are flexible structures and have coupled modes of vibration and hence require some special considerations during their seismic design. These in brief are, need to design for combined effect of the two horizontal and vertical components of earthquake; need for large expansion joints; spatial variation of ground motion; geometric nonlinearity and inability of cables to take compressive force; very low ductility of cables.

Modelling and Analysis for Seismic Design

The cable bridges undergo complex and coupled modes of vibration under earthquakes. The torsion of superstructure is combined with transverse vibrations. Similarly, the pylons are also subjected to torsion as a result of horizontal and vertical vibrations of the superstructure. 3-D model is necessary for seismic analysis and can be developed using line or frame elements or multiple types of elements.

Adequate Mode Participation

Seismic response in case of cable bridges is contributed by a large number of coupled modes. If the dynamic analysis is performed using the mode superposition method, it is important that enough modes are considered to result in 90% mass participation in all the directions.

Design Hazard Level, Importance Factor and Response Reduction Factor

Design for the DBE level earthquake forces with response reduction factor, R equal to 1.0 and the importance factor, I =1.5.

Damping

The damping in Cable Bridges is characteristically low. In absence of a better estimate of damping, 2%, 3%, and 4% of critical damping can be considered for cable bridges with steel, steel-concrete composite and RC decks, respectively.

Consideration of Effects of Soil

Two effects of soil are the most important: (i) soil amplification of ground motion due to impedance contrast in the medium of wave propagation, and (ii) soil flexibility resulting in elongation of period and permanent deformation of the structure. A simplified procedure to consider the major two effects of SSI is possible, in which the soil amplification is considered using the code-based response spectra/amplification factors or using the site-specific earthquake design parameters, whereas the soil flexibility effects are considered using nonlinear/bilinear equivalent springs.

Consideration of Spatial Variability of Ground Motion

It is possible to consider the ground motion variability using time history as well as response spectrum method. In time history analysis (linear or nonlinear) of a cable stayed bridge, the ground motions used in seismic analysis should take into account the effect of wave propagation, loss of coherency with distance, and variation in soil conditions below the different supports.

Conclusions

Design of such complex structures as cable bridges to be safe under wind or seismicity, both arising from randomly varying natural phenomena, even at the easiest poses a challenge. The related material contained in the guidelines under reference, should substantially help the designer in his task.

References

1.Mahesh Tandon ,“The New IRC Guidelines for Cable Stayed Bridges in India”

2.Alok Bhowmick ,“A new IRC Guideline for Design, Construction and Maintenance of Extradosed Bridges in India“ .

@The guidelines were prepared by a Technical Committee of the Indian Roads Congress, chaired by eminent Indian engineer Mr. G. Sharan.

ID-1241

Construction Aspects of Cable Stayed and Extradosed Bridges in New Indian Guidelines

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Abstract

Indian Roads Congress (IRC) is bringing out two independent guidelines on Cable Stayed and Extradosed Bridges pertaining to 'Design, Construction and Maintenance' aspects. As on date, there are documents on stay cable design and technological aspects like, fib bulletin 89, SETRA and PTI which have been universally followed for the design and construction of cable stayed and extradosed bridges. There is also a state of the art report SED17 on extradosed bridges by IABSE and specifications for design and construction of cable stayed and extradosed bridges by Japan Prestressed Concrete Institute. The Indian independent guidelines on cable stayed and extradosed bridges are unique and complete in all respects as such is expected to improve the quality of design and construction in India to a large extent. This paper deals with the construction aspects as delineated in the guidelines.

Keywords: Construction; Staging; Balanced cantilever; Free cantilever; Push launching; Geometric Control.

1 Introduction

The cable-stayed and extradosed bridges covered by these guidelines [1] & [2] differ from the girder bridges. There are some commonalities between cable-stayed and extradosed bridges, like use of cables, construction of upper pylon, installation and anchoring of cables. Despite these commonalities, as the size of cable stay bridges (Span, pylon heights etc.) are comparatively larger, stress and deformation produced in the members can be significantly influenced by the construction method and sequence adopted

With regards to construction, it is necessary to satisfy required conditions such as environmental effects, construction safety, cost and period, which are based on its relation to entirety, purpose, type, scale and characteristics of the project.

The construction planning of cable-stayed and extradosed bridges are prepared prior to the commencement of construction by considering the aspects, that are necessary to satisfy the required performance of structure and requirement of the project. In addition, aspects about the quality and schedule control are also examined while planning construction.

In comparison to other bridges, for cable stayed bridges, the influence of construction method, construction sequence and construction accuracy are significant. Therefore, it is important that qualified engineer(s) with sufficient knowledge and experience are constantly stationed at the construction site to provide appropriate construction management.

2 Deck Erection and Fabrication

Generally there are three methods of deck erection which are applicable for both cable stay and extradosed bridges. The *staging method* of erection is most often used where there is a low clearance requirement to the underside of the

structure and temporary bents will not interfere with any traffic below the bridge. Its advantage is accuracy in maintaining required geometry and gradient and its relatively low cost.

The *push-launching technique* has been used very rarely for cable stayed bridges where care must be taken not to interfere with traffic below the bridge and where cantilever construction is impractical. Millau viaduct is one such example.



Figure 45. Deck erection by staging method

The *cantilever erection method* is very often employed in cable-stayed and extradosed bridge construction where temporary supports are uneconomical or not applicable. In some cases, it may increase the steel requirements in terms of temporary post-tensioning bars, permanent pre-stressing or steel deck quantity over that required for final positioning to accommodate the increased moments and shears during the erection process. The principal advantage is that it does not interfere with traffic below the bridge.

3 Pylon Construction

The methods used for the construction of pylons are generally the same as for other tall, slender towers. The pylons could be in concrete or steel. Traditionally, pylons are designed with a pronounced slenderness in the longitudinal direction of the bridge to allow the pylon to follow the longitudinal displacements of the cable system. However, during construction of the pylons, the cable system is not in place so the pylons must possess the necessary resistance against horizontal wind load by themselves. Often the most critical phase in the construction of the pylon occurs in the period from when the pylon is at full height until the first stay cables or the catwalks are erected. In this period wind-induced oscillations of the pylon in the longitudinal direction of the bridge might be experienced. These are generally caused by the slenderness of the pylon in this direction, combined with the large area of the cross beam at the top exposed to wind and the climbing crane.



Figure 2. Balanced cantilever and Pylon construction

4 Construction of Saddles /Anchorages of cables

The installation position and inclination alignments of cables change through the duration of construction due to the changes of prestressing force and deflection of pylon and deformation of other members. However, basically, the positions during service of bridges shall be adjusted precisely in order to conform to design calculations. Therefore, in setting the saddle and anchorage of stay cables, the effects of sag of stay cable, camber when the main girder is constructed, concrete creep and shrinkage shall be considered to ensure that the saddle and anchorage will be in precise position during service of bridge.

5 Installation of extradosed and stay cables

This guidelines describes the methods of construction of cables, their installation, stressing etc. for getting the general idea, and may vary from project to project depending on the contractor and supplier of the cables.

6 Conclusion

The planning & construction aspects are covered very much in detail in these guidelines.

[1] IRC : 136, Guidelines for Design, Construction & Maintenance of Cable Stayed Bridges.

[2] IRC : 137, Guidelines for Design, Construction & Maintenance of extradosed Bridges.

ID-1242

Design and Analysis of Hybrid Cable-Stayed Bridges: A Comprehensive Study

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Abstract

This research paper aims to explore the design, analysis, and anticipated performance of hybrid cable-stayed bridges, with a specific focus on the Krishna River Bridge. Hybrid cable-stayed bridges offer structural advantage derived from unique combination of cable stayed and suspension structural arrangements leading to improved load-carrying capacity, structural efficiency, better foundation strata due to pylons placed nearer to the river banks, cost-effectiveness, and aesthetic appeal.

The paper will present a comprehensive study into various aspects involved in the analysis and design of hybrid cable-stayed bridges, with a particular emphasis on Krishna River Bridge Project on NH-167K in the States of Telangana & Andhra Pradesh in India. This will include examining the optimal structural configuration, cable arrangement and material selection for the bridge under different loading conditions. By conducting thorough analyses and simulations, this case study indicates that engineers and the client can make informed decisions during the design and construction phases of a bridge ensuring its safety, durability, functionality and cost effectiveness while achieving high aesthetic value making the structure an Iconic structure very well suited to the terrain and topographical features of the landscape at the Bridge site.

Keywords: hybrid cable stayed bridge, suspension , bridge anchor block

1 Hybrid Cable-Stayed Bridges

Cable-stayed and suspension hybrid structure: This type of hybrid bridge combines the cable-stayed and suspension bridge systems, typically by incorporating pylons with cables supporting the deck, along with cables extending to anchorages on the sides of the bridge. With a suspension cable supported on the same pylons/anchorages thereby facilitating longer spans without attendant increase in the height of the pylons.

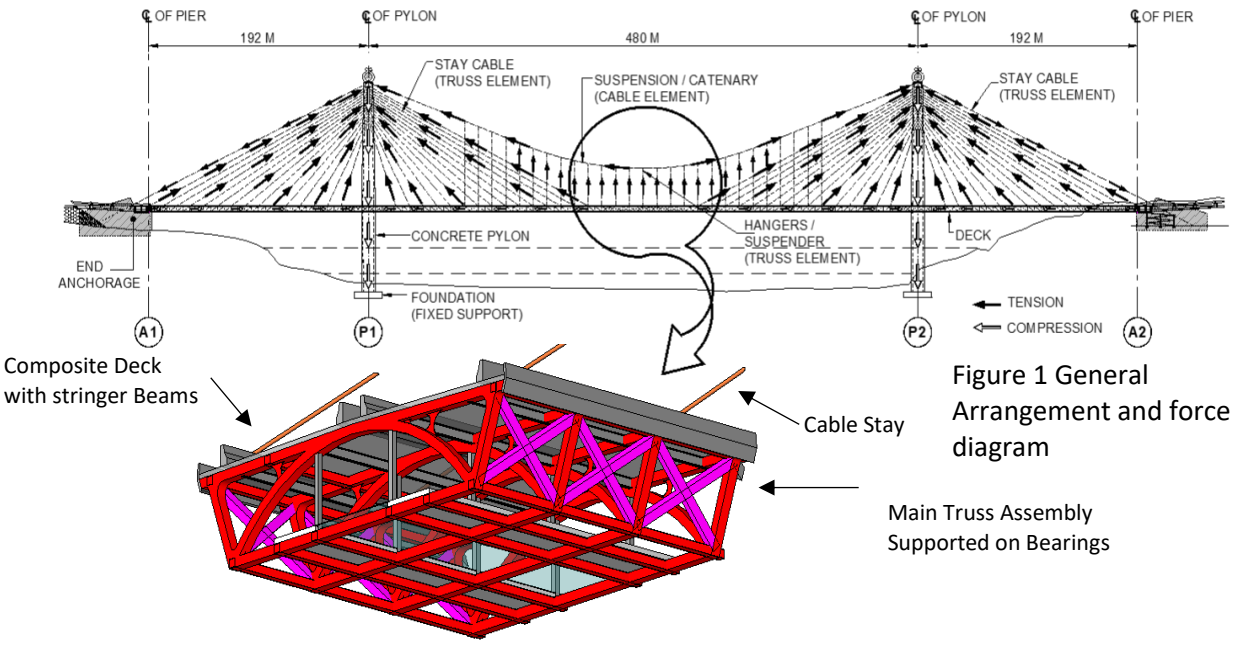


Figure 1 General Arrangement and force flow diagram

2 Structural Analysis of Hybrid Cable-Stayed Bridges- Case Study

The construction of the Krishna Bridge presents a unique set of challenges that engineers are prepared to tackle. Given the river's substantial width and anticipated heavy traffic demands, a hybrid cable-stayed cum suspension bridge has been proposed to address these requirements effectively. By integrating elements from both cable-stayed, suspension and traditional girder bridge designs, the Krishna Bridge aims to achieve an optimal balance between structural efficiency, aesthetics, and cost-effectiveness. In the planning and analysis phase of the project, advanced computational tools and sophisticated modelling techniques are utilized to simulate a wide range of load scenarios. Engineers employed state-of-the-art software and rigorous analytical methodologies to accurately predict and evaluate the bridge's behaviour under different conditions. This meticulous analysis will ensure the bridge's safety, stability, and long-term durability. The Krishna Bridge project holds great promise as it brings together innovative engineering concepts and practical application. The valuable lessons learned from this project, such as addressing wind-induced vibrations, optimizing dynamic response, and considering long-term maintenance requirements, will serve as a valuable knowledge base for future bridge designs.

3 Stay cables and suspension main cable

The proposed hybrid cable stayed cum suspension bridge structure was analysed in Finite Element Analysis (FEA) based software. The Geometric nonlinear analysis has been performed for main suspension cable. The cable forces are worked out for all critical load combinations. Stay Cables & Suspension cables are designed in such a way that all forces comply with the permissible stress limits for both Serviceability Limit State (SLS) and Ultimate Limit State (ULS) as per PTI/FIB bulletin no 89/ Setra specification or equivalent.

Modelling the geometry for modelling purposes, stay cables and suspension cables are modelled as cable elements. The superstructure, which is a truss, is modelled as beam elements. Elastic links are used to simulate bearings, and rigid links are utilized to model the exact behaviour of the structure. The pylon is represented as a two-noded beam element. For permanent loads, the stay cable forces are adjusted to achieve the desired bridge profile and effectively distribute internal forces.

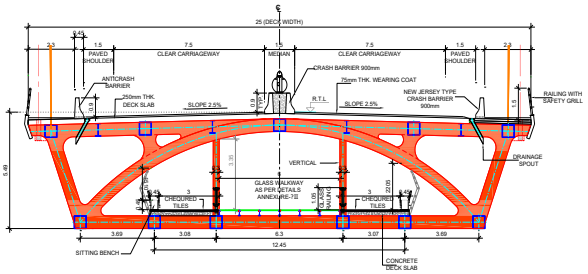


Figure 2 - Typical cross section of truss

4 Analysis and design criteria

Analysis for dead load, superimposed dead load and live load is carried out using MIDAS software for structural analysis. For arriving at dimensions of superstructure substructure and foundation.

In order to verify that the structure and structural elements perform adequately during its service life, the serviceability limit states have been achieved. The serviceability limit states are: Stress checking/verification in materials, Crack Width control and Deflection control. In calculation of stresses and deflection, the cross section was assumed as un-cracked provided tensile stress in concrete does not exceed f_{ctm} or $f_{ctm.fl}$ and calculation of minimum tension reinforcement is also based on the same value of f_{ctm} or $f_{ctm.fl}$. Where tensile stresses in concrete exceed this value, the cross section was assumed as cracked.

5 Conclusion

The Krishna River Bridge will be the first challenging hybrid cable-stayed bridge in India. It is evident that the hybrid system, combining cable-stayed and suspension bridge elements, has numerous advantages and competes favourably with conventional cable-stayed bridges. The successful completion of the Krishna River Bridge will demonstrate the superiority of the hybrid system.

Session 32

Case Studies in Sustainable Materials, Technology and Practices

ID-468

Semi Integral Structures - Mauritius Light Rail Transit System

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Abstract

Government of Mauritius (GoM) intends to provide a world class, sustainable public transport solution in the form of light rail system and associated works, to serve commuters travelling from the Curepipe to Port Louis. The corridor from Curepipe to Port Louis serves as one of the fastest growing areas in Mauritius and that will be of increasing importance to the country's future economic development strategy and prosperity. To enhance the economic development, urban sustainability, social amenity, and desirability of the area, it is imperial to improve upon the public transportation provision, connectivity, and accessibility, to reduce traffic congestion and to provide a mode shift from private to public transportation use.

Keywords: Precast post tensioned girder, box girder, in-situ, semi integral, flyover, light rail.

1 Introduction

Two significant and landmark structures were designed and constructed as part of Mauritius Metro Light Rail Project. One of them is Curepipe flyover, which is in the Curepipe town also known as La Ville-Lumière (The City of Light) and second one is Caudan flyover, which is gate way to city of Port Louis (Capital of Mauritius). Part of these two flyovers were designed as semi-integral structures considering the curvature, maintenance and sustainability aspects taking 100 years design life and notable wind loads on the structure. Due to 62m curve radius at Curepipe flyover, 2 span continuous box girder spans between piers STP-P1-P2 and P2-PP3-P4 were designed with cast in-situ post-tensioned PSC box girder with S-Shape curve arrangement. Due to 42 & 51 degree skew angle at Caudan flyover pier P10 & P11 three-span semi integral structure (P9-P12) consists of precast post-tensioned PSC I-Girder with curve radius 340m having 4 I-Girder arrangement were designed.

Semi integral structural arrangement added more value in terms of reducing maintenance cost, economical construction, elimination of bearings and expansion joints and increased overall sustainability of the structural arrangement with sharp radius at these locations. Figure 1 and 2 shows the site views of Curepipe and Caudan flyovers respectively prior to start of construction works at site.



Figure 46. Site View of Curepipe Flyover - preconstruction stage



Figure 47. Site View of Caudan Flyover- preconstruction stage

2 Structural Arrangement

The salient features of the flyover are as follows.

2.1 Curepipe Flyover:

- Structure type: PSC Box Girder (Cast in-situ semi-integral)
- Span Arrangement: 26,35m+26,35m (STP-P2); 26,35m+26,35m (P2- P4)
- Length of Semi integral S curve portion: 105,4m
- Curve radius: 61,950m
- Deck Depth: 2050mm
- Pre-stressing: 8Nos - 19K15 type
- Concrete Superstructure: C50/60
- Bearing: 4 Nos., POT cum PTFE type for outer piers

2.2 Caudan Flyover:

- Structure type: 4 Nos., Post-tensioned Girder (Precast)
- Span Arrangement: 29,866m+27,965m +30,322m (P9- P12)
- Length of Semi integral skewed portion: 88,153m
- Skew angle: 42°(P10) & 51° (P11)
- Curve radius: 342m
- Deck Depth: 2050mm
- Pre-stressing per girder: 3Nos - 19K15 type
- Concrete Superstructure: C50/60
- Bearing: Elastomeric for outer pier

3 Structural Analysis & Design

3.1 Modelling – Curepipe Flyover

The Curepipe flyover was modelled in MIDAS Civil software. Deck was modelled as longitudinal bar elements representing box section and assigned with respective box sectional properties as per geometry of flyover. At intermediate pier location, deck was integrated with substructure by rigid link.

3.2 Modelling – Caudan Flyover

The Caudan flyover was modelled in MIDAS Civil software. Deck was modelled as grillage elements representing I girder section and assigned with respective I girder with slab sectional properties as per geometry of flyover.

4 Design & Construction Challenges

During detailed design & construction of Curepipe and Caudan flyover many design challenges were handled, such as alignment constraint to provide integrated transport system, pier alignment and its shape, existing utility services where diversion is not possible considering existing MSE/RE wall, and modification of pile layout during construction stage etc.

These challenges were addressed by duly considering design and constructability aspects at each stage of design.

5 Conclusions

From analysis it was concluded that for high skew and smaller radius curve semi-integral construction is best and optimum solution compared to conventional structural system.

ID-500

Evaluation of longitudinal forces on substructure of railway bridges due to increased axle loading and speed through full scale field investigations

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Abstract

Bridges are the vital link for the highway and railway networks. There has been much progress in bridge design in recent years with increasing use of advanced analytical design methods, use of new materials and new bridge concepts. The new generation of locomotives produce approximately twice the tractive effort of older locomotives due to which the bridge substructures are subjected to greater longitudinal forces than the design load. Instrumentation and field testing has to be carried out in a comprehensive manner to get the distribution of these longitudinal forces at different levels starting from the coupler level to the substructure level. The existing codal provisions on the evaluation of longitudinal force is initially discussed in this paper. Details of the instrumentation adopted and the experimental investigations carried out on a typical bridge is presented. The percentage of force being transmitted to the substructure was evaluated and compared with the codal provisions.

Keywords: Prestressed concrete slab bridge; railway bridges; longitudinal force; instrumentation; experimental investigations; codal provisions

1 Introduction

Most of the civil infrastructures existing in India has been built earlier and are in service for a longer period of time. These structures are in service despite their aging and accumulation of damage. Hence the condition of these structures needs to be assessed and the performance of these structures under present loading conditions needs to be studied to decide upon the safety and the necessary maintenance to be carried out. Instrumentation and response measurement offers the potential for continuous and periodic assessment of these structures [1-2]. Indian Railways (IR) has about 1,27,768 bridges on a network route of 63,500 kilometres. Out of these, about 11,090 bridges are classified as Important / Major bridges [3-4]. In this paper the various provisions in the international and national standards on the dispersion of longitudinal force in railway bridges is briefly presented. The authors have carried out instrumentation and responses measurement in several railway bridges with different span lengths, bearings, super structure etc for evaluating the longitudinal force transmitted to the sub structure. Experimental investigations carried out on a typical railway bridge using standard test train formation and conducting various test cases such as tractive, braking, uniform speed for evaluating the dispersion of longitudinal force from the track to that of the sub structure is presented in detail.

2 International and national codal provisions on longitudinal force in railway bridges

Earlier there was less emphasize on the longitudinal forces as they were mostly resisted by the huge sub structure. But due to the increasing trend of axle loads, speed, heavy haulage locomotives. Longitudinal forces are very much essential to be considered during the design of bridges and its sub structures. There are several railway codes followed in different countries worldwide for the design of bridges and for the standard loadings to be used during the design of bridges. These codal provisions are country specific and are mainly formulated considering the axle loadings permitted in that country. Many factors will influence the dispersion and transmission of longitudinal forces and hence there is huge necessity to carry out instrumentation and experimental investigations to understand the phenomenon of longitudinal force dispersion and transmission.

3 Instrumentation scheme for measurement of longitudinal force

This prestressed concrete slab bridge is an existing railway bridge and comprises of two identical short spans (2x9.550m) with 0.66m girder depth (Fig. 1). Various sensors such as strain gages, accelerometers, Linear Variable Displacement Transducers (LVDTs) and special load cells for measuring longitudinal force in the girder were used in the investigation of the prestressed concrete slab bridge. The experimental investigations were carried out using a special test train formation comprising of two couple electrical locos at the front, followed by loaded wagons conforming to axle loading of around 23 tonnes and then a rear loco as shown in Fig. 1. The tests comprised of both static and dynamic tests. A typical time history response for longitudinal force generated in rail is as shown in Fig. 2.

4 Evaluation of longitudinal forces

From the table it can be seen that a maximum of 220 kN has been generated in the track level for the tractive case and 110 kN has been generated in the braking and uniform speed case. Around 40% of the longitudinal force that is being generated at the track level has been transferred to the substructure through the girder and the



Figure 48. Experimental investigations with test train formation

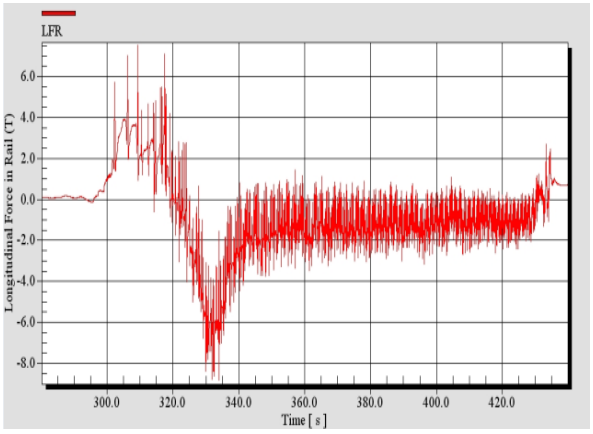


Figure 2. Typical strain response measured in rails

balance force is being dispersed through the rails as it is a continuous system over other spans and approaches. As per the IRS provisions the dispersion allowed in the track for elastomeric bearing is 35% which is very well within the limits of the results obtained from the experimental investigations. The axial and bending strain measured in the pier clearly indicate the

transmission of longitudinal force to the pier from the girder through the bearings. However a quantum of force is being absorbed by the elastomeric bearings and not all the force is transmitted to the sub structure. Large sets of data is required considering various parameters that influence the longitudinal force dispersion for developing a suitable design guideline for varying tractive forces. It is very much essential to carry out detailed experimental investigations in railway bridges to completely understand the dispersion of longitudinal forces for different configuration of bridges.

ID-621

Condition Assessment and measures to Repair and Retrofit Baghajatin ROB, Kolkata

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Abstract

This paper provides a comprehensive evaluation of Baghajatin ROB, located on the trunk route of the EM bypass of Kolkata Metropolitan, India. The bridge has been subjected to increased traffic volume, aggressive weathering conditions, and lack of proper maintenance over the years, resulting in its gradual deterioration. This paper aims to highlight the existing state of the ROB and discusses the methodology adopted to repair and retrofit. It includes the current progress of the repair and retrofitting at the site and the challenges involved in construction. This study provides value to engineers, policymakers, and infrastructure stakeholders seeking to develop effective strategies for maintaining and upgrading crucial infrastructure.

Keywords: Non-destructive testing; retrofitting; intermediate supporting arrangement; geocell; peel strength; geogrid; sustainable development.

1 Introduction

The Baghajatin Road Over Bridge (ROB) is situated in southern Kolkata. The ROB connects Garia to Ruby and lies between Garia and Baghajatin railway stations. The Eastern flank was constructed in 1999 and the Western flank in 2012. The ROB consists of a total of 47 spans, with 25 spans on the Eastern flank (LHS Carriageway) and 22 spans on the Western flank (RHS Carriageway). Three of the spans on the Eastern flank and one span on the Western flank fall within railway boundaries. The approach spans have four cast-in-situ RCC rectangular girders with an intermediate cross girder at the mid-span, while the railway spans have five or six plate girders with cast-in-situ RCC deck slabs. Each girder is supported on the elastomeric bearing. The substructure of approach spans consists of a rectangular pier cap supported on four nos. 1,1m diameter RCC circular piers which are supported by 550mm or 1000mm bored cast-in-situ pile foundations. The overall width of the deck slab is 12,1m with a three-lane 10,5m carriageway.

2 Retrofitting Methodology

The retrofitting consists of two phases: pre-investigation and post-investigation. During the pre-investigation phase, various tests were carried out to evaluate the durability and load-carrying capacity of the structure. To evaluate these, physical site inspection, non-destructive testing, laboratory testing of samples, span load testing, and analytical investigation were carried out.

The findings of the analysis pointed towards a gradual corrosion of the steel reinforcement, coupled with a significant decline in the strength of the concrete in the deck slab. The presence of structural cracks in the girder indicated poor internal integrity, revealing the distressed condition of the superstructure. However, the substructure and foundation were relatively less affected and could be retained with minor repair and rehabilitation. Furthermore, the analytical investigation revealed that the superstructure would be unable to sustain the present IRC loadings and would not be able to serve the future needs of the traffic.

In the post-investigation phase, it was decided to retrofit the superstructure of the ROB by providing intermediate support beneath the existing superstructure instead of replacing it with a new one. A built-up steel intermediate supporting arrangement was constructed at four different locations in a span. This approach allowed the retrofitting of the components that needed strengthening while keeping the existing ROB in place, achieving sustainable development goals by minimizing disruptions to traffic flow and reducing the need for new construction.

The deck slab of the ROB was supported by steel plates, steel stringer beams, and stub columns, which were in turn supported by a transverse beam and four columns resting on an RCC pedestal and strip foundation. The height of the columns varied according to the span's clear height. The system was analyzed using STAAD.Pro software was designed to withstand various vertical and lateral loads, including dead load, live load, wind load, and seismic forces. A grillage model was prepared for the superstructure, and a combination of IRC 70R-Wheeled vehicles and Class-A vehicles were considered for live load analysis. The stresses were found to be within the ULS and SLS limits set by IRC: 112.

The geotechnical investigation revealed that the subsoil was weak, with a safe bearing capacity of (SBC) of 6,0t/m^2 at 2,0m below the ground level. The design of foundation for the intermediate supporting system proved very challenging. A ground improvement solution was adopted with strip footings of 0,3m thickness. For ground improvement, three layers of Geo Grid in between four layers of aggregate and a layer of Geocell filled with 12mm downsize aggregates, and a Polymer sheet at the top was provided. The footing was supported over this improved ground. The modified soil achieved an SBC of 15,17t/m^2 at the top of the improved soil making it suitable and economical for the site constraints.

To prevent further damage to the ROB, a permanent load restriction was imposed and the installation of a weighing mechanism was proposed. Damaged bearings for the P11-P12 span were recommended to be replaced, while clogged expansion joints were to be cleaned. The wearing coat of both carriageways was found to be deteriorating and in need of replacement. The drainage system was also found to be dysfunctional, damaging the deck slab, and repair of damaged spouts, down-take pipes, and handrails was recommended.

3 Progress and Challenges

This section outlines the current progress and challenges encountered during the retrofitting process. The retrofitting scheme has been implemented with careful consideration for workers and public safety, minimizing inconvenience to commuters. As of March 24th, 2023, Ground improvement work has been completed for 18 spans, and the casting of footing has been completed for approximately 9 spans. The erection of intermediate steel supports has been completed for only one span.

Challenges faced during the retrofitting process included adverse weather conditions, Covid19-related supply chain disruptions, and unexpected site conditions. An interesting challenge involved lifting the Stringer beam, where the executing agency prioritized personnel safety and opted to reduce the beam's length by 150mm, ensuring safe lifting and minimal impact on the project schedule. This highlights prioritizing personnel safety and decision-making during construction activities.

4 Concluding Remark

The Baghajatin ROB condition assessment has identified structural deficiencies requiring immediate attention to ensure safety and longevity. Recommended repair and retrofit measures include strengthening the superstructure by the intermediate supporting system, replacing bearings, improving drainage, and imposing vehicle restrictions. Regular monitoring and maintenance are necessary for the effectiveness of the suggested measures, including periodic inspections, cleaning, and repairs. These recommendations have significant implications for infrastructure management, safety, and sustainability, serving as a model for similar projects worldwide.

ID-673

1D Consolidation of Soil at Sumari Uttarakhand Considering Variable Compressibility

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Abstract

The linear and elastic consolidation theory developed by Terzaghi is commonly used for evaluation of consolidation characteristics of fine-grained soils. As several simplifying assumptions have been made in the derivation of Terzaghi's theory, the application of this theory in many practical problems, especially those involving soft clays, may lead to significant errors. In particular, the assumption of constant value for coefficient of consolidation, C_v, during consolidation process is one of the major limitations in Terzaghi's theory. In this paper, soil sample from the village Sumari near Srinagar Garhwal, Uttarakhand where the permanent campus of NIT Uttarakhand will be constructed has been considered. Finite difference approach is utilized for solving one-dimensional non-linear partial differential equation. Two coefficients (C_n and α) are computed to describe changes in soil characteristics and incorporate the changes in C_v during consolidation. In order to understand the consolidation behaviour considering variable compressibility a simple problem has been considered. It has been observed that the degree of consolidation is over-estimated on consideration of constant coefficient of consolidation C_v and thus may have a substantial impact on the long-term behaviour of the structure resting over ground exhibiting such behaviour.

Keywords: Consolidation; Compressibility; Permeability; Non-linearity; Finite Difference Method; Partial Differential Equation.

1 Introduction

In order to predict the progress of consolidation with time in cohesive soils, the oedometer test is usually performed to determine consolidation characteristics of soil and Terzaghi's linear theory is commonly used for evaluation of the results. Terzaghi (1922) and other researchers assumed coefficient of consolidation constant as consolidation progresses. Lekha et al. (2003) and Zhuang et al. (2005) attempted to consider the variation of the C_v during consolidation, but their solutions gives the relation between degree of consolidation with time factor which is related to real time via coefficient of consolidation. A number of different numerical and analytical solutions have been proposed for the solution with different load and boundary conditions. In this paper, the authors explores the influence of considering the variable compressibility for a site located in Sumari, near Srinagar Garhwal, Uttarakhand.

2 Basic Governing Equation and adopted solution methodology

Coefficient of consolidation (C_v) varies as the coefficients of volume compressibility m_v and permeability k change during the consolidation process. In view of this, the current work highlights a non-linear partial differential equation for consolidation considering variation of compressibility and permeability using linear responses for $e - \log \sigma'$ and $e - \log k$. A one-dimensional non-linear partial differential

equation as per Abbasi et al. (2007) have been considered in the study.

$$\frac{\partial u_{(z,t)}}{\partial t} = C_n(\sigma_t - u)^{\alpha} \frac{\partial^2 u_{(z,t)}}{\partial z^2} \qquad (1)$$

Two coefficients (C_n and α) (both constant for a given soil) have been introduced to describe changes in soil characteristics with effective stress and thereby taken into consideration the changes in the coefficients of volume compressibility and permeability during consolidation. The values of the coefficients are acquired by performing a set of laboratory tests on soil samples obtained from the site in village Sumari near Srinagar Garhwal, Uttarakhand where the permanent campus of NIT Uttarakhand will be constructed. The soil profile of an illustrative example from Ranjan and Rao (2007) have been considered and mathematical model solved using finite difference approach with the help of iterative process in MATLAB software.

$$u_{(z,t+1)} = u_{(z,t)} + \left[\frac{\{C_n(\sigma_t - u)^{\alpha}\}\Delta t}{(\Delta z)^2}\right] \left[u_{(z+1,t)} - 2u_{(z,t)} + u_{(z-1,t)}\right] \qquad (2)$$

3 Major Inferences

The developed mathematical approach is validated with close form solution as in Taylor (1948). Isochrones as well as time required for 50% primary consolidation are obtained for constant and varying coefficient of consolidation C_v. The corresponding results are analysed. On assuming constant coefficient of consolidation C_v along depth, the Degree of Consolidation is over estimated by 30.36% and the time required is under-estimated by 84.37%, which can lead to a major misinterpretation during the analysis of soil strata. Therefore, it is necessary to consider variations in coefficient of consolidation C_v along depth using the non-linear mathematical formulation as mentioned in the paper, so that we can correctly predict the consolidation behaviour of soil.

4 References

[1] Terzaghi K. Der grundbruch an stauwerken und seine verhutung. *Wasserkraft*. 1922; 17: 445-9.

[2] Lekha K.R., Krishnaswamy N.R., and Basak P. Consolidation of clays for variable permeability and compressibility. *Journal of Geotechnical and Geoenvironmental Engineering*. 2003; 129(11): 1001-9.

[3] Zhuang YC, Xie KH, Li XB. Nonlinear analysis of consolidation with variable compressibility and permeability. *Journal of Zhejiang University-SCIENCE A*. 2005; 6(3): 181-7.

[4] Abbasi N., Rahimi H., Javadi A.A., and Fakher A. Finite difference approach for consolidation with variable compressibility and permeability. *Computers and Geotechnics*. 2007 ; 34(1): 41-52.

[5] Ranjan G., and Rao A.S. *Basic and applied soil mechanics*. New Age International; 2007.

[6] Taylor D.W. *Fundamental of soil mechanics.* New York: John Wiley & Sons; 1948.

ID-719

Design and Construction Challenges-Extradosed Bridge over River Hatania Doania in West Bengal

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Abstract

Bridge across river Hatania-Doania is a priority project which now connects the island of Bhakkali with the main land Namkhana in South 24 Parganas, in the state of West Bengal at about 100km south of Kolkata. Though Bakkhali and its neighbourhood provide a real feast for the eyes, being a popular tourist attraction, tourists used to avoid the area because of the delay that is caused in crossing the river. To reach Bakkhali, the tourists had to cross Hatania-Doania river by motorboats while vehicles were ferried by the barges. Under emergency, during late night hours, crossing the river was a nightmare. The navigable river serves as a shorter route channel for inland waterway traffic, hence requires a vertical clearance of 10m in 100m central width. Large size barges ply on the route. The project is meant for three lane of traffic with 1.5m wide footpath on either side and have a main module of 85+170+85m extra-dosed bridge deck across main river followed by viaduct portion on either side of the bridge. Bridge Deck is monolithically connected at intermediate pylon location and resting on POT-cum-PTFE bearings at end spans. Deck is laterally supported by 2 plane of stay cables arranged in a semi-fan fashion. The spans are resting on twin D caisson foundation at pylon locations.

This paper is about long span extradosed bridge in India. Construction of this bridge was entrusted to S.P.Singla Constructions Pvt. Ltd. on EPC mode in December 2014 and the construction was successfully completed in May 2019 after facing several challenges. This bridge is Gold Award winner of National Highways Excellence Award 2019 for outstanding work in challenging conditions. This paper describes the design aspects of the Extradosed bridge along with challenges faced in construction of deep well foundations for the main river bridge.

The total length of project is 3.266 km. The project involves construction of a new bridge across river Hatania - Doania including its immediate approach road/embankment and viaduct spans etc. Length of Main Extradosed Bridge is 340m.
As per tender document, proposed span arrangement of Main River Bridge is 75m+120m+75m. River Hatania-Doania is a tidal river wherein the daily variation in water level is around 6m, construction of intermediate piers was difficult in the river, hence a longer span having span arrangement of 85m+170m+85m was preferred and piers were proposed on banks of the river. This river serves as a shorter route channel for Inland waterway traffic. Bridge satisfies the Minimum navigational clearance of 10m in 100m central width. The deck was built by cantilever construction technique, with cast-in-

situ segments. The deck is integrally connected to the pylons and resting on bearings near expansion joints. Bridge is following straight alignment in plan and has mild summit curve in elevation.
This paper also covers in detail about the deck cross-section, bridge construction material, pylon geometry, foundations, design load and load combinations including SLS and ULS checks, stay geometry & stay cable design. Further it also covers modelling and analysis aspects which includes longitudinal analysis as well as transverse analysis by FEM shell element model. Paper also covers bridge construction methodology along with erection and construction stage checks including camber control.
Considering the topography, the country should have more number of such long and aesthetical bridges.

Keywords: Extradosed Bridge; Long Span Bridge; Cantilever Construction; Well Foundation; Concrete Bridge

Session 33

Analysis, Research and Standardisation

ID-597

Flexural Behaviour of Carbon Textile Reinforced Concrete (CTRC)Panel

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Abstract

Textile-reinforced concrete (TRC) is novel high performance composite material blooming in the 21st century globally. This paper aims to investigate the flexural behaviour of carbon textile-reinforced concrete (CTRC) panel through four-point bending test The results highlight that the behaviour of carbon textile reinforcement under pure flexure performs well with flexural cracks forming only at the pure bending zone. The flexural behaviour of only 4-layer textiles were limited to this study considering the over reinforced design criteria. Further, the performance can be enhanced while optimising the no of layers of textiles required in further research.

Keywords: Carbon Textile Reinforced Concrete (CTRC), Flexural behaviour, TRC, Fine-grained Cementitious Matrix.

1 Introduction

The growing interest in cost-effective solutions for the structural components has gradually oriented research towards the optimisation of high-performance cement based composited originally conceived for new lightweight constructions. TRC distinctly differs from fibre reinforced polymer bar reinforced concrete, which is much more comparable to conventional concrete in component size, reinforcement diameter, stiffness in transversal direction, and shape [15-17]. In India, there is a lack of structural applicability of TRC, its due to the lack of general building authority approvals, guidelines, and standards. To date, not all details of the load-bearing behaviour of TRC has been clarified. The aim of the present article is to give insight on the flexural behaviour of TRC panels applicable for housing construction in India. Experimental studies have been carried out on using a four-point bending tests on these panels.

2 Experimental Program

2.1. Casting of CTRC Panels

CTRC panels measuring 300 x 1000 x 30 mm comprised of 4 layers were cast in a specifically fabricated moulds, which enables to fix the position of the textile at various layers. The specimens were demoulded at the age of 24 hours, and subsequently cured for 28 days. The mortar test was carried out while testing these panels and the compressive strength was around 56±2MPa.

3.Experimental Procedure

3.1. Four Point Bending Test

In this study, flexural 4-point loading test of CTRC panel was conducted in a manual load-control conditions using a screw gauge. The load was gradually applied to achieve slow rate of mid

-span displacement. The span length of flexural loading was 900 mm. The schematic view of the experimental setup and details of the measuring instruments are shown in Fig 1.

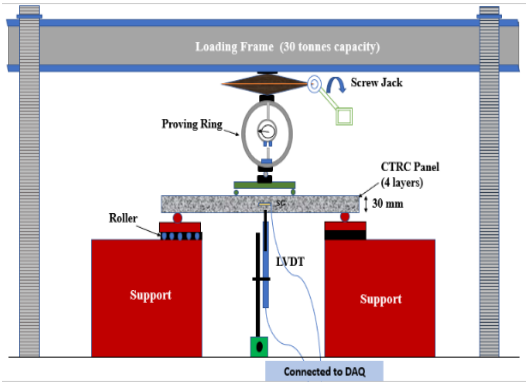


Fig 1. *The schematic view of the Flexural 4-point experimental setup.*

To measure the mid span displacement of the CTRC panel, LVDT of 100mm displacement transducer was used. Proving ring of 10kN capacity was used to record the load applied on the specimen.

4. Results and Discussions:

The flexural load vs deflection is shown in Fig 2. The point A signifies first crack in the panel depicting the cracking of concrete. Point B& C represents the further cracking with change in stiffness. The cracking mechanism is the once concrete cracks it transfers the load to the textiles at the bottom layer. From point C to D entirely the textile layers take up the flexural load until failure. The point D represents the ultimate load the specimen can withstand. For 4 layers of CTRC panels the load was about 1050N with maximum mid span deflection around 43mm.

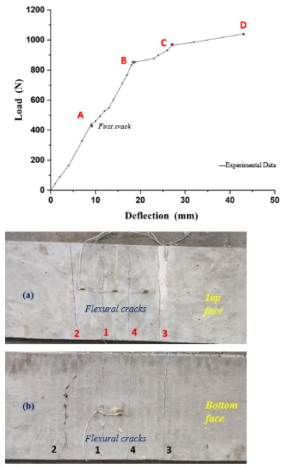


Fig 2. *Flexural Load-deflection response of CTRC*

The failure of the panel and the development of flexural cracks are depicted in Fig 2 & 3.

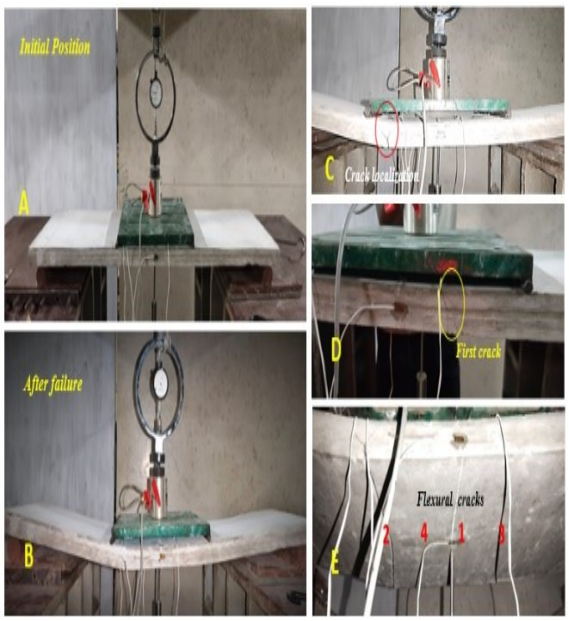


Fig 8*. Failure of CTRC panel*

5. Conclusions

According to the experimental studies made the following conclusions are arrived:

a) The CTRC panels achieved excellent flexural performance. For 30 mm thickness maximum number of layers could be only 4 layers considering the concrete cover.

b) The max load for 4 layers of CTRC panel 1m span was 1.05kN with max deflection of 43mm at the mid span.

c) The panel seemed over-reinforced section with 4 layers, optimising the number of layers for a particular thickness of the panel is required.

6. References

[1] Hegger J, Horstmann M, Zell M. Applications for TRC. In Proceedings of the 15th International Congress of the International Glass fibre Reinforced Concrete Association (GRCA), Prague, Czech Republic 2008 Apr (pp. 20-23).

[2] Mansur de Castro Silva R, de Andrade Silva F. Carbon textile reinforced concrete: materials and structural

analysis. Materials and Structures. 2020 Feb;53(1):17.

[3] Valeri P, Guaita P, Baur R, Fernández Ruiz M, Fernández-Ordóñez D, Muttoni A. Textile reinforced concrete for sustainable structures: Future perspectives and application to a prototype pavilion. Structural Concrete. 2020 Dec;21(6):2251- 67.

ID-706

Classifying Failure Modes of Ultra-High-Performance Fiber Reinforced Concrete Fracture Beams Using Acoustic Emission Technique

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Abstract

Due to its homogenized microstructure and discrete fibers, ultra-high-performance fiber-reinforced concrete (UHPFRC) possesses exceptional compressive and tensile strength. They also have excellent ductility, and durability. As UHPFRC is increasingly used in bridge construction, non-destructive health monitoring can be used to understand its damage behaviour. This study examines the fracture behavior of UHPFRC beams under different parameters, such as fiber volume fractions 1.0% and 2.0%. The Acoustic Emission (AE) is employed to monitor all test beam fracture processes and to determine the crack type. The unsupervised K-means clustering technique is used to analyze AE parameters based on peak frequency and amplitude parameters. The research findings indicated that the failure mode in UHPFRC notched beams was primarily due to fiber pullout. The conventional failure mode classification and k-means clustering are not the same. Similarly, the clustering classification is carried out using the peak frequency versus amplitude. The ranges are decided based on the type of failure modes, such as fiber pullout, matrix debonding, and combined fiber pullout and matrix cracking.

Keywords: UHPFRC; Acoustic emission; Fracture test; Crack classification; Fracture process zone, Machine Learning, K-means.

1 Introduction

Ultra-high performance fiber reinforced concrete (UHPFRC) is a type of concrete that has closely packed fine particles and discrete steel fibers(1–4). Due to the absence of aggregates and more fibers, the failure mode of UHPFRC concrete is different. Due to the excellent mechanical and durability properties of UHPFRC concrete (5–9), structural engineers are inclined to use this material in important structures. To understand the level of damage after certain age or service load, it is important to identify the type of crack and level of damage in the system. Concrete failure is more dominantly due to tension or crushing. The severity of the damage depends on the mode of failure, such as shear mode or flexure mode. According to previous research, the shear mode of failure is more critical than the flexure mode in FRC. The aim of the current research is to identify the type of failure mode before it reaches the final failure mode based on acoustic emission parameters.

2 Experimental Program

2.1 Test Setup and instrumentation

The notched beams of length 500 mm having cross-section dimensions of 100×100 mm are tested in this study. The UHPFRC concrete specimens are prepared using a diamond cutting blade. The notch depth is maintained as h/6 (16.33 for 100 mm x 100 mm) and 5mm

width. The supports are placed so that a clear span is 450mm. The load is applied at the mid span of the beam. The instrumentation details include, crack mouth opening displacement (CMOD) gauges, linear variable displacement transducer (LVDT) and non-constrain full-field strain measurement DIC technique. The specimens are tested at a rate of 0.5 µm/sec.

Twelve UHPFRC specimens were tested with the variables of volume fraction of fibers (1% and 2%) and types of fibers (straight and hooked-ended). Where SF represents steel fibers of 12 mm length and 0.3mm diameter.

2.2 Experimental results

The samples considered for analysis were SF100 and SF200. The samples consisted of 1 and 2 % volume fractions of straight fibers (V_f), respectively. The load-CMOD response of test beams are shown in **Error! Reference source not found.**.

Although the conventional approach is being followed to classify cracks based on RA value and average frequency for a long time, there is no definite proof of the criterion of proportioning between the two parameters mentioned above. An illustration of the conventional approach is shown in **Error! Reference source not found.** for SF100-2. The current study attempts to classify the cracks using the K-means clustering technique using two sets of parameters, comprising (a) RA value and average frequency and (b) peak frequency and amplitude.

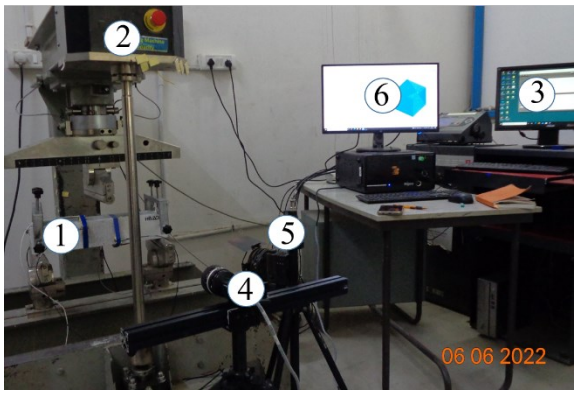


Figure 49. Experimental Setup showing (1) Test sample, (2) 300 kN FTM frame, (3) FTM monitor, (4) DIC camera, (5) Light source, (6) AE acquisition system.

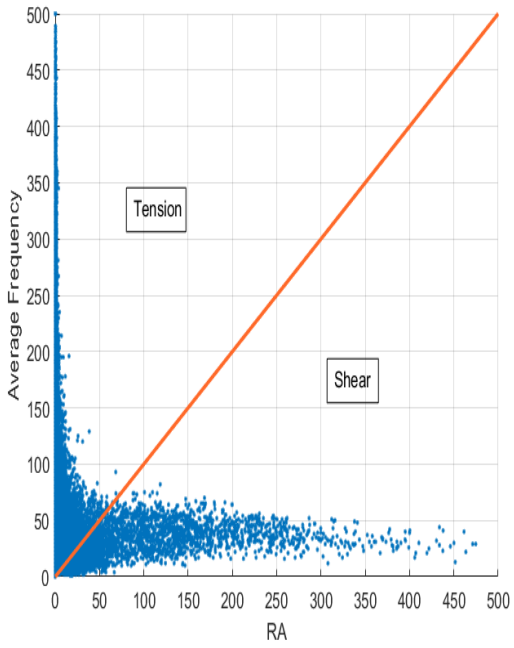


Figure 50. A conventional approach for classification.

Clustering was employed for both sets, as shown in **Error! Reference source not found.** a nd **Error! Reference source not found.**. **Error! Reference source not found.** compares the conventional approach and the classification obtained by the K-means clustering.

3 Conclusions

Based on the experimental test of UHPFRC concrete fracture beams and AE analysis, the following conclusions can be drawn:

1. The internal cracks and their location in the UHPFRC concrete beams of chosen dimensions can be accurately identified using the Acoustic Emission technique by using six sensors.
2. The traditional method of crack classification, such as shear and tension crack proportion, need to be re-evaluated for UHPFRC concrete as thier behavior is different than conventional concrete.
3. In UHPFRC beams, the fiber slip can be identified as a shear category event

having high duration with an average frequency of range 0-170 kHz.

4. For the average frequency range above 170 kHz, it can be said with certain certainty that the events are tensile in nature. However, it is hard to differentiate between the matrix breakage or fiber fracture. Further studies are required to delineate the different damage mechanisms.

ID-713

Effect of Vertical Irregularities on Buildings in Different Seismic Zones of India

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Abstract

Vertically irregular buildings are frequently constructed all over the world for both functional and aesthetic reasons. However, post-earthquake fact-finding survey studies reported that buildings with vertical irregularities were extremely seismically vulnerable. As a result, it is critical to investigate the causes of their high seismic vulnerability in order to enhance their performance. The vertical irregularities in the buildings are caused by asymmetric distributions of mass, stiffness, and strength. These irregularities in the structures results in the floor rotations (torsional response) in addition to floor translations. In this study, the seismic behaviour of vertical irregular buildings located in different seismic zones of India are assessed. The vertical irregular building configurations such as step back, set back, step back-set back, and split foundation are considered in this study. The analysis is performed using finite element software. From the study, it is observed that the performance of vertically irregular building is different in different seismic zones.

Keywords: Include a list of not more than 10 keywords, for example: post-tensioning; anchors; slabs; walls; high-rise buildings.

Keywords: Irregular Building; Seismic Zone, Earthquake resistant design.

1 Introduction

India's seismicity and topography pose significant challenges for building design, as the country is located in a region that is prone to earthquakes and home to a diverse range of geographical features[1]. Several regions of India are classified as high or moderate seismic zones, and buildings and infrastructure in these areas must be designed to withstand seismic forces, including ground shaking, liquefaction, and landslides[2]. Building codes [2] and regulations in India take into account these factors to ensure that buildings and infrastructure are safe and resilient. India's seismic activity is classified into four seismic zones based on the level of seismic activity. These seismic zones are defined in the Indian Standard code of practice for earthquake-resistant design of structures, IS 1893.

The vertical irregularities in buildings are common in construction practices in India, but their impact on the seismic performance of buildings is not well understood. This research aims to evaluate the seismic performance of vertically irregular buildings in different seismic zones of India. The study will investigate the effect of various types of vertical irregularities on the seismic response of buildings and their vulnerability to damage during earthquakes. The research findings will provide valuable insights into the design and retrofitting of buildings to improve their seismic performance and reduce the risk of damage and loss of life during earthquakes.

2 Methodology

In this study, STAAD.pro connect Edition is used to model and analyse the regular and irregular buildings in different seismic zones (ZONE III, ZONE IV, ZONE V) of India. Five different types of buildings were modelled in STAAD.pro. The building Model considered are Regular building **(RB)**, setback **(SB)**, split foundation **(SF)**, Setpback **(SSB)** and setpback setback **(SBSB).** The loading acting on the building structure based on the seismic zone and building code requirements. The six storey regular building model data considered from [3]. The same building model parameters are utilized for other four building configurations. Validation of STAAD.pro building model is done by comparing the manually calculated values presented by Shah and Jain (2005) [3] and Software calculated parameters for regular 6 Storey building in seismic zone III. The shear force, bending moment and inter storey displacement are compared

2.1 Results and Discussion

The three important parameter Maximum Bending moment, Maximum shear force and inter storey displacement of all five are compared in three different seismic zones III, IV and V. Building with split foundations and step back setbacks in Zone Ⅲ exhibit the most bending moments, while step back buildings exhibit the least. This is due to the effect of seismic waves. Buildings with split foundations and step back setbacks have the greatest bending moments when subjected to seismic load in zone Ⅳ.

The variation of shear force of various buildings from zone Ⅲ to zone Ⅴ. On Zone Ⅲ, a split foundation exhibits the highest shear force when subjected to seismic waves, whereas a step-back building exhibits the lowest shear force. With the action of seismic waves, a step-back setback building exhibits greatest shear force in zone Ⅳ, while a setback building exhibits least shear force. Buildings with setbacks exhibit the greatest bent shear force in zone Ⅴ, while structures with split foundations exhibit the least amount of bent shear force.

The diversity of inter storey displacement of various building from zone Ⅲ to zone Ⅴ. Buildings with split foundation stepback and stepback-setback exhibit the greatest inter-story displacement with the action of seismic waves in Zones Ⅳ and Ⅴ, which makes them more vulnerable.

3 Conclusions

Based on the results, it is concluded that the diversity of structural behaviour varies for different types of buildings in seismic zones. The split foundation and step back setbacks exhibit the most bending moments and inter-story displacement, while step back buildings exhibit the least. Buildings with setbacks experience the greatest bent shear force, whereas structures with split foundations experience the least. The step-back setback building exhibits the greatest shear force in zone Ⅳ, while a setback building exhibits the least shear force. The vulnerability of buildings with split foundation and stepback-setback is high due to the greater inter-story displacement caused by seismic waves.

4 Acknowledgements

This work is supported by the core research grant funding (grant no. CRG/2022/005334), Science and Engineering Research Board, Department of Science and Technology, Government of India.

5 References

[1] M. Surana, Y. Singh, D.H. Lang, Seismic Characterization and Vulnerability of Building Stock in Hilly Regions, Nat. Hazards Rev. 19 (2018) 1–16. https://doi.org/10.1061/(asce)nh.1527-6996.0000275.

[2] IS 1893 (Part 1). “Criteria for earthquake resistant design of structures.” Part I: General provisions and buildings, Bureau of Indian Standards., 2016.

[3] H.J. Shah, Design Example of a Six Storey Building, Des. Ex. a Six Storey Build. 3.0 (2005) 51.

ID-1049

The Sheaf: Expressive Geometry Through Collaborative Computational Design and Low-Tech Construction Methods

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Abstract

This paper presents the design development of The Sheaf — a 12-meter-high iconic timber-diagrid hyperboloid lookout tower, from concept to detailed design. The Sheaf was the winning proposal in an architectural competition in 2019 for a lookout tower in Varberg, Sweden. A close dialogue between architect and engineer propelled the iterative design development, initially exploring the concept and later solving details leading to a sustainable, material-efficient, and expressive tower using simple, affordable building elements. The alternating use of digital parametric models and physical model tests supported the decision-making, allowing quick exploration of viable alternatives and the client to get involved.

Keywords: timber tower, design work, reciprocal, parametric design, sustainability



Figure 51. Competition entry rendering of The Sheaf, a hyperboloid timber-diagrid lookout tower.

The work, constrained by a limited budget, construction rationales, and sustainable solutions, was possible due to advanced computational design modelling and low-tech construction based on simple principles and construction methods using a pure geometrical setup as a basis for architect-engineer-client collaboration.

The central question is how the collaboration between architect and engineer affects the result of the building. Is it possible to identify any special conditions for fruitful collaboration? Can the analysis lead to more possibilities to design innovative buildings using a similar design process?

The ambition was to have an alignment between structural principles and architecture, which led to an initial exploration of the structural systems and their architectural expression.

The diagrid on a hyperboloid of one sheet was decided upon, offering an organic three-dimensional structure. With the hyperboloid idea chosen, a parametric digital model enabling rapid exploration of the tower height, radius, twist, grid density, and placement in the landscape model was created. The digital model was also used to create 3d-printed physical models for quick design decisions.

In the end, a 12 m high tower with a maximum diameter of about 7 m was proposed, created using 144 2x4 inch timber laths, each around 13 m long sourced locally.

As the design investigation proceeded, it became more and more geometrically complex and challenging for the team and the client to understand the different alternatives. Therefore, several model types improved the ability to understand, communicate, and convince all parties about alternative solutions, for example, digital virtual-reality models, renderings, and assembly drawings, full-scale mock-ups, and 3d-printed models.

Without these aids, the client would have difficulty grasping the complex geometry and might have chosen a simpler geometry, and thus the result would have been different. Furthermore, it helped the design team to communicate and explore design alternatives.

The first approach for the connection design was to explore individual connections between the laths at every intersection.

Individual connections would keep the buckling length of the laths to a minimum but have the disadvantage of requiring many details with varying geometry. Furthermore, the assembly would be complex, requiring provisional support to position each timber lath correctly.

The second approach investigated the use of horizontal rings placed at equal distances along the tower height. The use of rings significantly reduced the number of connections and provided additional stiffness and redundant load paths to the tower. Furthermore, the rings could double as guide and support for the laths during assembly.

The tower foundation consists of a concrete cylinder below ground resting on seven Ø140-10 mm and 7 m long piles. The cylinder is filled with gravel providing enough weight to counteract overturning lifting forces due to wind.

The platform at the top of the tower is reached via an internal spiral steel stair and designed as a reciprocal structure, with beams parallel to the long sides of the timber laths they connect to.

Already in the competition phase of the Sheaf, a collaboration between architect and engineer was established, leading to the choice of a rational and expressive structural principle. Using a shared digital model provided valuable insights on how computational design workflows can be used within conventional architectural practice, to achieve stunning results at the budget of conventional construction.

The design process using both digital and physical models has enabled an understanding of the geometrical problems, which is important for the definition of the solutions. The models will also be used as an aid during the assembly of the building.

It is an advantage for the creative process when the architect has good knowledge of structural engineering, and the structural engineer has an interest in architectural design. In such cases, their shared interests serve as a basis for a fruitful and creative dialogue between architect and engineer.

ID-1124

Studying The Effect of Vertical Irregularities on The Seismic Vulnerability of Setback Buildings Using Linear and Non-Linear Methods

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Abstract

The need of extensive building construction has increased in recent decades. Overgrowing population, urbanization and scarcity of new space has created a huge demand for the construction of new high-rise buildings or expansion of existing structures in vertical direction. Due to aesthetic and other considerations such as demand by asset owners, sufficient availability of daylight and ventilation, the irregularities in the vertical direction are inevitable. For meeting these demands, the usage of setbacks is becoming popular now a days. The common practice is to increase the horizontal dimension of the lateral force resisting system in a particular story by more than 130% as compared to the adjacent storey. The high-rise buildings, meeting the needs of infrastructures, has certain structural disadvantages. The high-rise buildings are more susceptible to damage due to seismic excitation compared to normal buildings. Hence, it becomes necessary to conduct the seismic analysis of structure for analysing its response. The method of analysis can be broadly categorized into linear static analysis, non-linear static analysis and nonlinear dynamic analysis depending on the type of external actions and structural behaviour.

The present study aims to analyse the effect of vertical irregularities on the seismic response of high-rise buildings using Finite element (FE) program-SAP2000. Three different plans (S1, S2 and S3) having three locations of setbacks were considered which were referred as S1-5, S1-6, S1-7 for S1 model, S2-5-7, S2-6-7, S2-7-7 for S2 model and S3-5-7, S3-6-7, S3-7-7 for S3 model respectively. The numerical value in the model nomenclature represents the storey at which the setback is provided. Nine Building model contains 10 number of stories and bay width of 4m in X and Y direction. Both the method- Response spectrum analysis (RSA) and time history analysis (THA) were utilized in the present study. The seismic parameters considered in dynamic analysis of all the models are assumed according to IS 1893 (Part 1): 2002. The model building is assumed to be in Zone IV with the peak ground acceleration value of 0.24g. The importance factor, 'I' is considered as 1.0 and the Response reduction factor 'R' as 5 for SMRF system of the buildings. The soil strata beneath the foundation is assumed to be medium soil. The gravity and imposed loads are considered according to IS 875 (Part 1 and 2).

Response spectrum analysis (RSA) was performed, and results showed that the setback has significant influence on the response against the seismic excitations. For instance, in case of regular, S1 and S3 models, when seismic load applied in X or Y direction separately, response was obtained only in the direction of applied seismic force . For S2-type model, application of load in any (X or Y) direction results in response in both directions. That showed, the involvement of building resistance in both directions even if the excitation is unidirectional. This is accounted due to the presence of

eccentricity i.e., the centre of mass does not coincide with centre of stiffness in S2-type model. Also, for S1 and S3- type models, it was observed that base shear increases with increase in setback height in both X and Y direction while with increase in setback height for S2-type model, base shear increases in X direction only and does not increase in Y–direction. In addition, the base shear decreases in X direction and increases in Y direction with increase in the angle of incidence of earthquake when applied in X direction for all the models. Similarly, base shear increases in X direction and decreases in Y direction with increase in the angle of incidence of earthquake when applied in Y direction. Results were obtained for the time period which showed that setback buildings have lesser time period than that of similar regular building. Further, Time period of structure increases with respect to increase in the setback height. The buildings with same maximum height and same maximum width may have different time periods depending upon the amount of irregularities present in the buildings. Also, the setback height was found to have a significant influence on the storey displacement. Response spectrum analysis showed that 1) For model S1 type, having aspect ratio 0.5, 0.6 and 0.7, the percentage decrease in the top storey displacement are 57.7%, 47.77% and 35.92% respectively as compared with regular model, 2) For S2 type model having aspect ratio 0.5, 0.6 and 0.7, the percentage decrease in the top storey displacement are 35.18%, 24.92% and 22.23% respectively as compared with regular model and 3) For S3 type, the percentage decrease in the top storey displacement are 52.31%, 43.66% and 30.95% respectively as compared with regular model. Further analysis showed that the column and beam moment tend to decrease on increasing the aspect ratio in all setback models. It was found for model S1-type, having aspect ratio 0.5, 0.6 and 0.7 the percentage decrease with respect to regular model are 29.4%, 23.63% and 16.07% respectively in case of column moments and 29.39%, 23.64% and 20.73% in case of beam moments. On comparing the RSA with THA, it was observed that the percentage decrease in base shear models Regular, S1-5, S2-5-7 and S3-5-7 along x-direction by response spectrum analysis is 60.45%, 63.97%, 61.55% and 40.56% respectively when the same models were analysed by time history method. Comparison of the storey displacement by RSA and THA for 0.3g, it was found that the percentage decrease in top storey displacement of model Regular, S1-5, S2-5-7 and S3-5-7 along X-direction by response spectrum analysis is 81.14%, 84.05%, 83.18% and 83.44% respectively when the same models were analysed by time history method. In conclusion, it can be drawn from the study, that location of setback as well as plan configuration has a significant influence on the important design parameters such as base shear, time-period, column & beam moment, and storey displacement. Significant difference was observed in the responses using RSA and THA.

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Is Nonlinear Analysis Becoming a Standard Tool for Design and Assessment of Reinforced Concrete Structures?

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Abstract

When the nonlinear finite element method is used in the design of reinforced concrete bridges, it offers advantages over linear solutions as it can realistically capture material behavior, including crack formation or concrete crushing. This study summarizes its application in practice, covering nonlinear material models, solution methods, and validation against experimental data. The accuracy of the nonlinear tool determines a model partial safety factor, which is used for the evaluation of the design structural resistance. An example is presented, assessing a post-tensioned reinforced concrete bridge with strengthening provisions for a critical region with cracks.

Keywords: finite element analysis; reinforced concrete structures; nonlinear simulation; damage mechanics; smeared crack models; reliability analysis.

1 Introduction

The nonlinear finite element method (FEM) has become a standard tool serving engineers during the design and assessment of structures. This study summarises the most important aspects of the nonlinear FEM.

2 Nonlinear analysis overview

The key factor in the nonlinear simulations is the material models that can realistically describe the actual material performance. For concrete, it should include crack formation when subjected to tensile stresses exceeding the tensile strength and crushing when subjected to high compression. In the model of Červenka et al. [1,2] used in the ATENA software [3], this is simulated by the smeared crack approach with a crack band in tension and plasticity approach in compression. Furthermore, a nonlinear response can be defined for the reinforcement elements to simulate their yielding or even rupture.

The nonlinear tools should be validated against experimental data and in blind prediction competitions. Based on these validations, the model partial safety factor can be deduced for a given material model and software package.

To apply the results obtained by the nonlinear analysis in engineering practice, the appropriate standard needs to be available. Currently, it is available in the *fib* Model Code [4]. For engineering applications, mainly the partial factor method and estimate of the coefficient of variation (ECoV) method are significant.

3 Example of application

The nonlinear FEM was used to assess the crack width in the structure of a highway viaduct in the Czech Republic. From the structural viewpoint, it is a post-tensioned box girder bridge. During an interruption in the construction process, diagonal cracks formed in the web near the pier supports. To strengthen this region, additional post-tensioned cables anchored at steel deviators were proposed.

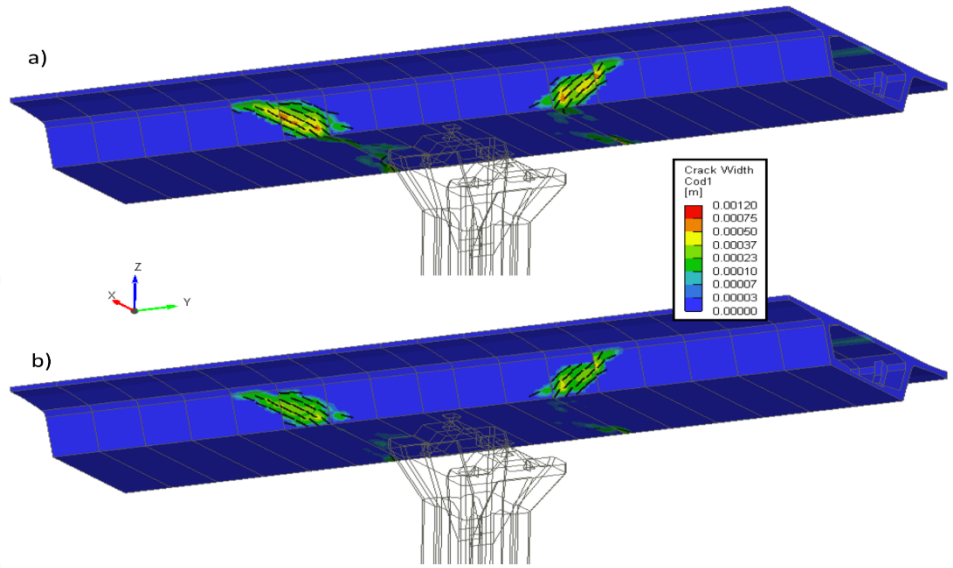


Figure 52. Results of the strengthening of the investigated viaduct: a) crack width before strengthening and b) crack width after strengthening (only cracks larger than 0.1 mm are emphasized

When the construction process was simulated using the ATENA software package [3], the formation of cracks was successfully reproduced. In the next step, the application of additional strengthening was simulated. The results showed that the cracks with a width of approximately 0.50 - 0.75 mm in the web of the box girder can be reduced to approximately 0.20 - 0.40 mm by application of the additional pre-stressing inside of the box girder. The results are plotted in **Error! R eference source not found.**.

4 Summary

An overview of the most important aspects of nonlinear finite element modeling is given in this study together with the code-based framework allowing its application in the engineering practice. Furthermore, an application example is presented showing how the nonlinear analysis can evaluate the crack formation in the post-tensioned reinforced concrete box girder bridge, including simulation of additional strengthening provisions.

5 Acknowledgments

The data presented in this study were obtained with the financial support of the Czech Technological Agency under the project TM04000012 “BRIHIS - A concrete bridge health interpretation system based on mutual boost of big data and physical mechanism” within the Delta 2 Programme. The financial support is greatly acknowledged.

6 References

[1] Červenka J, Papanikolaou VK. Three dimensional combined fracture–plastic material model for concrete. Int J Plast. 2008 Dec 1;**24**(12):2192–220.

[2] Červenka J, Červenka V, Eligehausen R. Fracture-plastic material model for concrete, application to analysis of powder actuated anchors. In: Proceedings FRAMCOS (3). 1998. p. 1107–16.

[3] Červenka V, Jendele L, Červenka J. ATENA Program Documentation: Part 1 Theory. Prague; 2022. 360 p.

[4] International Federation for Structural Concrete. fib Model Code for Concrete Structures 2010. 2013. 434 p.

Session 34

Sustainability in Built Environment

ID-315

Innovative Solution to Urban Infrastructure: Special Solution to Conventional Structure Planning

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Abstract

Most ancient cities' business and suburban worker centres are unplanned. Increased CBD traffic strains commuter facilities. Urban road infrastructure and unrestricted expansion hinder mobility. Construction duration and environmental impact matter today. Innovation uses an evolutionary engineering process to meet new requirements.

Keywords: Innovation, Innovative Structure, Precast Unit

1 Introduction

Today's materialistic society values time most. Time as a resource shortens civil infrastructure project gestation, accelerating returns. Construction can speed results. Project conception and design speed up the remaining tasks. Innovation in structure design globally improves material efficiency, reducing construction time and cost. This paper will discuss a few global innovations that boost the economy and a few Indian examples the lead author is involved in.

2 Innovation in Design and Planning of Infrastructure

In unplanned growth, ancient city engulfs surrounding suburbs for expansion, but connecting roadways become insufficient to serve the growing number of commuters. Creating a Mass Transit System to encourage people to use the Public Transport System to decongest roads, or building infrastructure to segregate traffic flow and increase road capacity, such as a subway foot-over bridge, are two common solutions.

3 Emerging Technologies in Bridge Construction

Because humans want to overcome any crossing's challenges, bridge design has evolved over the centuries. Well-established practises, codes, and building techniques have evolved it. New materials and methods in bridge design take years. Bridge design has changed due to fast-developing technologies and materials. Engineers lacked resources and software to build accurate bridge models. Bridge engineers now use advanced materials, tools, and software.

- Building Information Modelling (BIM)
- Innovative new construction materials for bridges
- Smart Construction
- Prefabrication
- Powerful Computer-Aided Software

4 Innovative Bridges Example:

The following Few examples are from worldwide innovations in bridge design & Construction in past 20 years.

- Network Tied Arch Bridges
- Lupu Bridge
- Taizhou Yangtze River Bridge
- Golden Ears Bridge
- Yahagi-Gawa Bridge

5 Development in India:

Most Indian innovations are incremental, adapting and improving existing technologies for local use. Technology advances incrementally over time.

- Some Developments in Delhi
    - Punjabi Bagh : Four Level Interchange

Top-down construction simplified traffic diversion, site activities, and shoring. This design and construction philosophy was first adopted in Delhi, possibly in India, though not globally.

    - Raja Garden : Precast Pedestrian Underpass

Prefabricated concrete elements accelerated construction of 60-meter long Delhi Rajagarden pedestrian subway.

- Innovative Structures in Kolkata: Nivedita Setu

Nivedita Setu, India's first cable-stayed extradosed superstructure was named as most innovative bridge design in 2007 by American Segmental Bridge Institute. It supports over 29 m wide precast segments across multiple spans (ASBI). Bridge: 880.00 m. It has two 55.0-meter exterior spans and seven 110-meter interior spans. At the third, fifth, and seventh span midspans, expansion joints were 220m apart.

6 Innovations & Infrastructures: Impacting Climate Change

COVID-19 slowed carbon emission reduction. Global lockdowns reduced emissions, but recovery was not green. Sustainable cities and communities should use energy-efficient buildings, smart lighting, efficient transportation, renewable energy, and water use and disposal using Data Science. Net Zero means carbon emissions equal atmospheric removal. Zero carbon emissions require balance and awareness. Emitting less on the way to net zero reduces damage. Material quantity reduction, and alternative materials contribute most. Polluters should use a global-local approach to calculate carbon footprints for construction, O&M, and low-impact materials.

7 Conclusions

Since every site and project is different, one should look from a fresh perspective to find the best solution to complete the project quickly and well. Experience shows that proper planning and consistent communication among stakeholders can greatly improve work quality and project outcomes.

8 References

[1] A Chakrabarti, B C Roy. 2000. Precast Pedestrian Subway at Raja Garden Intersection, Delhi: Paper Published in IABSE Lucerne

[2] R Ekambaram, T Guha, B C Roy. Top down construction of integrated underpass and pedestrian subway at Punjabi Bagh

[3] S S Chakraborty, B C Roy. 2000. Four Level Grade Separator at Congested Intersection in New Delhi: Paper Published in IABSE Lucerne

[4] B C Roy. 2004. Planning of Transportation System in Indian Metropolis

[5] B C Roy. 2008. Transport Infrastructure in Indian Urban Environment.

[6] https://home.uia.no/pert/data/The%20Network%20Arch%2019-08-2014.pdf

[7] Tamio YOSHIOKA. The latest technologies of prestressed concrete bridges in Japan: https://www.jsce.or.jp/committee/concrete/e/newsletter/newsletter05/6-Vietnam%20Joint%20Seminar(Yoshioka).pdf

ID-545

A roadmap for implementing integrated asset management for sustainable water Infrastructure in India

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Abstract

Water is an essential aspect of economic and social development, playing a critical role in enhancing resilience in India's communities and ecosystems. It is imperative to manage this precious resource rationally and efficiently to ensure sustainable replenishment of water resources. Despite regulatory measures, over-exploitation and contamination persist, making the application of asset management principles in the Indian water industry increasingly important.

Water insecurity can have a significant drag on global economic growth, as water and water-related hazards have a statistically significant effect on the economy. For example, the Niti Aayog's 2018 Composite Water Management Index (CWMI) study found 21 major cities in India, including Delhi, Bengaluru, Chennai, and Hyderabad, are rapidly depleting their groundwater reserves, and are approaching a state of zero groundwater levels, disrupting the availability of water for 100 million people. By 2030, the nation's water market is predicted to be double the existing supply, leading to catastrophic water shortages for hundreds of millions of people and a 6% loss in GDP.

According to The Sustainable Development Goals Report 2022, the global water stress level was deemed safe at 18.6% in 2019. However, Southern Asia, which includes India, and Central Asia experienced high levels of water stress, surpassing 75%. Northern Africa, on the other hand, suffered from critical water stress levels, exceeding 100%. The report outlines the SDG 6 target and highlights the importance of a broader emerging framework and application of Integrated Water Resource Management (IWRM) in India. Therefore, it is crucial to implement an IWRM approach to manage water resources sustainably, especially in regions with high water stress levels.

Integrated Water Resources Development and Management (IWRDM) is a comprehensive approach to sustainable water resource management, encompassing both water supply and wastewater systems. This methodology provides a framework for identifying functions and interactions, determining the direction of water management planning, and offering flexible yet consistent guidance to address diverse conditions.

In India, the need for IWRM is becoming increasingly apparent due to the growing water crisis. According to the United Nations, India is expected to face a 40% water deficit by 2030 if no action is taken. The situation is further exacerbated by increasing pollution of water resources, which is causing significant harm to human health and the environment. Recent data from the Central Pollution Control Board (CPCB) in 2019 shows that nearly 70% of India's water bodies are polluted.

India, as a rapidly developing nation, faces significant water-related challenges. With a population of over 1.3 billion people, water scarcity is becoming increasingly common across

the country. The Indian government released the Composite Water Management Index (CWMI) report 2018, stating major cities are facing a problem of decreasing capacity of groundwater sources. In addition, the lack of proper sanitation infrastructure and the pollution of water bodies is causing major health and environmental problems, leading to a loss of economic productivity, and hindering sustainable development.

The present study emphasizes the need for a wholesome approach to water resources management and highlights the variables that have been influencing the effective management of water resources in India.

The paper presents a roadmap for the development and management of water resources in a integrated manner, considering both water supply and wastewater systems. It outlines a comprehensive water management framework from an infrastructure management perspective, emphasizing the significance of civil engineers in the process. The framework balances cost, risk, and performance across the water sector, considering the diverse range of drivers, constraints, benefits, and outcomes.

The paper also attempts to draw the attention of policymakers by presenting various dimensions of the sustainable water management and human well-being nexus relevant to water-stressed nations like India, through a case study of the Municipal Corporation of Greater Mumbai (MCGM) responsible for water supply in Mumbai, India.

The methodology can serve as a blueprint for identifying functions and interactions, specifying the direction of water management planning, and providing consistent guidance with ample flexibility to meet varied conditions. It highlights the main challenges and provides a structured procedure for supporting Integrated Water Resources Development and Management (IWRDM) in India.

The process involves multi-disciplinary organizations comprising of different stakeholders to promote integrated water resources development and management. Civil engineers with knowledge, skills, and experience possess integrated, both physical and technical skills for the management of water resources and play a vital role in the process.

Civil engineers can play many different roles in IWRDM from a planner, engineer, policymaker, regulator, etc. Some of the main functions include designing and constructing water infrastructure, analyzing water resource systems, developing, and implementing water management policies, and overseeing the operation and maintenance of water systems. The framework outlined in the paper emphasizes the significance of civil engineers in the process of sustainable water management.

In conclusion, the IWRDM approach presented in this paper provides a comprehensive methodology for the development and management of sustainable water resource management systems. The methodology serves as a blueprint for identifying functions and interactions, specifying the direction of water management planning, and providing consistent guidance with ample flexibility to meet varied conditions.

Keywords: Water resource; Roadmap; Integrated Asset Management; Environmental Sustainability; Water Infrastructure; SDG; Water & Sanitation; IWRDM; Civil Engineer

ID-657

Different Approach of the Construction Sustainability

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The new approach, presented in this paper, is based on the specific model but instead of the calculation of **the sustainability index SI** the evaluation considers the price of each parameter of the tree dimensions and finally **the sustainability cost SC** is obtained [1],[2], [4].

1. Specific model

The specific model is based on simple mathematical equations, which combine the results of the quantified parameters in a rational way, obtaining finally a Sustainability Index SI:

$$SI = S_{env} + S_{eco} + S_{soc} \quad (1)$$

$$S_{env} = \sum_{i=1}^{n} \alpha_i \times \frac{P_{i,env}^{R}}{P_{i,env}}; \qquad S_{eco} = \sum_{i=1}^{n} \beta_i \times \frac{P_{i,eco}^{R}}{P_{i,eco}};$$

$$S_{soc} = \sum_{i=1}^{n} \gamma_i \times \frac{P_{i,soc}^{R}}{P_{i,soc}} \quad (2)$$

Where:

SI – Sustainability Index,

S_{env} , S_{eco} , S_{soc} – sustainability indexes for the environmental, economic and social dimensions,

α_i , β_i , γ_i – weighting factors of each parameter of the environmental, economic and social dimensions,

$P_{i,env}$, $P_{i,eco}$, $P_{i,soc}$ – calculated value for each parameter,

$P_{i,env}^{R}$, $P_{i,eco}^{R}$, $P_{i,soc}^{R}$ – reference value for each parameter.

In case of a comparison between different solutions, the reference values can be taken as the best values of the parameters from each solution; in case of a self assessment the best available practices are taken as reference values.

For those situations, where the higher value of a parameter is considered more sustainable, the ratios of these parameters in Equation (2) become P_i/P_i^R .

The result of the developed specific model is a Sustainability Index SI, with a dimensionless value between 0 and 1, where 1 is the best and 0 is the worst value.

2. Sustainability cost

The simple approach of specific construction works sustainability cost is presented below [4]. It has a larger applicability and can be use for: partial building works; production of building materials; rehabilitation works; transport of prefabricated elements; construction technologies etc.

$$SC = SC_{env} + SC_{eco} + SC_{soc} \quad (3)$$

In which:

$$SC_{env} = \sum_{i=1}^{n} \alpha_i \cdot P_{i,env}; \qquad SC_{eco} = \sum_{i=1}^{n} \beta_i \cdot P_{i,eco};$$

$$SC_{soc} = \sum_{i=1}^{n} \gamma_i \cdot P_{i,soc} \quad (4)$$

Where:

SC – sustainability cost,

SC_{env}, SC_{eco}, SC_{soc} – sustainability cost for environmental, economic and social dimensions,

α_i , β_i , γ_i – weighting factor of each parameter for environmental, economic and social dimensions,

$P_{i,env}$, $P_{i,eco}$, $P_{i,soc}$ - calculated value for each parameter.

The Sustainability cost is the best for minimum value and the worst for the maximum value.

3. Case studies

The specific model for obtaining the Building Sustainability Index as well as the Sustainability Cost is presented below.

3.1. The analysis of a multi-store structure

There is a building with three different types of structural elements: R.C. structure; Steel structure; Masonry structure; each of them with specific dimensions.

For the sustainability evaluation of each structure, different parameters have been assessed: energy consumption E, in kWh/m^2; direct cost C, in Eur/m^2,

manpower(workload) M, in manpower/m^2; capable horizontal force for seismic actions F, in kN/m^2.

The most sustainable solution, for both indexes SI and SC, will be by using R.C. structure Fig.1.

3.2. Sustainability of the hydrothermal rehabilitation

The old buildings built in the 18th and 19th centuries represent a significant part of the total patrimony built in the European countries. The greatest challenge for the real estate developers and investors from the construction field lies in finding methods of structural and hydrothermal rehabilitation for the improvement of functional use of old buildings in the light of comfort standard.

One of the greatest problems of hydrothermal rehabilitation is the elimination of thermal bridges as well as the possibility that humidity resulted from condensation or through capillary ascension can be eliminated.

In this article we present a hydrothermal rehabilitation model for a building rehabilitated after project made for building rehabilitation [3].

The building has the following characteristics:

- a surface area of 160 m^2/level $\Rightarrow$ 320 m^2/building,
- year of construction: 1890,
- structure: brick, wood framing, roofing tiles,
- wood carpentry.
-

The hydrothermal rehabilitation of an old building according to an innovative method that provides the compliance of comfort standards criteria, assures the conservation of the building and the use thereof in optimal conditions. At the same time, it represents a milestone for using the patrimony built by providing the possibility of using it in different utilities. According to the determinations made and the methods for determining sustainability, the rehabilitation method by using an internal heat insulation with aerated layer proves to be the most sustainable method, resulting in multiple benefits for medium and-long-term investors.

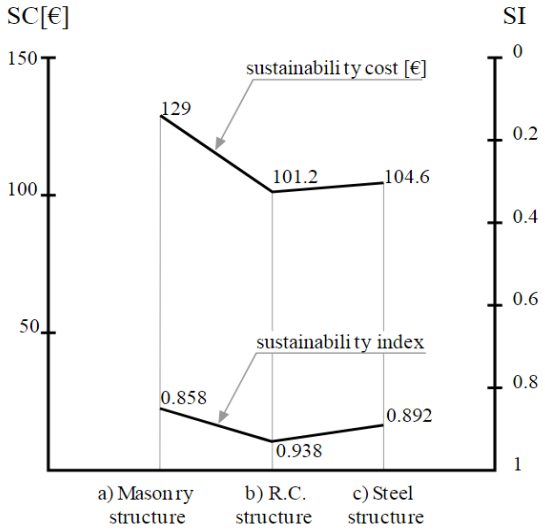


Fig.1 Sustainability evaluation of each structure

References

[1] Bob C., Dencsak T., Bob L. A Sustainability Model for the Assessment of Civil Engineer Works. Proceedings of the 10th WSEAS International Conference on EEESD 114, 2014.

[2] Bob C., Dencsak T. Building Sustainability. Civil Engineer Approach. Lambert Academic Publishing, Saarbrücken, Germany, 2010.

[3] Bob C., Leontiuc C. Sustainability of the intervention for the hydrothermal rehabilitation of a historical building using an inner insulation with aired layer. International multidisciplinary scientific Conference on social science and arts/SGEM Vienna, 2016.

[4] Bob C. A new approach of a specific sustainability model. Journal of Civil and Environmental Eng., Vol.8, Issue 3, 2018.

ID-680

A sustainable roadmap for affordable housing in India. A benchmarking approach to achieve the SDGs

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1 Introduction

Addressing the housing shortage in developing nations such as India has recently become a burning socio-economic problem. Meeting these housing needs contributes significantly to the economic and social growth of such economies. However, promoting such extensive housing development programs drastically strains many natural resources, including energy, water, and land, and leads to higher pollution and carbon emissions [1]. In this context, sustainability benchmarking gains relevance. Benchmarking refers to defining targets or reference points for performance measurement in the context of a firm, product, or process. Therefore, this study introduces a benchmarking scheme for different sustainability indicators in the affordable housing segment in India. Given the dearth of data and lack of tools to forecast the dynamic nature of sustainability, a system simulation and modeling approach is devised to develop a benchmarking scale for this segment. Thus, the benchmarking scheme would serve as a roadmap for this segment to help achieve the country's sustainable development goals (SDGs) and targets.

2 Methodology

The steps to develop the benchmarking scheme for affordable housing in India are shown in Figure 1.

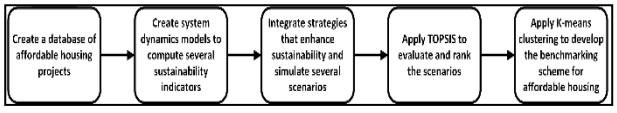


Figure 53. Research Methodology

The first step in the methodology is to create a database of projects that belong to the affordable housing category. In this case, a set of 40 projects were chosen from all over the country, and the input database that consists of the project area, location, materials used, and period of construction and use was compiled. Based on the system dynamics methodology proposed for the sustainability assessment of buildings by Francis and Thomas [2]. The third step involves integrating sustainability improvement measures into the system dynamics models, which include measures related to materials, water, and energy. The fourth step integrates the multi-criteria decision-making (MCDM) method into the system dynamics modelling method as described in Francis and Thomas [3]. Each project in the affordable housing segment is subject to 2500 generating 1,00,0000 scenarios. For the database of affordable housing projects the MCDM ranks these scenarios from best to worst. On subjecting the ranking values to a clustering algorithm, a scale is generated for the affordable housing segment. This scale is used to define the sustainability of affordable housing to high, medium and low.

3 Results

The effect of various scenarios on the base case of these projects in terms of the behavior of the individual indicators was investigated. Figure 2 below shows the behavior of the footprint family plotted for the 40 projects on implementing the 2500 scenarios. The plots show only about a 20% reduction in the carbon and ecological footprint due to materials, water, and waste policy interventions alone. However, with individual energy policies such as renewable energy penetration (from 10-100%), interventions, implementing ECBC scenarios or a combination of energy, material, water, and waste-related policies, the reduction in carbon and ecological footprint alone from 20% to 90% could be achieved. Similarly, introducing renewable energy

penetration above 70% alone would lead to a superior reduction in impacts on the same scale as that observed on implementing aggressive policies across the material, energy, waste, and water-related policy interventions. However, these observations made by examining individual indicators might not favor in achieving a collective improvement across all sustainability indicators. Therefore, to examine various projects and their alternatives for better decision-making and policy formation, a benchmarking scale is proposed for the affordable mass housing segment in India. Figure 3 illustrates the scale with sustainability levels denoted as low (BSV=0-0.391), medium (BSV=0.391-0.548), and high (BSV=0.548-1)

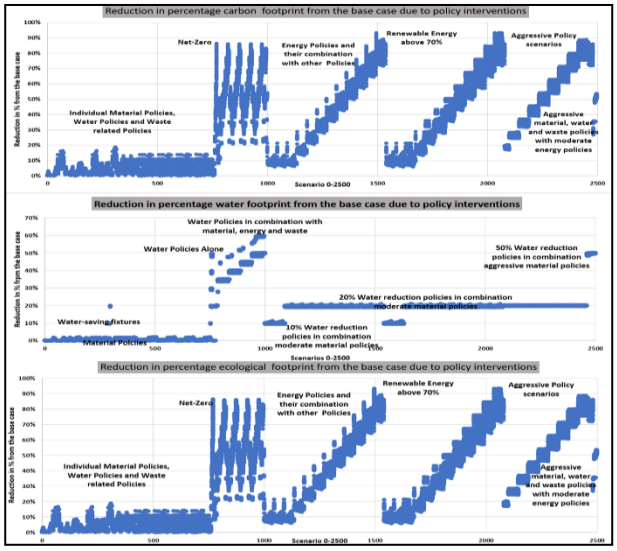


Figure 2 – Behavior of the footprint family on implementing different policies

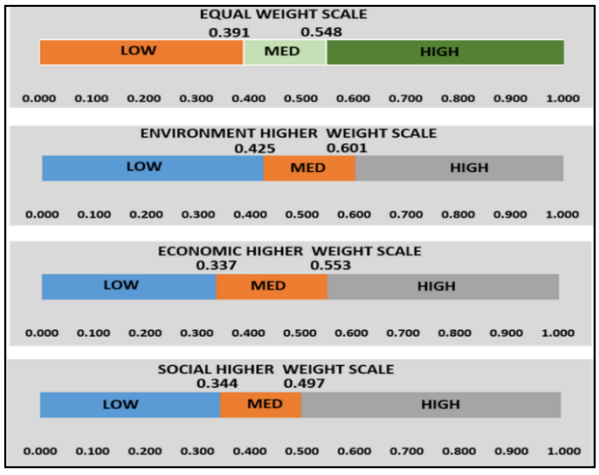


Figure 3 – Benchmarking scale for different weighting criteria

4 Discussions and Conclusions

The study brings out crucial results regarding the country-level emission targets set for India to meet Goal 13 of the SDGs which is related to climate action. It concludes that without aggressive sustainability interventions, the residential sector's share in meeting the emission reduction target of one billion tonnes by 2030 cannot be achieved at the rate of the proposed growth of this segment. However, if the segment matches up with the benchmarks derived from this study and implements sector-wide policies for improvement, it is possible to meet the reduction goals by the year 2050. This is more realistic for the growing affordable housing segment, which would significantly contribute to the peaking of country-level emissions by 2040. However, if the road map prescribed by the benchmarking scheme is rigorously implemented, the building sector could steer the nation's journey toward a net-zero economy by 2070.

5 References

[1] B. Sizirici, Y. Fseha, C. S. Cho, I. Yildiz, and Y. J. Byon, “A review of carbon footprint reduction in construction industry, from design to operation,” *Materials (Basel).*, vol. 14, no. 20, pp. 1–18, 2021, doi: 10.3390/ma14206094.

[2] A. Francis and A. Thomas, “A framework for dynamic life cycle sustainability assessment and policy analysis of built environment through a system dynamics approach,” *Sustain. Cities Soc.*, vol. 76, no. October 2021, p. 103521, 2022, doi: 10.1016/j.scs.2021.103521.

[3] A. Francis and A. Thomas, “System dynamics modelling coupled with multi-criteria decision-making (MCDM) for sustainability-related policy analysis and decision-making in the built environment,” *Smart Sustain. Built Environ.*, vol. ahead-of-p, no. ahead-of-print, Jan. 2022, doi: 10.1108/SASBE-09-2021-0156.

ID-1018

Life Cycle Cost Analysis and Use of Continuously Reinforced Concrete Pavement (CRCP) in the Bharatmala Pariyojana Project

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Abstract

Since the investments in road building are very high, proper investigation needs to be made while choosing the right type of pavement. One has to carefully exercise the choice, considering various factors such as traffic, environmental conditions, availability of materials and initial cost of construction, serviceability life of pavement, cost of maintenance, road user cost, resistance to overloading and life cycle costs.

Institute for Steel Development and Growth (INSDAG) with its mission to provide and promote the cost effective and efficient designs has carried out a study to establish the techno-economic feasibility of adopting Continuously Reinforced Concrete Pavement (CRCP) in National Highway Projects in place of conventional flexible bituminous pavements and Jointed Plain Concrete Pavements. Based on Life Cycle Cost (LCC) study, CRCP is the most preferable pavement option. CRCP provides all the attributes a roadway designer seeks: Strength, Durability, Smoothness, Traction, Very Low Maintenance, Long Life and Low Life Cycle Costs. Further, it offers much better riding quality, less dislocations to traffic movement.

Continuously Reinforced Concrete Pavement, CRCP is a concrete pavement that is reinforced with steel bars in the direction of traffic. CRCP is a durable pavement solution, advancement to plain concrete pavement. Reinforcement is used in CRCP, to tackle the problem of concrete slab cracking, which is otherwise taken care by joints provided in conventional Jointed Plain Concrete Pavement (JPCP). Joints are the weakest points of failure. On the other hand reinforcement provided in CRCP allows elimination of joints, and improves the strength and life of pavement. Maintenance is virtually eliminated in CRCP. CRCP is the most superior pavement solution than JPCP due to elimination of joints altogether.

Among the three types of road variants, direct cost of bitumen road comes out to be the lowest; however this is very uneconomical on the long term i.e. on LCC basis due to shorter life and increased fuel consumption of vehicles.

Vehicle Operating Costs (VOC) studies made in several countries including India show that rigid pavements offer fuel savings of upto 20% in comparison to flexible pavements. Any advantage of flexible pavement on account of low initial cost is not significant on life cycle costs.

LCC Study carried out by INSDAG indicates that the CRCP is the most economical option for highways as its LCC is much lower, by about Rs 19.50 crore (2.45 million USD) / Km (4 lane carriage way; 18 m wide) compared to that of flexible pavement considering fuel saving for 20 year period. The savings will be about 38.50 crore (4.8 million USD) / Km considering the fuel savings for 30 year period. Obviously these savings will be much higher for 6 and 8 lane carriageway. Also the concrete's white surface reduces the street lighting cost. Cooler surfaces and air reduce the need for air conditioning, saving energy. Cooler air can also reduce air pollution by slowing the chemical reactions that produce pollution.

Keywords: Continuously Reinforced Concrete Pavement (CRCP); Life Cycle Cost (LCC); Vehicle Operating Costs (VOC); Jointed Plain Concrete Pavement (JPCP).

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ID-1231

Effects of Moisture Ingression in Building Envelope Through Moisture Index (MI) and Wind Driven Rain Index (WDRI)

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Abstract

Moisture ingression in building envelopes offers significant structural integrity and performance challenges, leading to costly rehabilitation repairs and reduced comfort for residents. Building moisture can cause Inadequate Ventilation, fungal growth and other microbial contamination, corrosion, salt crystallization, and other moisture-related deterioration. This study investigates the effect of moisture ingress due to rainwater infiltration and its diffusion into the building facades. In addition, this research utilizes moisture modelling using moisture index (MI) and wind-driven rain index (WDRI). Furthermore, Indian standard codes and instructions were used for WDRI computations. Finally, hygrothermal analysis was conducted using WUFI simulation software, concentrating on 2D elements (slabs and walls) found in various locations with varied MI and WDRI values. This research highlights the importance of climate change when constructing structures and the potential benefits of sustainable construction techniques to reduce moisture-related problems.

Keywords: Moisture index (MI); wind driven rain index (WDRI); relative humidity(RH); dry-bulb temperature(DBT); wet-bulb temperature(WBT); climate change; sustainable construction; building comfort.

1 Introduction

The building envelope is an essential aspect of architecture and construction that demarcates the border between a structure's interior and the external environment. Moisture diffusion through the building envelope compromises structural integrity, degrades interior air quality, improves energy inefficiency, and increases maintenance costs [1]. Extreme weather events, such as heavy and wind-driven rain, occur more frequently and with greater severity as climate change accelerates [2]. The primary objectives of this study are as follows:

- To Study the ingress of moisture in a building, by considering adequate depth of concrete cover and other measures that can be used to prevent the ingress of moisture into the building.
- Investigate the Moisture Index and Wind-driven rain index, which can be used for moisture modeling.
- Production of MI map and WDRI map for India.

2 Methodology

This study deploys the Moisture Index (MI) and Wind Driven Rain Index (WDRI) to explore the consequences of moisture infiltration in building envelopes. This investigation includes quantitative and qualitative evaluations to fully comprehend the relationship between moisture ingress, environmental conditions, and building performance. Appropriate rainfall data and wind data was used to study the impact of moisture on buildings.

3 Results and Discussions

In this study, the authors calculated the moisture index using the available data for various cities and

states and plotted a map for India. The author represents only Srinagar as having a high moisture index for this study. Using all the data available, analyses were performed, and MI for each city was found and plotted on Map of India using ArcGIS. The WUFI simulations generated important information on the moisture performance of the building assembly. Figure 1 shows RH levels drop below 80% within the first six months of simulation at the critical points.

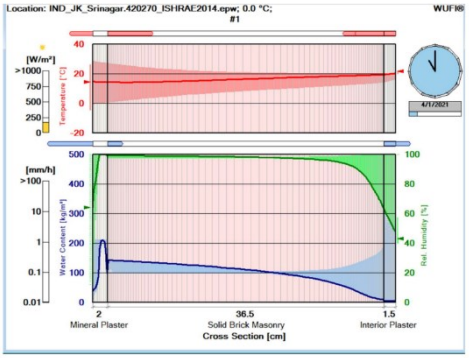


Figure 1. Wall system 6 months after the start

Figure 2 depicts the moisture is not accumulating in the system, but a problem has arisen with RH, which is at the critical point above 80.

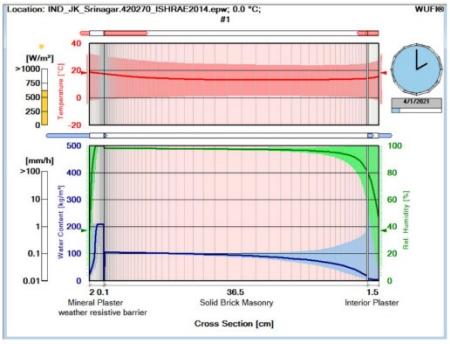


Figure 2. Modified wall system after 6 months of exposure

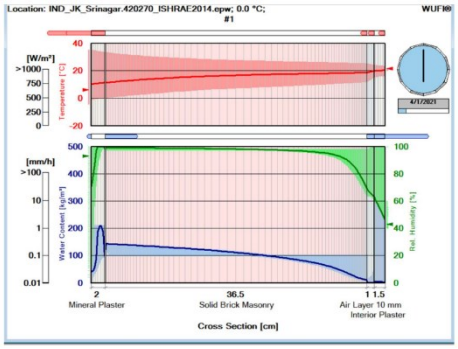


Figure 3. Wall system after 6 months

Figure 3 shows the relative humidity (RH) levels have begun to fall below the required threshold of 80% within six months. In Figure 4, conditions of no moisture accumulation and RH at the critical point were below 80%.

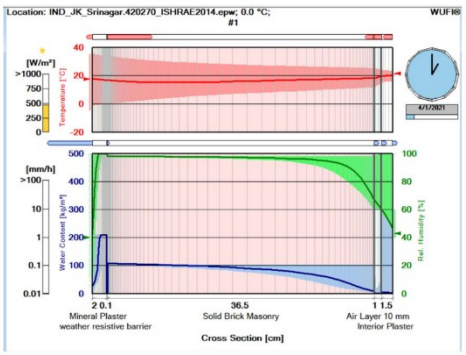


Figure 4. Modified wall with weather barrier and air layer after 6 months

4 Conclusions

In conclusion, this study highlights the crucial need for controlling moisture intrusion inside building envelopes since it poses numerous issues involving structural integrity, resident comfort, and economic consequences. The present findings sheds light on the complicated interplay between climatic conditions and construction durability by delving into the effects of moisture infiltration caused by rainfall exposure and subsequent diffusion through building facades. The research emphasizes the need to implement sustainable building approaches in the face of climate change to mitigate moisture-induced problems, using hygrothermal analysis through WUFI simulation software, including varied regions and varying indices.

5 References

[1] Simonson, C. J., Ojanen, T., & Salonvaara, M. (2005). Moisture performance of an airtight, vapor-permeable building envelope in a cold climate. Journal of Thermal Envelope and Building Science, 28(3), 205-226.

[2] Nik, V. M., Mundt-Petersen, S. O., Kalagasidis, A. S., & De Wilde, P. (2015). Future moisture loads for building facades in Sweden: Climate change and wind-driven rain. Building and Environment, 93, 362-375.

Session 35

Sustainability in Built Environment

ID-70

Protecting Reinforced Concrete Structures with Thermal Sprayed Zinc Anodes

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Abstract

Corrosion damage to reinforced concrete constructions is very common and often leads to severe damage and the need for expensive repair work. It is thus necessary to install a corrosion protection system for reinforced concrete structures that are subjected to corrosive environmental conditions, such as chloride contamination.

Metallic zinc coatings provide corrosion protection for steel by acting first as a barrier coating and secondly as a sacrificial anode. Whether exposed to the atmosphere or embedded in concrete, if the coating is scratched or compromised in any way, the zinc will still provide galvanic protection to the steel.

In the same way, concrete structures reinforced with plain or bare steel can be galvanically protected with external zinc anodes. Thermal sprayed metallic zinc on the exposed surface of the concrete are electrically connected to the steel reinforcement and provide corrosion protection to the steel. The external zinc anode will corrode instead of the steel reinforcement, reducing formation of ferrous corrosion products which stress and degrade the concrete. Thermal sprayed metallic zinc coatings can easily be applied on new and existing structures, don´t require external power to function, are maintenance-free and are fail-safe.

Thermal sprayed zinc coatings were used as anodes on the historic reinforced concrete Cape Creek Bridge, Yaquina Bay Bridge and Depoe Bay Bridge on US Route 101 in Oregon. The 20-plus-year performance confirms that the service life of existing reinforced concrete structures can be significantly and economically extended by using metallic zinc anodes to protect the plain steel reinforcement from further corrosion.

Keywords: Thermal sprayed zinc; sacrificial anode; corrosion; zinc; rebar.

ID-71

Continuous Galvanized Reinforcing Bars for Concrete Structure Durability

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Abstract

Galvanizing is used to extend the life of steel-reinforced concrete structures exposed to aggressive environments that promote reinforcement corrosion. It is very effective in combating the effects of carbonization-induced reinforcement corrosion and increases resistance to chloride corrosion. Galvanizing reinforcing steel has been an established practice for some 70-80 years in many countries.

In the case of the reinforcing bar (rebar), the most widely used method to apply the zinc is by the batch hot-dip method. It involves the immersion of batches of single cleaned steel bars into a bath of molten zinc at 450°C. This produces a coating on the steel made up of a series of zinc-iron alloy and zinc layers. These coatings can have a mass of up to 1,100 g/m2 (150 um thick), can be brittle and may damage at bending or forming, which requires on-site coating repairs. A remedy to this is to galvanize the rebar structures (columns, cages) after bending, but this requires additional time and logistical efforts.

A new innovative method to apply the zinc is by hot dipping it into a zinc bath with small aluminium additions (0.2-0.3%). The aluminium acts as an inhibitor to the zinc-iron reaction, so the coating is mostly pure zinc. These coatings typically have a mass of 360 g/m2 (50 um thick), are strong, ductile and deform with bending and forming the rebar on-site without getting damaged. On-site repairs or galvanizing after fabrication of the structures are not required anymore.

This new innovative galvanizing method is done in a continuous process, which saves time, labour and zinc compared with the batch process. Coating thicknesses can be better controlled while meeting the required protection and lifetime of the rebar. The continuous galvanized rebar (CGR) product is standardized in A1094/A1094M (2018) and a national Indian standard is currently being developed.

ID-598

Glass Fibre Reinforced High Volume Fly Ash Mixed Green Sustainable Concrete

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Abstract

In this paper the materials used in my projects such as coarse aggregate, fine aggregate, glass fibre, fly ash and other constituents of fly ash-based glass fibre reinforced concrete have been focused. In India, all old glass materials are considered as waste materials. It is disposed to the disposal ground just like other materials. The old glass materials can be recycled in factories. These recycled glass materials become an important ingredient for making GFRC. The primary aim of using glass fibre is to examine the strength of concrete made with glass fibre in comparison to plain concrete. The secondary aim is to examine the economy of GFRC for which an economic analysis could be made. Proper literature review has been done. The characteristics of glass fibre have considerable influence on the design, efficiency, output and particularly the reliability and durability of the glass fibre-based concrete. The glass fibre characteristics play a vital role in controlling the atmospheric pollution of concrete industries. All the materials with the specifications which I used for my experiments have been elaborately discussed. The apparatus and the instruments which were used for performing my experiment have also been mentioned. All the test results for all kind of specimens (cubes and beams) have been stated. The efficacy of the test results has also been discussed. Particulars in regards to design mix, especially its calculation have been furnished. Glass fibre reinforced concrete is considered to be a very useful item needed for the present concrete industries. The comparative cost of GFRC and conventional concrete has been stated here. It was found that the percentage of saving per cubic meter of fly ash-based glass fibre reinforced concrete is to the tune of 3% compared to conventional concrete. Glass fibre reinforced fly ash mixed green and sustainable concrete is a high strength high performance concrete as per our compression and flexural experiment results. The service life of GFRC is higher than that of traditional concrete and thus GFRC is widely used in architecture, building and other concerned engineering applications.Compressive Strength of

Concrete: Experimental Results

Sr. No.	Cube Specification	Grade of concrete (fck = 20 N/mm²)	Age of specimen in days	Dimension of specimen in cm	Cross sectional area of specimen in cm²	Actual crushing load in Kg	Comp. strength in Kg/cm²	Average comp. strength in Kg/cm²	Specified limit for days Kg/cm²	
									7days	28days
1	1	M20	7	15×15×15	225	31500	140.00	142.22		
2	2	M20	7	15×15×15	225	32500	144.44		M20	M20
3	3	M20	7	15×15×15	225	32000	142.22		135	200
4	1	M20	28	15×15×15	225	46500	206.67	208.89		
5	2	M20	28	15×15×15	225	47500	211.11			
6	3	M20	28	15×15×15	225	47000	208.89			
7	1	M20	56	15×15×15	225	50000	222.22	223.70		
8	2	M20	56	15×15×15	225	51000	226.67			
9	3	M20	56	15×15×15	225	50000	222.22			
10	1	M20	90	15×15×15	225	53500	237.78	237.04		
11	2	M20	90	15×15×15	225	53500	237.78			
12	3	M20	90	15×15×15	225	53000	235.56			

The 7 days, 28 days, 56 days and 90 days compressive strengths were studied and the values are shown in the tabular form in the above table for three specimens in each category. The compressive strength of concrete with maximum nominal size of aggregates 20mm was studied.

Flexural Strength of Concrete: Experimental Results



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JADAVPUR UNIVERSITY
BLOCK-LB, PLOT-8, SECTOR-III, SALT LAKE
KOLKATA-700 098, INDIA
☎ : 9477246579

Ref.: JU/Con/Salt Lake/Beam Testing/18th Jan/2019 Date: 24/01/2019

Laboratory Test Certificate

1. Test done for : Mr. Somsubhra De, M-Tech Student (Structural Engg.), Techno India, Salt Lake, Sector – V, Kolkata.
2. Letter Memo No. : Nil Dated:- 18/01/2019
3. Sample Size : 1) 500mm X 100mm X 100mm 2) 700mm X 150mm X 150mm
4. Grade of Concrete : M20
5. Type of Test : Flexural Strength of Concrete Beam (as per IS: 516)

Test Results :-

Sample Marked	Date of Casting	Date of Testing	Strength (N/mm²)
Sample – 1 (Size – 500mm X 100mm X 100mm)	19/09/2018	22/01/2019	4.12
Sample – 2 (Size – 500mm X 100mm X 100mm)			4.36
Sample – 3 (Size – 700mm X 150mm X 150mm)			4.82

Note:- 1. Tests were conducted in the laboratory as per relevant code on the samples as sent by the party.

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We recommend the average value of 4.12 and 4.36 i.e. (4.12 + 4.36) / 2 = 4.24 N/mm^2. The crack width is also lesser than normal concrete beam.

Keywords: Glass fibre reinforced concrete, High volume fly ash based GFRC, High strength, Compression and flexural experiments, High performance

ID-694

Application of Textile Waste Fiber in Mortar Strengthening towards Upgrading the Performance of Masonry Structure

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Abstract

The failure of masonry structures under gravity or lateral loading primarily initiates in the mortar. Significant research was carried out to strengthen masonry mortar using composites or fibers. Till now, waste plastic fibers, coconut fibers, polypropylene fibers, steel fibers, etc., have been used in mortar strengthening. However, strengthening masonry mortar through the textile fiber is rarely attempted. Nylon is a prevalent material found in numerous regularly disposed-of products. The primary contributors to the accumulation of nylon-based waste are fishing nets, carpets, and ropes. Reports indicate that discarded fishing nets alone account for nearly 10% of total marine waste, and because they are non-biodegradable, they pose a significant threat to the marine ecosystem. Additionally, consuming fish from polluted seawater containing waste fishing nets can lead to severe health issues, including lung and endocrine disruption, as the fish can ingest the fibers from the nets and pass them on to humans who consume them. Furthermore, disposing of used carpets and ropes made from nylon in landfills can cause land pollution and reduce available land area. To address these concerns, it is crucial to monitor pollution caused by nylon products and find effective ways to utilize this waste. In this context, recycled nylon fibers (textile waste) were used as reinforcement in the mortar to augment the performance of masonry mortar used in both joints (head and bed) and plaster. Three proportions of recycled nylon fiber were used to determine the optimum quantity. In the first phase, the compressive and flexural strength of reinforced mortar specimens were obtained by performing compression and three-point bending test, respectively. The compressive strength of reinforced mortar cubes was observed to be reduced compared to the unreinforced mortar. Nonetheless, the flexural strength of reinforced mortar prisms enhanced significantly compared to the unreinforced ones. An increase in porosity due to the addition of fiber in the mortar may be attributed to the reduction in compression strength. Moreover, the increase in the flexural strength of mortar may be due to the fiber-bridging mechanism. Further, compressive strength and bond strength (flexural and shear) of masonry specimens were obtained as these parameters play an essential role in the load-carrying capacity of masonry walls. A significant improvement in all three parameters was observed. The compressive strength of reinforced masonry prism enhanced up to 22%, whereas increment up to 44% and 110% was observed for flexural bond and shear bond strength, respectively. The failure pattern of the masonry specimens also improved as the reinforced fibers acted as pseudo-ductile material. In the last phase, In-plane and out-of-plane tests were conducted on the masonry wallettes by performing the diagonal shear and four-point bending tests, respectively. The in-plane load-carrying

capacity of reinforced masonry wallette was augmented up to 42%, whereas for out-of-plane loading capacity, the enhancement was up to 53%. Furthermore, the crack widths were reduced due to better distribution of stress by fibers, and the ductility of masonry wallettes was improved due to fiber-bridging action, leading to an upgrade in the overall performance of the structure.

Keywords: Recycled nylon fiber; masonry; mortar; reinforcing; bond strength; load-carrying capacity; ductility.

ID-1095

Resource-efficient and climate-friendly design of concrete structures through advanced structural safety concepts

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Abstract

As the bones and muscles of our built environment, engineering structures support all kind of societal activities. However, they consume huge amounts of resources and significantly contribute to impact on our environment. Structural design codes play an important matter in this regard since they regulate the use of materials by means of prescribed decision rules. These relatively simple and generalised rules offer significant potential for improvement. Grounded on risk-based optimisation approaches, this paper explores this potential in connection with the design of reinforced concrete floor systems. Assuming a large variety of realistic design situations, representative sets of such members are defined and designed according to the semi-probabilistic safety concept in the Eurocodes. The benefits of a risk-informed structural design compared to the use of these standardised decision rules is demonstrated in terms of material consumption and CO_2 emissions.

Keywords: Sustainability, embodied greenhouse gas emissions, optimisation, structural reliability, risk-based design, risk-informed decision making, structural design codes, concrete structures

1 Context

Engineering structures consume large amounts of raw materials and contribute significantly to greenhouse gas emissions worldwide [1]. Structural design codes, which regulate the safety of our built environment and the corresponding use of structural materials play a major role in this regard. They feature safety concepts that are highly generalized to make them simple and applicable to a large variety of structures at the same time. This leads to structures that are sufficiently safe and functional, but where structural material is not utilized in an optimal manner. For a sustainable built environment, this is not good enough. We need to unlock the potential offered by risk-based decision approaches in order to utilize our resources in structural design procedures as efficient as possible.

In the past, the objective of such optimisation procedures was mainly the minimisation of costs. While this approach may contribute likewise to mitigation of material consumption and greenhouse gas emissions, it was recently suggested to explore the potential benefits of addressing such environmental objectives explicitly, since the corresponding optimum might significantly deviate from the solution based on an economic decision framework [2].

2 Objective

On the grounds of an emission-based objective function (Eqn. 1) with the aim to identify optimal decisions p_{opt} that minimise the total expected emissions CE_{tot} (Figure 1), the paper assesses the environmental saving potential through a risk-informed design of floor structures with RC members (Figure 2). The benefits compared to the application of the Partial Factor Method defined in the Eurocodes (EC) are demonstrated.

$$p_{opt} = arg\min_{p}(CE_{tot}) \quad (1)$$

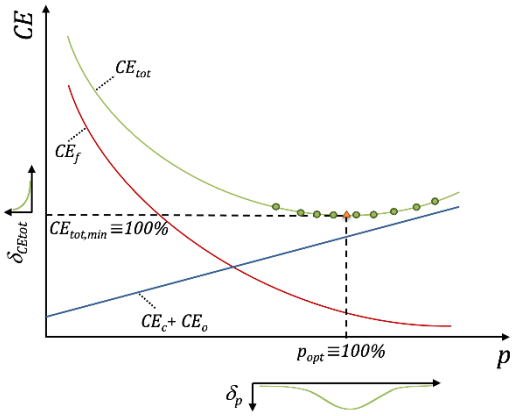


Figure 54. Illustration of the carbon emission-based optimization principle and deviations $\delta_{CE,tot}$ and δ_p from the minimum total emissions ($CE_{tot,min}$) and optimal decision parameter (p_{opt}), respectively.

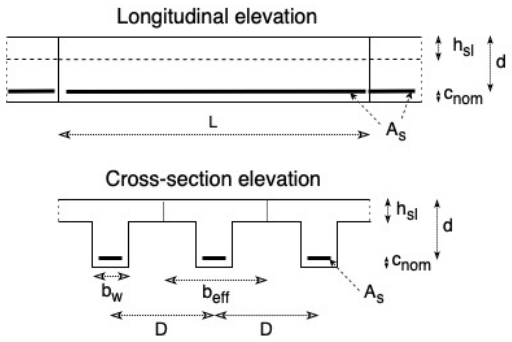


Figure 2. Sketch of the floor systems with T-beams

3 Results

The results (Figure 3) point to a relatively low saving potential δ_{CEtot} (Figure 1) of the risk-based optimisation (with respect to the EC solution) in terms of the total expected carbon-emissions, CE_{tot}. However, the potential emission savings at the design stage, δ_p (Figure 1), are found to be significant. Given the *need for urgent measures* to reduce embodied greenhouse gas emissions in constructions, the opportunity for potential "immediate" reductions of the order of δ_p = 7-10% (average of results in Figure 3b), achieved through application of advanced safety concepts in structural design procedures, should not be ignored.

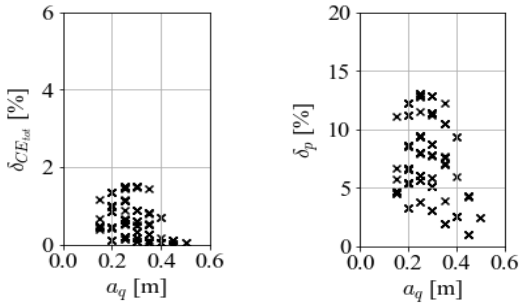


Figure 3. Savings of the risk-based design with respect to the EC solution; a) in terms of expected total emissions, δ_{CEtot} b) in terms of material use and associated emissions at the design stage, δ_p

4 Conclusions and outlook

The development of sustainable built environment systems requires substantial modifications at the systemic level of the rules and regulations, which implicitly control most structural engineering decisions. Its high level of detail in regard to the representation of the decision problem makes explicit risk-informed decision analysis an appropriate tool for this purpose. A case study has illustrated this. Future studies should increase the scope of the study to other materials, failure modes and loading scenarios, providing the basis for a consistent risk-based calibration of the standardised design rules and hence for a broad implementation of sustainability principles in structural engineering decision making.

5 Acknowledgements

This study has received funding from the EU's Horizon 2020 research and innovation programme. M. Sklodowska-Curie grant agreement No 893527.

6 References

[1] Joint Committee on the Globe Consensus (Globe). Decarbonizing global construction - Draft, September 2022, http://globe-consensus.com.

[2] Hingorani R, Köhler J. Towards optimized decisions for resource and carbon-efficient structural design. Civil Engineering and Environmental Systems. 2023.

ID-1055

The Feasibility Study of Net Zero Energy Building with Carbon Credits for Sustainable Future: A Case Study in Chandigarh

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Abstract

The paradigm of 'waste to energy, mitigation of carbon and its sequestration is relegated to a secondary level which conversely results in India discarding 68.8 million tonne in landfills and comes third after China and US in total GHGs emission. The study highlight the adept schemes for successful co-composting of food, fruit and green waste, with a mechanism to mitigate carbon leakage in the developing countries.The present study deals with implementing green building concept to improve energy efficiency through the adaptation & integration of technologies to achieve decarbonisation target to limit global temperature to 1.5^{O}C to avoid catastrophic impacts of climate. Under dynamic modelling, the present pioneer work analysed three aspects to maximize on site renewable energy to reach the net zero energy target The three aspects are; (i) Solid waste Management (ii) Solar grid system (iii) Grey water potential. The present study aimed to analyze and compare the impacts on the environment due to MSW management, solar grid system and grey water use potential scenario evaluating greenhouse emission to achieve "Net Zero energy building (NZEB)". The MSW management has devised two strategies: (i)Single Stage Composting (SSC):The windrow plant consists of screening facilities, solid waste separator, charging and composting units.where the organic wastes were accumulated in 3x4m brick lined charging unit with basal bulking agent(green waste)layer, which was sequentially alternates with food ,fruit and vegetable waste(30cm each) in three different layers. The repetition of the layers is done till the cumulative pile reached 1.5m high.The piles in windrows were turned manually on 6th and 11th day to generate micro-positive pressure making windrows aerobic,(ii)Two stage Composting (TSC):In TSC, the organic waste was initially added to a bioreactor 'FOODIE' for and after 7days the semi-digested organic cakes were de-confined from the bioreactor and transferred to windrow composting plant. The cakes added to square 64m2 open site windrow composting plant .The Municipal Solid waste (MSW) windrow composting process results in mitigation of Carbon leakage to 346.6 metric ton annually and 564 quintals organic compost. The present study is the pioneer attempt to produce bio-stable, organoleptic and agronomic feasible organic compost evaluating the physicochemical parameters using the two stage composting (TSC) comprising bioreactor and windrows using mixture of raw materials: 50%green waste (60% leaves,35%grass clippings and 5%tree branches),50%food and fruit waste of total 300 per day , to produce compatible compost in 110 days in TSC, to highlight best organic waste management strategies to achieve co-composting of food, fruit and green waste. The high quality final compost has 40^{o}C temperature, 7.6 pH, 42% moisture content, 3.36ds/m electrical conductivity and 25 C/N ratio [1].[2],[3],[4].A grid connection photovoltaic (mono crystalline Silicon Solar PV) power system of 495 kV, which consists of solar panels, conditioning unit and grid connection equipment. When conversely, onsite energy generation exceeds the building energy requirements, due to energy storage cost limitations the surplus energy was offsets, hence, the grid connection is necessary to enable the Net Zero Energy balance.A solar rooftop system is the investment that appreciate with time as there is constant increase in savings and every unit of solar energy helps prevent 0.7 kg of carbon dioxide emission. Installing I KWp solar rooftop plant is thus equivalent to planting two trees in terms of carbon Sequestration .A solar energy plant installed in April 1, 2014 with capacity 495 KWp in Post Graduate Government College for Girls, Sector-11,Chandigarh.A solar energy plant installed in April 1, 2014 with capacity 495 KWp in Post Graduate Government College for Girls,

Sector-11, Chandigarh, providing the benefit of 60 thousand units and computation of electricity bill in 2019-2020 depicts average 22,421 units and the not utilized units offsets to grid system, hence reduce the electricity usage by 75.24%, saving 42 metric ton carbon dioxide, generating 42 carbon credits. Grey water (GY) harvesting, a dual economy process a futuristic approach for sustainable growth, is a water reutilization system design on energy saving and carbon footprint benefits, mitigating 47.7 metric tonne of CO_2 annually, generating 47.7 carbon credits, hence the total carbon credits generated are 436 in accord with earlier studies[5],[6].The Net Zero Energy concept results green building with micro-climatic moderation, reducing global warming with eco-restoration with carbon footprint benefits. The major success of any projects fall in its reproducibility and scalability and presently, when the project is extended for the society, its success is assessed at different sites and areas. In this parameter, the project is replicated at two institutes:(i)Judicial Academy, Sector-43, Chandigarh(ii)Post Graduate Government College, Sector-1, Panchkula. The main objective of the present study was to analyse and overview the configuration technology, analytical parameters and feasibility of net zero energy improving building resilience. The present study entails ascertaining how WtE can serve as a circular economy tool toward carbon footprint benefits and climate change mitigation that will ensure environmental sustainability, in two fronts: First, there is social awareness, the main stumbling block of which is attitude shift of consumers at source segregation of the waste and second level is mitigation of carbon footprint with circular economy, a tool needed to make paradigmatic change to achieve zero waste sustainable future in the present era.to achieve decarbonisation target. (i)The main objective of the present project is to monitor the physico-chemical parameters (temperature, moisture content, pH, electrical conductivity, C: N ratio).to produce stabilized compost in 110 days & 3 LCA (Life Cycle Assessment) cycles of TSC. A membrane covered windrow composting system generating micro-positive pressure was used to investigate the odor emission, microbial degradation acceleration with reduction of GHGs,(ii) The problem solved due to the bioconversion of solid waste are its management are unscientific land filling, avoiding the breeding grounds for, saving precious Farm yard Manure (FYM), which are used in Agriculture fields and in Biogas Plants for sustainable development(iii)the concept of circular economy (CE), restorative and regenerative system by design has contributed to a paradigm shift in the transformation of Waste-to-Energy (WtE) in the management of municipal solid waste. The present study entails ascertaining how WtE can serve as a circular economy tool toward carbon foot print benefits and climate change mitigation that will ensure environmental sustainability. The present investigation provide better insight on the feasibility, applicability and reproducibility of the single stage windrow composting and two stage composting technology to ensure the efficiency and effectiveness of TSC in producing bio-fertilizer and reducing landfills and the organic compost generated increased yield of agronomic and floriculture crops and have more yield and protect human race from bio-magnification of pesticides and weedicides and in this era of increasing population, the both aspects helped in the development of nation.The net zero energy concepts was to maintain eco-restoration in the building with carbon foot print benefits, which eventually reduce global warming and results in moderation of its micro-climatic temperature, making the building a green building. . In conclusion, net zero energy buildings are source of opportunities to undertake global energy revolution with integration of energy conserving technology. Hence, with the increasing degradation of the environment, the net zero environment conscious buildings are essential and to meet the zero energy goal to achieve sustainable future.

References

[1] Oviedo-Ocaña E.R., María A., H-Gómez, Ríos M., *et al*. A Comparison of Two-Stage and Traditional Co-composting of Green Waste and Food Waste Amended with Phosphate Rock and sawdust', Sustainability, 2021;**13**: 1109.

[2] Sharma V. Carbon credits from Windrow composting of Municipal solid waste to combat climate change: a case study in Chandigarh. Poll. Res., 2022a;**41(3)**:189-195.

[3] Sharma, V.A Micro- positive pressure aeration for windrow composting of municipal solid waste in Chandigarh: An opportunity in a carbon conscious world for combating climate change. Pollution Res., 2022b; **41(3)**:388-393.

[4] Voberkova, S., Maxianova, A., Schlosserova, N., Adamcova, D., Vosanska, M., et al. Food waste composting-Is it really so simple as stated in scientific literature -A case study. Science of the Total Environment.2020;7**23**: 138202.

[5]Dhakal R., Sedai A S., Paneru, S., Yosofrand M., &Moussa H. Towards a Net Zero Building using Photovoltaic Panels: A case study in an Educational Building', Int. J. of Renewable Energy Research, 2021, **11(2)**:1-11.

[6] Filali H., Barsan N.,Souguir D., Nedeff V., Tomozei C., and Mohamed Hachicha M. Grey water as an Alternative Solution for a Sustainable Management of Water Resources—A Review',*Sustainability,2022;***14(2)**:665

Session 36

Sustainability in Transportation Structures

ID-81

A Synthesis of Techniques and Ideas to Optimise The Life Cycle of Bridges In Practice

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Abstract

Bridges are subjected to various forms of deterioration during their service life which reduce their performance. Bridge asset owners, facing budgetary constraints while striving for decarbonisation and sustainability, have the challenge of preserving their existing bridge network while maintaining their safety and functionality in spite of deterioration. This paper explores some techniques and ideas which can be used to optimise the life cycle of bridges. First, sustainable development is discussed in relation to bridges. Next, a bridge life extension project case study is presented, along with key inferences from the case study. Subsequently, structural performance assessment, in particular the use nonlinear finite element analysis in practice, is examined. Finally, the changing role of design consultancies, structural health monitoring, and performance-based design codes are highlighted as catalysts to help achieve more optimal bridge life cycles.

Keywords: life cycle; sustainability; bridge; asset management; service life; structural performance.

1 Introduction

With limited funding and resources available, bridge asset owners seek management strategies to optimise the life cycle of the bridges in their network. There is no definitive interpretation of what an 'optimal' bridge life cycle looks like. This is because a bridge has many performance criteria which must be balanced by the engineers and asset owners. Decisions made by a bridge asset owner at any stage of a bridge's life cycle, from initial planning through to decommissioning, can be influenced by prejudices or political motives. However, this paper will focus on techniques and ideas which can assist bridge asset owners to make informed, objective decisions. The challenge becomes quantifying certain metrics of bridge performance, such as sustainability, so that an optimisation problem can be defined and solved.

2 Sustainability in relation to bridges

An increasing number of bridge engineers now acknowledge the importance of considering life cycle sustainability during the planning and design phases of projects. Stakeholders in infrastructure projects may have different interpretations of what 'sustainable' design is. For sustainability to be truly realised in bridge and infrastructure projects, further discussion is needed among all stakeholders to agree upon a unified approach to achieve sustainable infrastructure. Sustainable decision making through the life cycle of a bridge involves balancing the three pillars of sustainability: social, environmental, and economic. The challenge is finding the right balance between the three pillars. Historically, and even today, the economic pillar usually dominates decision making in infrastructure projects.

3 Project case study

Jacobs was involved in a significant rail bridge life extension project in Australia from 2009 to 2013. A detailed assessment and testing program was performed, and two remediation measures were implemented. A couple of inferences drawn from this project case study are listed below.

- For important existing bridges, asset owners are generally able to justify spending large amounts of money on assessment if there is the possibility of not replacing the bridge.
- For a group of bridges with similar critical elements and expected to fail in the same manner, detailed investigations and analysis can be undertaken for one (or a few) of the bridges, with the results used to inform maintenance decision making for the other bridges in the group.

4 Structural performance assessment

Structural performance of bridges is one of the main considerations of bridge asset owners in life cycle management (LCM). Keeping existing structures where possible is a common goal for asset owners. Often, this involves justifying a higher load-carrying capacity for structures which were designed for lesser loads. Nonlinear finite element analysis (NLFEA) can find the reserve strength of structures and predict the failure mechanism. However, the main challenge practitioners face with using NLFEA to assess an existing bridge is the validation of the model. Material samples must be taken from the bridge to determine material properties at the time of assessment, and probabilistic modelling of deterioration should also be performed.

5 Techniques and ideas to be adopted in practice in future

In future, as a result of bridge engineering design consultancies using more automation in design, more financially competitive bids for projects may be submitted, ultimately leading to lower fees for consultancies to do new design work. In response, consultancies are likely to adapt by offering bridge asset management services to clients such as transport authorities and local councils, rather than focusing primarily on new designs.

As the cost of structural health monitoring (SHM) systems comes down, and more practitioners become familiar with how to operate SHM systems, there will be a greater uptake of SHM by bridge asset owners in the future. A good LCM framework should be flexible to change. That is, upon analysis of field data collected through inspections and/or SHM, the maintenance plan for each bridge can be optimally adjusted. As new SHM technologies emerge, it is becoming possible to collect data on a wider range of parameters. However, the engineers must determine what the critical elements of the bridge are, and what monitoring systems would give sufficient warning before a performance threshold of those critical elements is reached.

Many design codes today are prescriptive in nature. As an alternative, performance-based design codes can offer more freedom for designers to innovate, allow the use of newer materials and technologies, and enable greater efficiencies to be realised compared to prescriptive design codes. Many prescriptive design codes maintain the same target reliability indices for both new designs and existing structures. However, the relative costs of safety measures would be higher for existing structures than new structures, so it would be logical for the target reliability indices for existing structures to be lower than for new design. The flexibility to choose an appropriate target reliability index for each bridge within a network would give bridge asset owners the opportunity to further optimise their LCM strategy.

6 Conclusions

To better incorporate sustainability throughout the life cycle of bridges, more work is needed to devise a rational and widely accepted way to quantify the bridge performance metric of sustainability, particularly the pillars of environment and social. The continued collaboration and development between bridge design consultants, bridge asset owners, academics, and companies producing SHM systems will lead to more optimal bridge life cycles.

ID- 130

Tibetan Bridges - From Adventure to Sustainability

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Abstract

This paper relates to the design of suspended footbridges for tourist attractions, with particular focus to a peculiar suspension system developed for the world longest "tibetan" bridge built on 2019 in Italy.
Tibetan-style bridge are becoming really popular as recreation structures, capable to offer an adrenaline, but safe experience not only for the most adventurous people, but also for families, surrounded by nature.
In a world in which the development or improvement of sustainable mobility is quite urgent, they has the potential to become a great solution in mountain and rural areas.
Having a light structure, they are not only well integrated in the landscape, but they are also an ideal solution to cross rivers or valleys, to connect isolated villages and finally to add touristic assets to the area.
Although this, a significant number of simple suspension pedestrian bridges has been designed without focusing to the need for easy installation and reduced maintenance.
The ultimate target of this project is to build a package of pre-engineered solutions, capable to fit different locations using modular components, lightweight materials, economically smart systema and environmentally friendly style.

The proposed solution has the following key properties:

- From adventure bridge to family skywalk, the deck is composed by a **modular unit**, that can be duplicated in different arrangements based on specific accessibility requirements;
- The deck is made with **lightweight and reusable materials** that minimize the environmental impact;
- The bridge has been designed in order to use materials and equipment easily available everywhere, giving **priority to local manufacturers**;
- A particular **dismountable solution** has been developed for the **end terminations** of the suspension ropes with adjustable length, in order to facilitate the transportation and the installation of the load-bearing structure.

Two bridge categories for two different user's range have been identified:

- The first one, design with purely adventure purposes, with a discontinuous deck made up with gratings and hangers connected to them for the parapets, and with slopes that can reach also 10%. For safety reasons, this type of bridge has to be walked with harness and ferrata kits, connected to two safety ropes running over the handrail ones for the total length.
- The second one, designed for families, is characterized by a continuous deck, usually made up with gratings and a continuous parapet

with metal meshes and hangers to support them. In this case the suggested maximum slope is given by Standards and has not to exceed 8%, in order to ensure a certain comfort during the walk.

As already mentioned, one of the key points of this project is the use of innovative materials, especially for the deck, that is composed by fiber-glass grating panel. FRP materials are light-weight, high strength and durable materials, that require minimum maintenance. The surface can be smooth or rough in order to improve adherence and it can also be painted with colours like the ones of the local soils, improving the impact on the landscape.

The modularity of the system allows to use the same panels for the two different type of bridges, just only multiplying the dimensions or the number of elements side by side.

The grating panels are rested and blocked on a fiberglass frame connected to the lower ropes between bolted clamps. All the connections are designed using standard components, easy to find in every hardware shop.

The deck can be pre-assembled at the starting point of the bridge without completely tightening the bolts and then moved to the right position time to time, making the installation easier.

The parapet is composed by 6 mm steel wire ropes arranged in a triple triangular pattern, directly connected to the four suspension ropes with standard steel bolted clips. This solution allows to maintain all the bearing system independent from the deck, thus improving the distribution of the loads and facilitating the replacements of individual elements.

The standardization of the load bearing structure has been one of the main subject of study and the results have been finalized during the design and construction phases of the "bridge between two parks", built in Castelsaraceno, a little village in the South of Italy, in 2021. **It is an impressive work of engineering, 586 m long and 80 m above the ground, built with strategies oriented towards developing tourism in an area facing a general trend of depopulation.**

In this way, the bridge has become not only an attraction for touristic purposes, but also a way to relaunch the country.

In that case the close collaboration between structural engineers, ropes manufacturers and construction company has allowed to develop some innovative solutions for the suspension structure.

The resulted load-bearing structure is composed by four open spiral strand ropes with a diameter of 35 mm.

The ropes which are typically used for these systems are connected to the ground with adjustable sockets. Standard ones are not so sustainable, in particular in case of small lengths, because of their weight and the necessity to manufacture them in a dedicated foundry.

The result is a system which is difficult to transport and to handle during installation, increasing the risk of cable damaging and impossible to inspect after installation.

For this reason, a dismountable socket has been developed, composed by different elements that can be transported in a wooden box, separately from the rope. The rope arrives to the construction site already equipped with a small cylindrical end termination. Being a dismountable system, it was possible to transport ropes with cylindrical sockets and grubscrews separately from the joints tubes, reducing costs. All the dismountable sockets been manufactured in local shops, promoting regional industry, and making this bridge an example of sustainable structure.

Moreover, the attention given to the development of solution easy to inspect and to maintain is another strength of this bridge. After inauguration, in 2021, has reached an international success, with hundreds of visitors per day, increasing the tourism of a village that was going to die.

Another Tibetan-style bridge is planned to be built, as a prolongation of the existing one, probably using all the innovative solutions explained in this paper.

ID- 215

Lightly Loaded Bridge

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Abstract

This paper deals with a live load optimization of bridge design to cater only to the passenger vehicle segment known as lightly loaded bridge and which is exclusively designed to carry only the passenger vehicle segments whose live load is usually less than 5 kN/sqm. In a densely populated city, there will always be an alternative route to reach a destination that can be used for heavy commercial vehicles. This lightly loaded bridge shall be used only for the passenger vehicle segment. Adopting this may have many advantages such as reduction of material consumption leading to sustainability, aesthetically pleasing structure, and lesser requirement of the vehicle turning radius + steeper gradient helps to leverage alignment geometry control. This lightly loaded bridge has some limitations but with some mitigative solutions explained in this paper.

Keywords: Lightly loaded bridge, sustainability, load optimization, and material optimization.

1 Introduction

In the present state of the art, a Bridge Engineer usually optimizes by providing an appropriate structural solution, adopting an efficient cross-section, optimizing permanent load, and introducing lightweight material.

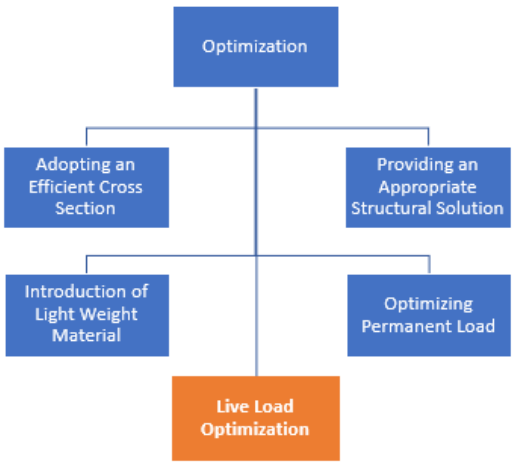


Figure 55. Proposed Methods of Optimizations

But there is a vertical by which a Bridge Engineer can optimize the structural component known as "Live Load Optimization".

Here the proposed optimization of the bridge is done by reducing the application of live load by restricting certain groups of traffic or allowing only certain segments of vehicles to make this optimization possible. This can be achieved by imposing the height restriction gantry at the entry point of this lightly loaded bridge.

2 Designing Lightly Loaded Bridge (LLB)

2.1 Criterion for Designing LLB

Designing this lightly loaded bridge is subject to deviation from the current code requirement and hence the design criteria for justifying the deviation has been explained in this section.

2.1.1 Design Criteria 1

The vehicle volume in the road is majorly classified into two types of vehicles namely passenger vehicle segment and commercial vehicle segment. Around 90% of vehicles on the road are passenger vehicle segment and only 10% of the vehicle is in commercial vehicle segment.

2.1.2 Design Criteria 2

In a densely populated city, there will always be an alternative route to reach a destination that can be used for heavy commercial vehicles. This lightly loaded bridge shall be used only for the passenger vehicle segment.

2.2 Solution

In common practice, a Bridge Engineer shall design the bridge to carry all types of traffic whose vehicle load which will be in the range of 5 to 15kN/sqm.

But based on this new approach, the Bridge Engineer shall design a bridge by controlling the traffic to only passenger segment vehicles whose weight is less than 5 kN/sqm and by restricting the entry of commercial vehicle traffic.

Lightly loaded bridge which exclusively caries only passenger vehicle segments which are less than 5 kN/sqm vertical load.

The main goal of developing this concept is to implement it only in densely populated cities to ease traffic congestion, where there is an existing alternative route to transport commercial vehicle segments.

2.3 Advantages of LLB

There are many advantages in adopting a Lightly Loaded Bridge and those are as shown below,

- Reduction in Superstructure Member Force
- Reduction in Transverse Deck Slab Member Force
- Reduction in Crosshead/Portal Member Force
- Reduction in Pier Member Force
- Reduction in Foundation Force
- Reduction in Braking Force
- Lesser Turning Radius
- Lesser Head Room Clearance Requirement

2.4 Limitations of Adopting Lightly Loaded Bridge

2.4.1 During a Fire in the Bridge

If the bridge is designed as a lightly loaded bridge with a live load weight of less than 5 kN/sqm then during a fire emergency in the bridge, a fire engine cannot access the spot by traveling over the lightly loaded bridge, since the bridge is not designed for fire engine vehicle load. But this lightly loaded bridge concept is developed to facilitate inside a city where there will be easy for a fire engine to access the affected area from at-grade to put off the fire.

2.4.2 During an Accident over the Bridge

In this case, a crane cannot access the location by traveling over the lightly loaded bridge since the bridge is not designed for crane loading. But as mentioned in the previous scenario the crane can access the location by reaching it at-grade.

3 Conclusions

This paper discusses the new vertical on the optimization of the bridge through reducing the live load intensity and explains its merit and demerits. This live load optimization, directly and indirectly, helps in reducing the material requirement in constructing the bridge leading to a sustainable solution. This live load reduction also can help in the evolvement of aesthetically pleasing structures due to its sleek member sizes with the possibility of enlarging the structural span.

4 References

[1] BD37/01: Loads for highway.

[2] BD 60(DMRB 1.3): Design of highway bridges for vehicle collision loads.

BS 6779-2: Highway parapets for bridges and other structures.

ID-1178

Modular Designs for Sustainable Railway Stations

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Abstract

Indian Railways (IR) has taken up station redevelopment of over 1200 stations (from a total of 8000+) through an ambitious program called Amrit Baharat Station Scheme (ABSS). The Government of India wants to accelerate redevelopment of stations as city centres to provide a fillip to the urban rejuvenation surrounding railway stations. IR work at, or above, their capacity and a very-very large number of people use IR trains daily. Implementing ABSS works on brownfield sites with speed and quality needs an approach different from conventional.

To achieve these objectives, a key strategy is to modularise specific station components using prefabricated/pre-engineered parts. The adoption of standardised value-engineered components would secure significant reductions in construction programmes and economies of scale.

Keywords: Stations; Railways; Structures; Architecture; Sustainability; Modular Design.

1 Introduction

This paper summarises the Draft Design Handbook (DDH) prepared by Arup on behalf of the RLDA.

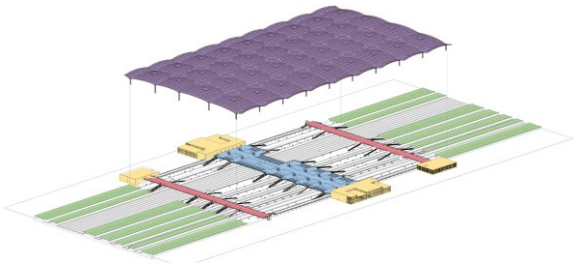
Purpose and Vision: The purpose and vision of the DDH is to adopt a total station design approach, providing integrated solutions and modular designs that optimize architecture, structure, MEPF and construction through cost effective designs that are scalable and with shorter construction programme outcomes.

Outcomes Optimise across cost, time and replicability; Ensure durable prefabricated modules to reduce long term maintenance cost; Establish visual consistency across the wider station's capital programme; Maximise local adaptation to suit environmental and contextual factors; Promote green construction with optimised use of material.

Challenges: Complex installation requirements, e.g., launching over rail, OHE; Diversity of architectural concepts; Numerous existing utilities, identification, protection & diversion; Rail Blocks and Operations of railway; Interference and integration of existing infrastructure, FOBs, existing heritage buildings; Ventilation strategies)

Opportunities: Improved planning of pre-construction; Standardisation of spatial arrangements; Standardised parameters, e.g. ceiling heights; Standard organisational principles like station grids; Simplified construction methods, Offsite fabrication and mass production of components; new technologies, e.g. glulam and weathering steels, Incentivised target price contracts to share risk with contractors.

2 Station Components



3 Station Design Process Flow

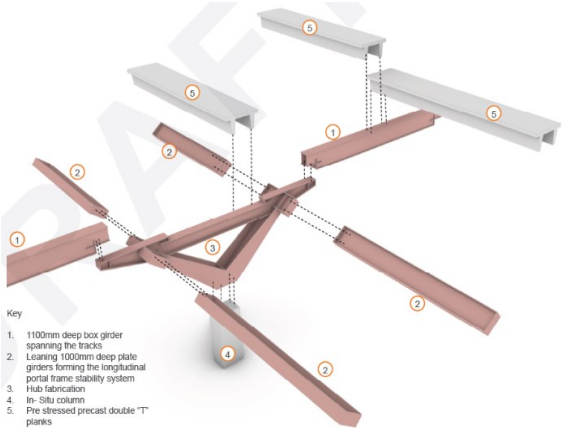
A sequence of essential steps to design stations: 1. Defining the station specific requirements; 2. Establishing design principles, like VCEs; 3. Laying out the components on the grid. 4. Specific choices.

4 Sustainable Station Principles

The sustainability strategy is tied to the thermal comfort strategy and energy consumption of the stations. Comfort cooling should only be used for VIP spaces, the rest of the station should be naturally ventilated. This passive strategy provides waiting travellers with a more comfortable environment than the external conditions and reduces the operational energy consumption, and therefore cost and carbon.

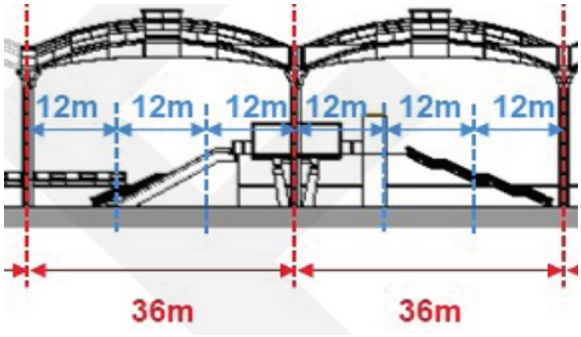
5 Grids

The grid sets up a framework for modular design. In turn, modularity guarantees the speed of construction. It becomes a tool for bringing together and setting out all individual elements, it ensures applicability and repetition of elements. The unifying grid system provides future proofing with an extendable structure/roof, allowing augmentation of the stations over their lifetime.



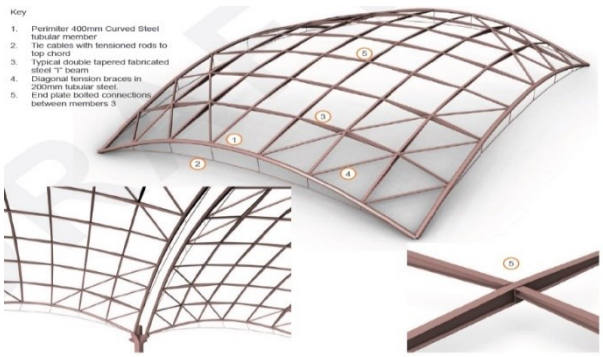
7 Through Roof

The Through roof is a large footprint canopy that covers the entirety of the concourse and can extend out beyond this to cover as much of the station length as is desired. The roof shape is determined by form finding to achieve pure axial behaviour for uniform permanent loading.



6 Station Concourse

The paid concourse connects the paid section of the station building to the platforms via associated vertical transportation and escalators. The platform widths and spans across the tracks between platform edges varies between stations. Modular branching "Y" columns can significantly reduce the structural spans, and thus allow shallower deck structures.



8 Conclusions

The DDH provides guidelines for the redevelopment of brownfield aged railway stations that based on sustainability principles, standardised grid and design of modular structural components that are replicable and are scalable. The guide provides the consistency required to enable modularisation. These principles are currently being tested in the redevelopment of Safdarjung Station in New Delhi.

ID-698

The Climate Action Plan and Sustainability in Construction

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Abstract

It is a universal truth that infrastructure and construction are the driving force of any economy and that the development of a country is primarily judged through its infrastructural development. However, with the rampant rate of climactic adversities, a dire need to change the processes and end – results of construction have arisen. During the United Nations Conference of Parties (hereinafter referred to as 'CoP26'), the Indian ambassador expressed the country's intention of attaining net zero carbon emissions by 2070 and of reducing these emissions by at least 1 billion tonnes by 2030.

The Ministry of Environment, Forest and Climate Change (MoEFCC), through its submission to the United Nations Framework Convention on Climate Change (UNFCCC) highlighted the contribution of building stocks up to 40% in the total national energy consumption of the country. Focusing upon the major polluting sectors of power, steel and cement industries, the Government of India aims to curb the amount of carbon emission being generated within these energy-intensive units to reduce dependency upon coal for 70% of power generation in India. The Indian Government also aims to enhance the usage of non-fossil fuels within the energy generation sector to control the amount of carbon emission from bulk coal burning. In addition to this, the Global 2022 Building Status Report published by the United Nations Environment Programme, the building construction stocks amounted to a total of 39% energy consumption while the carbon emissions were considerable.

To attain these targets, India would have to take drastic steps to incorporate the values of sustainability within all its sectors, including that of construction. While most of the construction companies are currently more inclined towards managing capital costs, this goal may force them to look for more environmentally feasible and sustainable options.

NITI Aayog, in its report titled, Indian Infrastructure Body of Knowledge, which was published well before the newly created ambitions of the country, appropriately acknowledged this fact and provided a comprehensive guidebook on how some values of sustainability be included within the construction process.

Additionally, the Energy Conservation Building Code, 2017, published by the Bureau of Energy Efficiency for voluntary adoption by many states in India, also provides for detailed directives for compliance by commercial buildings, to enable them in attaining energy efficiency.

However, the most important question arising out of the aforementioned and the other existing measures pertains too their implementation, which, in effect is lagging, when compared to the rate of global warming.

When in 2015, the United Nations Environment Programme established the 17 Sustainable Development Goals, they sought to include industry and infrastructure, as well as sustainable cities and communities, as specific goals. These goals were sub-divided into individual targets, wherein, sustainable construction

was made to be an essential element. It is although essential to mention, that the Sustainable Development Goal Index, developed by the NITI Aayog for tracking the adoption of these goals, the target of such sustainability in construction, lost its place to various other targets.

At this juncture, it is also needful to note that in all the targets set by the Sustainable Development Goal Index, India is now in the green, which can provide for ample opportunity for the country to start another journey towards adding new targets, including that of imbibing construction.

The International Institute for Sustainable Development published a report proving accountancy of fossil fuels for almost 76% of the total primary energy supply in India. Reflecting upon such dependency on non-renewable resources, the Energy Conservation (Amendment) Bill, 2022 was passed into law on 8th August, 2022 to validate the regulatory framework for establishing carbon markets in India.

The Bill primarily sought amendments in the Energy Conservation Act, 2001 as an endorsement of Panchamrit towards efficient decarbonisation of Indian economy. Additionally, the amendment provides legal recognition of the draft blueprint of 'National Carbon market for Stakeholders Consultation' published by Bureau of Energy Efficiency (BEE) in 2021.

With the intention to curb the amount of carbon emission and to achieve the goal of net zero carbon emission by 2070 pronounced within the Paris Agreement, the Gujarat Government on 23rd May 2022 signed a Memorandum of Understanding with Energy Policy Institute at the University of Chicago Trust in India (EPIC India) and the Abdul Jameel Poverty Action Lab (J-PAL) to setup and execute cap and trade system for establishing domestic cap and trade market in India.

Over the years, rampant unplanned urbanization in the country has resulted in unrepairable environmental damage. With the realization pertaining to the over-exploitation of resources, frequent progressive measures have been inculcated within already established legislation to ensure compulsory implementation within the country. Focusing on curbing the impact of exponentially increased carbon emissions on climate change with a majority contribution from the construction sector of India, periodical amendments in the building codes and policies have ensured positive changes within the present regime. However, even though regular revisions ensure the successful implementation of sustainable components within the industry, economists and users have detected significant loopholes in amended policies' execution mechanisms.

Notably, flourishing economic development can efficiently be achieved through striking a strategic balance between economic, social, and environmental components of sustainability. The recent developments and innovative construction policies, either through the employment of sustainable components or technology, have enabled the reformation of primitive infrastructure practices in the building sector of India. Recently amended buildings codes and policies for construction of residential and commercial buildings by eminent authorities try to ensure inclusion of operative and widely accepted sustainable components to cull out innovative sustainability goals with major concern towards amending climatic conditions.

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