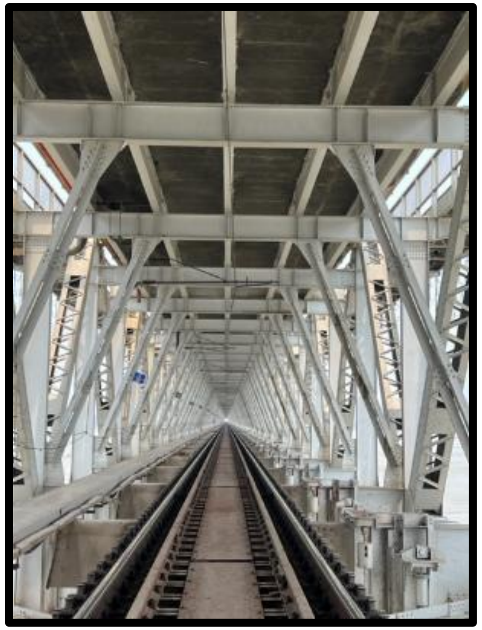
Structural assessment, Repair and Rehabilitation of Mokama bridge

ING-IABSE Workshop on "Design, Construction and Maintenance of Steel Bridges" , Dehradun, 19th & 20th October, 2024

Mr. Jatin Singla is a highly motivated Bridge Design Engineer with over five years of experience. Specializing in concrete and steel bridges for highways and railways, he excels in diverse bridge component design. Currently, he is a Design Engineer at B&S Engineering Consultant Private Limited and a member of the Young Engineering Commission at IABSE Zurich. He is also a young member of various other National & international organizations.

Sumantra Sengupta, born in 1967, received his Ph.D. degree from IIT Guwahati in 2023. His Ph.D. topic was "Studies of Long High-level railway Bridges in High Seismic zone". He completed his graduation in Civil engineering in 1990 and post-graduation in Structural engineering in 1992, both from Jadavpur University, Kolkata. He has 32 years of experience in designing Rail and Road Bridges, Underground Metro Railway stations, Port and Harbour structures, Industrial structures, Stadium structures, PHE structures, Rehabilitation of Bridge structures. His specialisation is in seismic analysis of Bridges.



CONTENT :

1. BACKGROUND & HISTORY OF THE BRIDGE
2. SALIENT FEATURES OF THE PROJECT
3. HISTORY OF REPAIR / REHABILITATIONS CARRIED OUT IN THE PAST
4. STRUCTURAL ASSESSMENT (ESTIMATION OF DEMAND, CAPACITY, FATIGUE LIFE)
5. STRUCTURAL INTERVENTION PROPOSED
6. SUMMARY & CONCLUSIONS

Mokama Bridge – 100km D/S of Patna

1. **No bridge existing between Varanasi Bridge & Harding Bridge – 1000 km distance**
2. **Development in North Bihar was badly affected.**
3. **The bridge site was approved by Sir M. Visvesvaraya**
4. **Ganga Bridge Project (GBP) formed**
5. **Ganga Bridge Construction Company formed by HCC & BBJ who constructed the bridge from 1954 to 1959**


1. Foundation Stone was laid by Dr Rajendra Prasad, 1st President of independent India
2. Bridge was inaugurated by Pt. Jawahar Lal Nehru, 1st Prime Minister of India (1959)

Paper No. 6425

DESIGN, FABRICATION, AND ERECTION OF GANGA BRIDGE, MOKAMEH, INDIA

by

Sidney Turley, B.Sc., A.M.I.C.E.
A Senior Engineer, Messrs Freeman, Fox & Partners, Consulting Engineers

Sadashiv Gangadhar Savarkar
Agent, The Hindustan Construction Company

John Williams
Agent, Messrs Braithwaite, Burn & Jessop Construction Co. Ltd

and

Rathlin John Clinton Tweed, M.A.(Cantab.), M.I.C.E.
Braithwaite & Co. Engineers, Ltd (loaned to The Braithwaite, Burn & Jessop Construction Co. Ltd, to advise on the tender and execution of their portion of the Ganga Bridge contract)

For discussion at an Ordinary Meeting on Tuesday, 26 April, 1960, at 5.30 p.m., and for subsequent written discussion

DISCUSSION ON DESIGN, FABRICATION, AND ERECTION OF GANGA BRIDGE, MOKAMEH, INDIA 81

Paper No. 6425

Design, fabrication, and erection of Ganga Bridge, Mokameh, India†

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Sadashiv Gangadhar Savarkar

John Williams

and

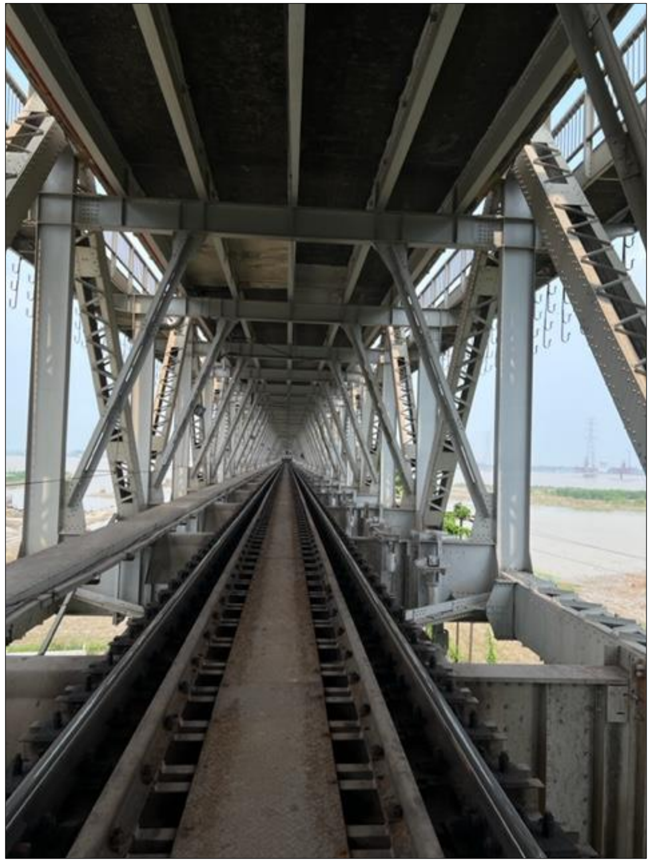
Rathlin John Clinton Tweed, M.A.(Cantab.), M.I.C.E.

Source of information – Papers in ICE, 1960 and As built drawings

Emboss on Bridge

STEEL WORK **SUPPLY & ERECTION BY**
B.B.J
CONSTRUCTION CO. LTD., CALCUTTA
WORK ORDER NO. A/W/O8(1) DATED 29-9-1954
RAILWAY DECK : IRS LOADING BG STANDARD ML OF 1926
ROADWAY DECK : IRC LOADING SINGLE LANE CLASS AA OR TWO LANE CLASS A
1959

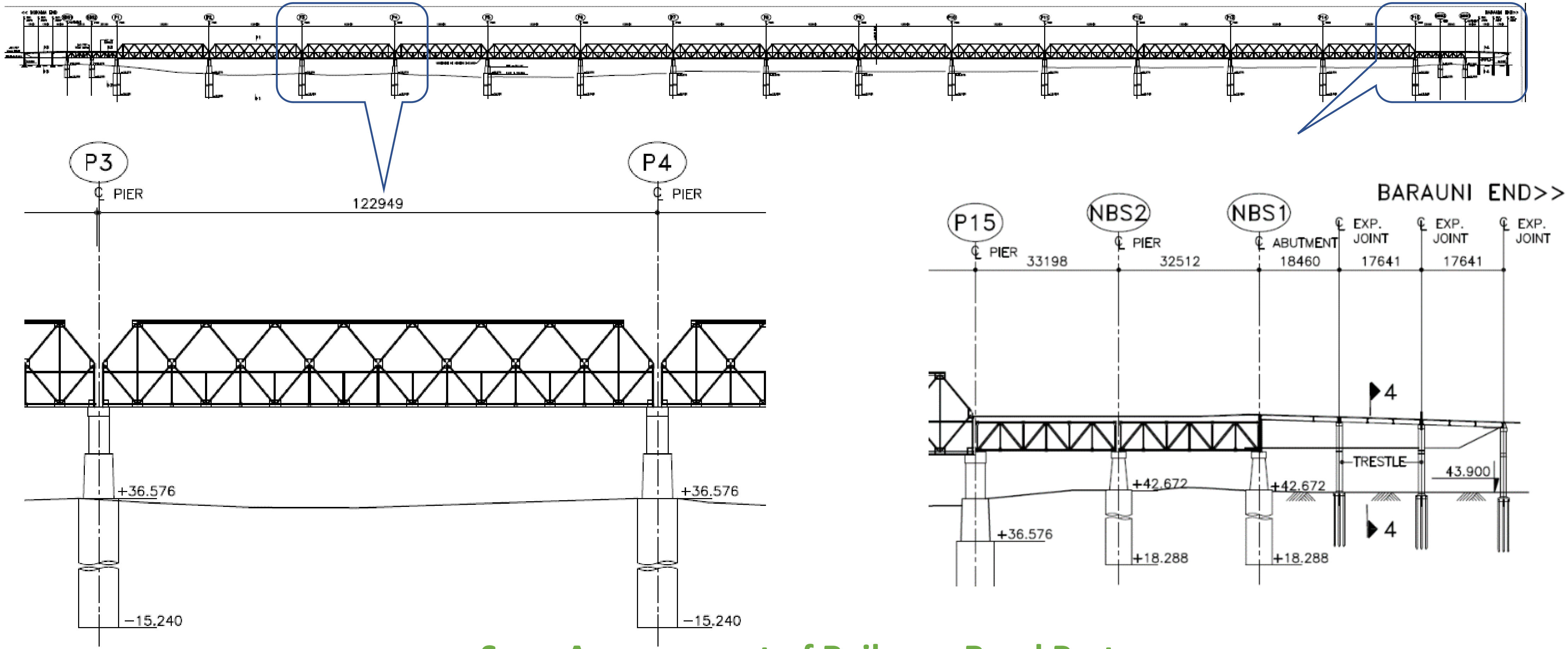
View at Road Level



View at Rail Level

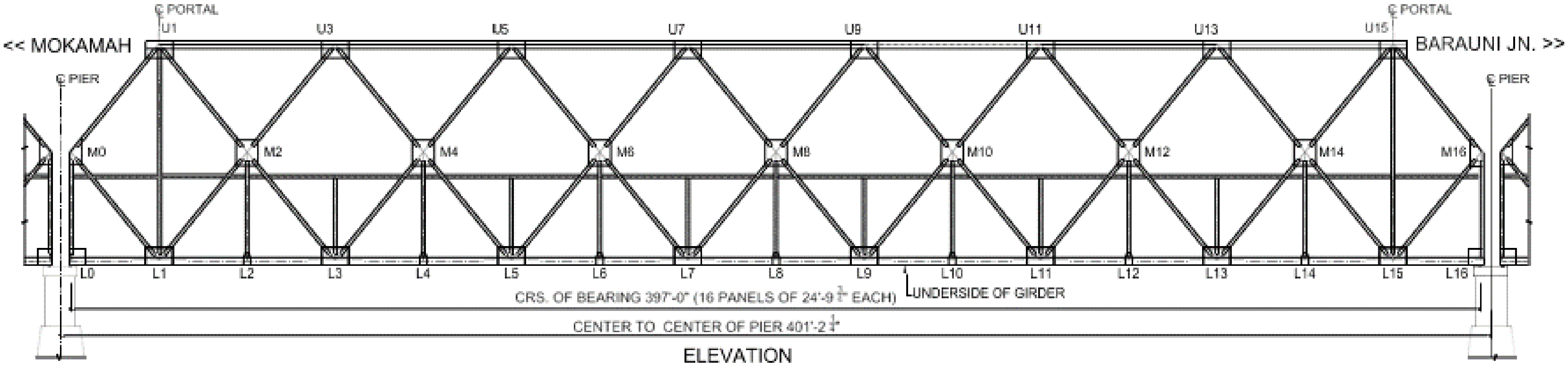
CONTENT :

Salient features of the project – GA drawing

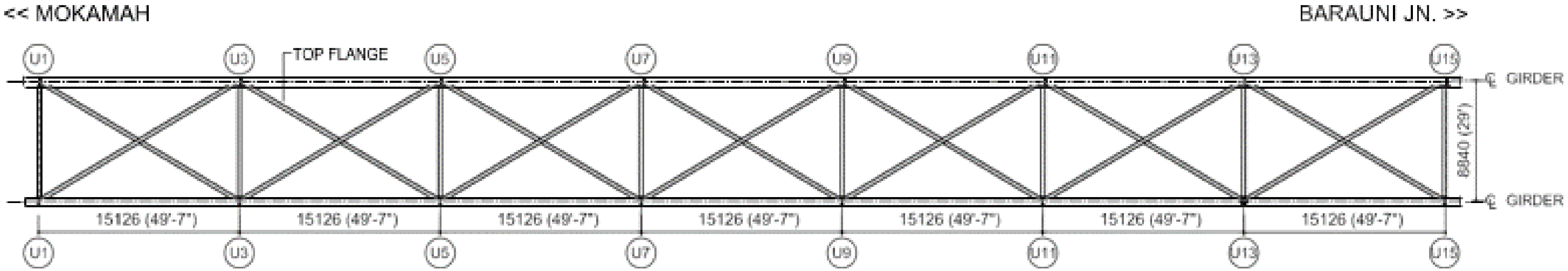


Span Arrangement of Rail cum Road Part :
(32.512m+33.2m) + (14x122.95m) +
(33.2m+32.512m) : (TOTAL LENGTH : 1721.3m)

Salient features of the project
Superstructure detail

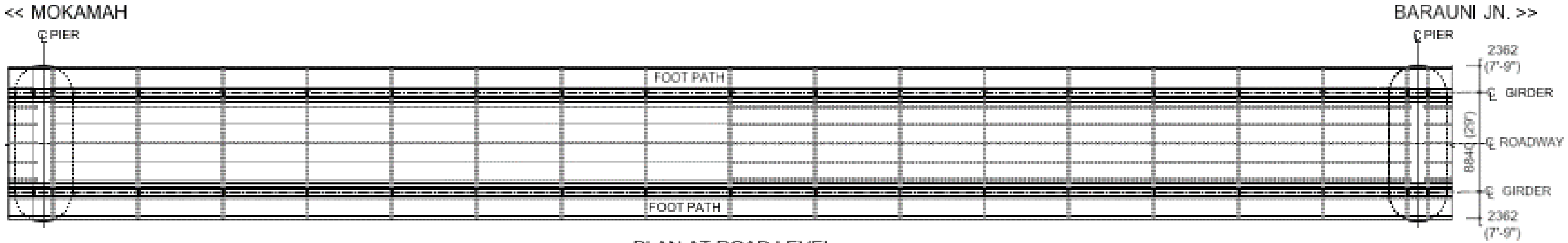


ELEVATION

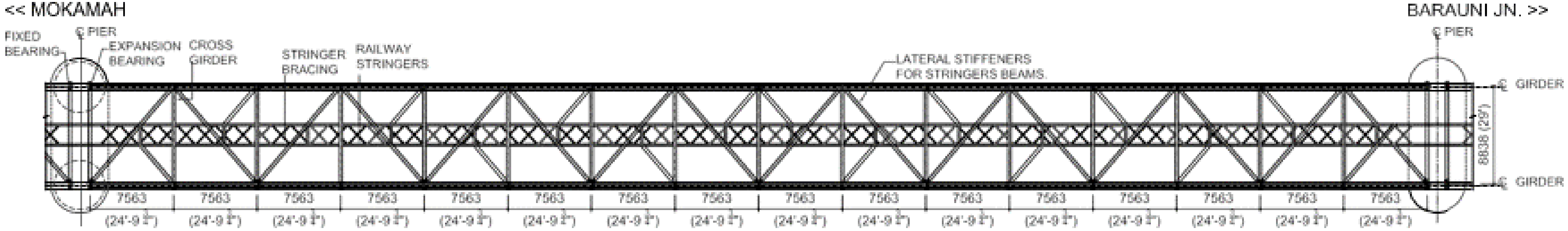


PLAN AT TOP LATERALS

Salient features of the project
Superstructure detail

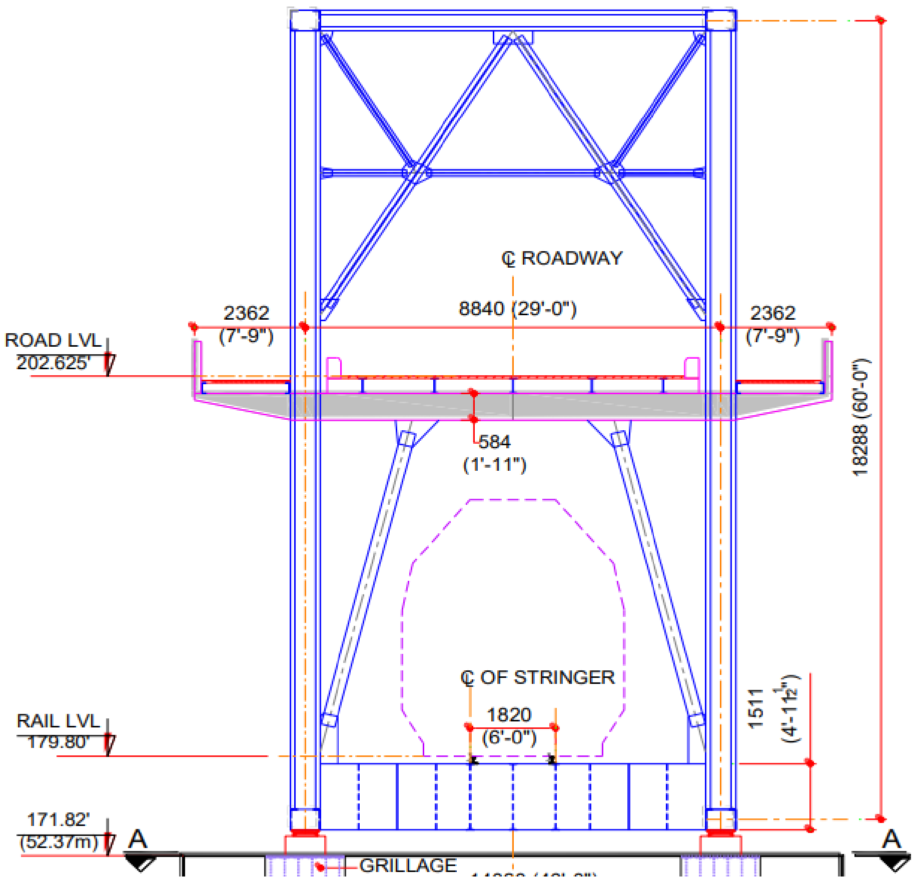


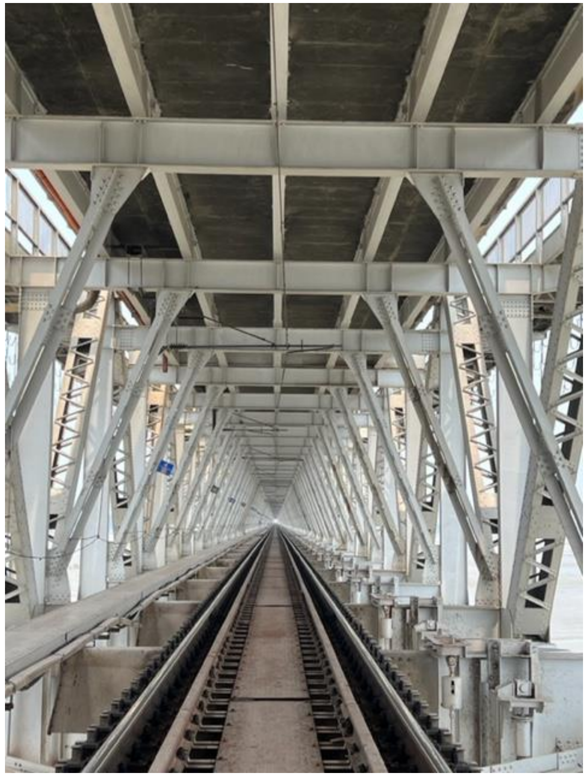
PLAN AT ROAD LEVEL



PLAN AT BOTTOM LATERALS

Salient features of the project
Superstructure detail



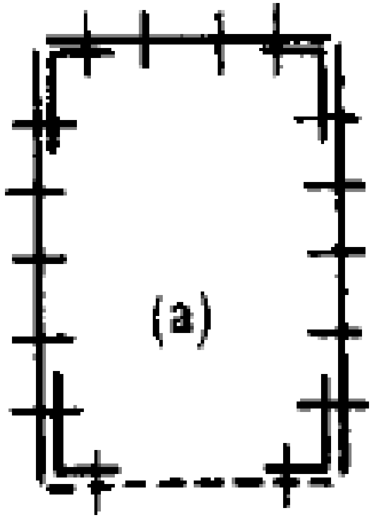


Rail Level

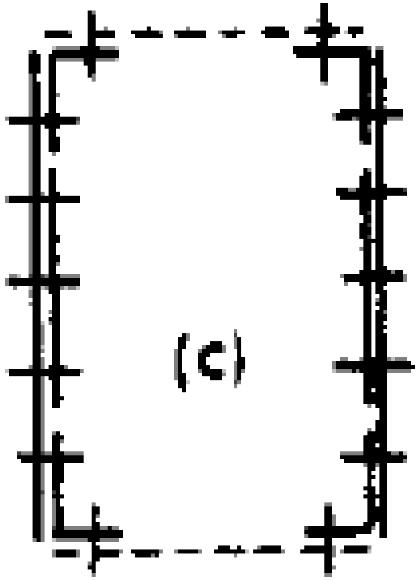
Road Level

Total structural steel – 840 ton per span

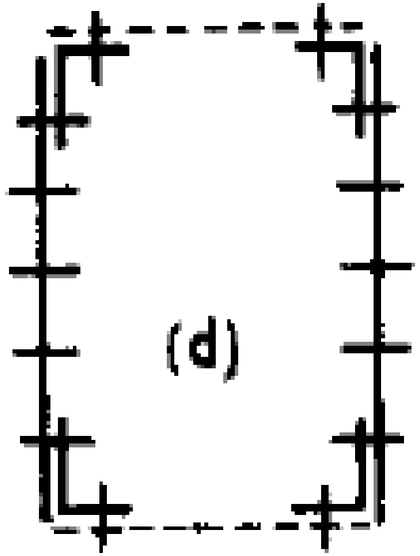
Salient features of the project
Superstructure detail



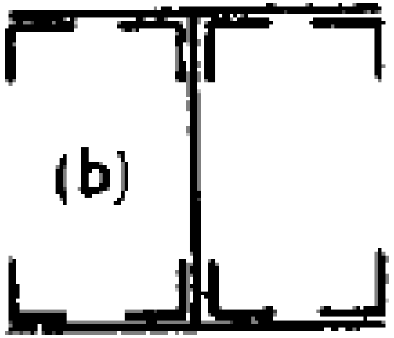
Top Chord



Bottom Chord

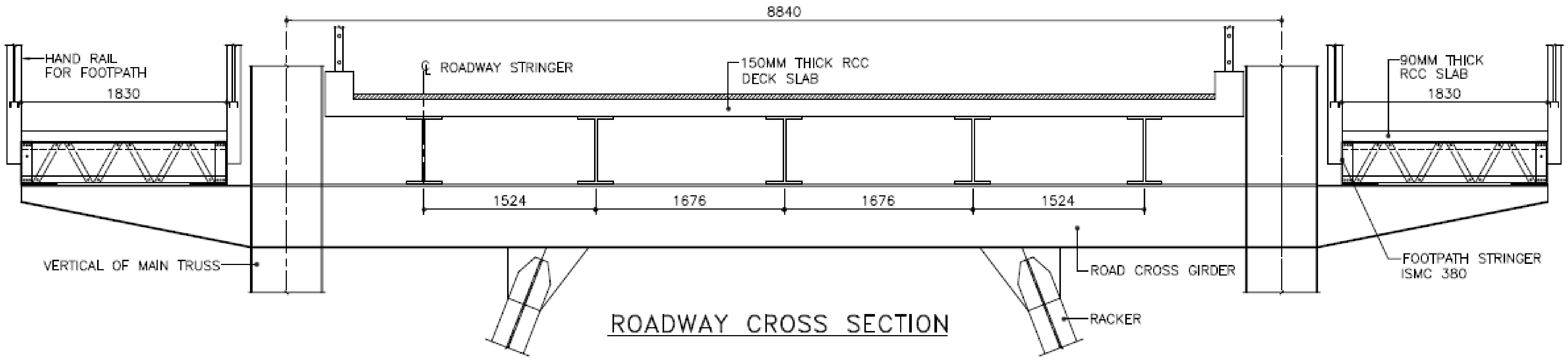


Diagonals



End Verticals

Salient features of the project
Arrangement at Rail level



- 150mm thick deck is monolithic with stringers
- Stringers are resting on top of cross girders
- Cross girders are supported at two ends and on the two rackers
- Two expansion joint at each 121m span in the original design – later those are removed

Salient features of the project
Arrangement at Rail level

- The rail is directly seating over railway stringers, which in turn is supported between the rail cross girders.
- The provision for expansion has been kept at each stringer by providing slotted hole in the seating arrangement of stringer at one end.
- Longitudinal loads on the stringers from braking or traction and earthquake or wind are transmitted to the bottom chords of the main truss by braking girders/ bracing system in every panel.
- Lateral loads on the railway stringers from racking, wind and earthquake are transmitted to the cross girders, by means of a single angle bracing riveted directly to the underside of the stringer top flanges.
- The c/c distance between two rail stringers is 1.676m.

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Salient features of the project
Arrangement at Rail level

Public Works Department, Uttarakhand

ING-IABSE Workshop on "Design, Construction and Maintenance of Steel Bridges" , Dehradun, 19th & 20th October, 2024

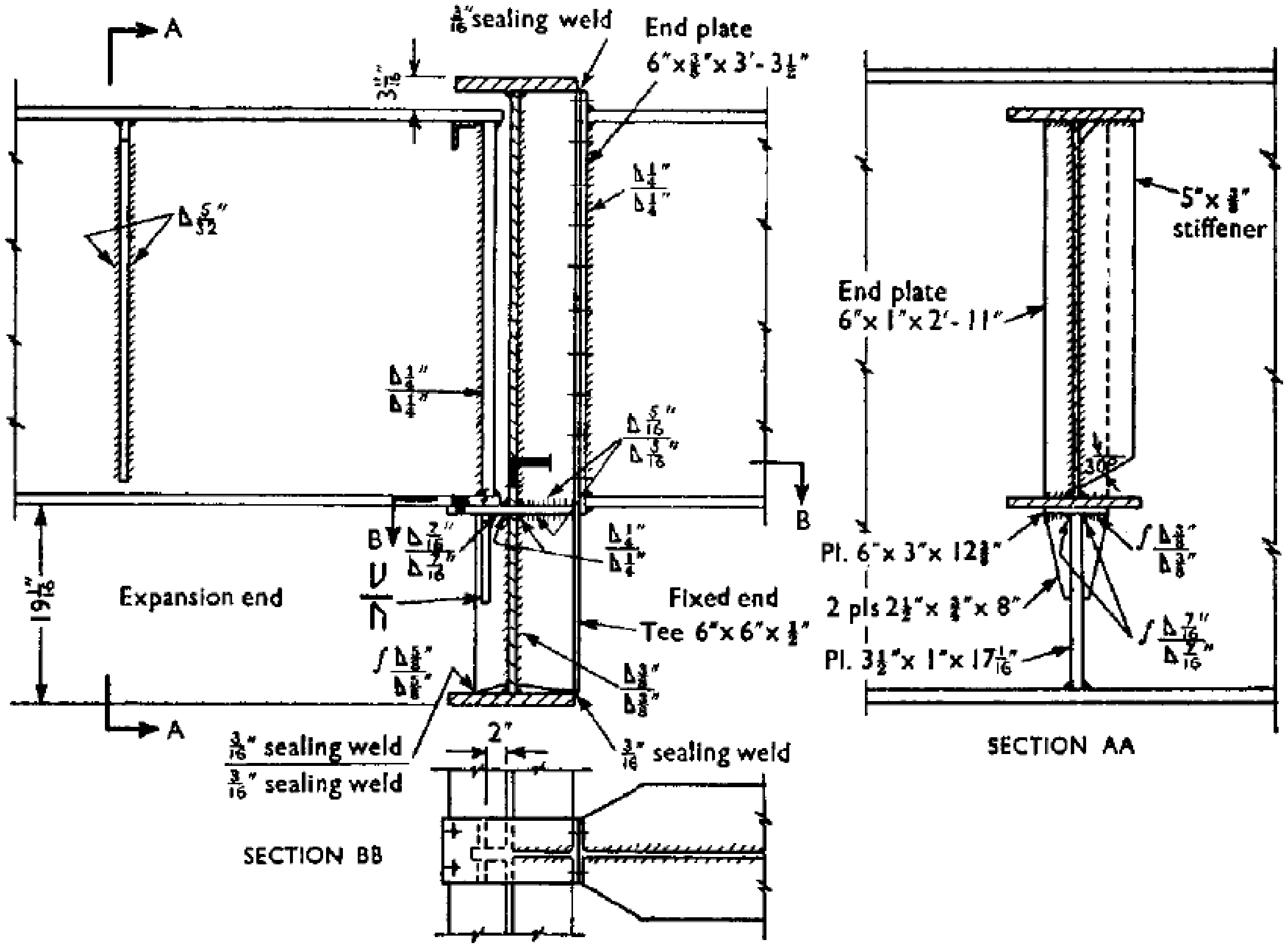

FIG. 9.—CONNEXION OF RAILWAY STRINGER TO CROSS-GIRDER

Salient features of the project
Materal property of Superstructure

- High tensile steel is used for the entire main truss elements. Steel was imported from UK (since sufficient quantity was not available in India).

- Steel Bridge code does not permit use of welding for high tensile steel, hence they are rivetted with high tensile rivets

- The floor system like stringer, cross girders and the rolled section bracing systems in Main Bridge are of Mild steel and they are all welded built-up sections.

- All cross girders and stringers at rail and road level for 30.5m span are rivetted

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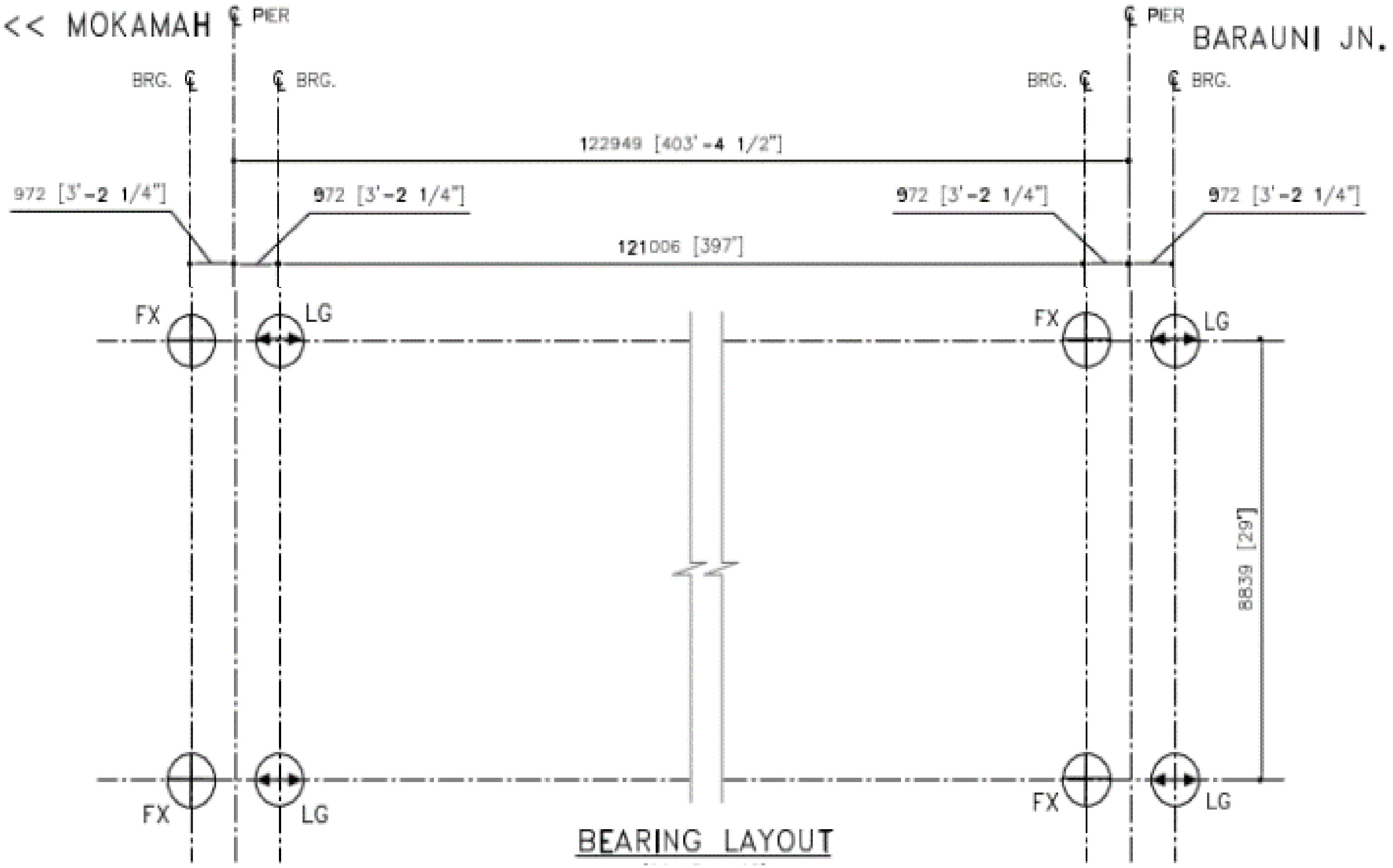
Salient features of the project
Bearing Layout

Public Works Department, Uttarakhand



Salient features of the project
Bearing of 30.5m span

Salient features of the project
Foundation and Substructure

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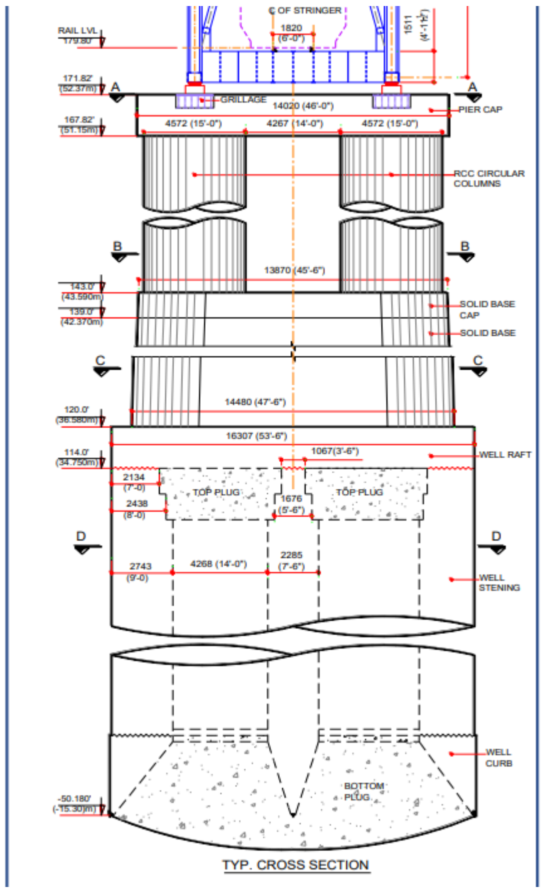
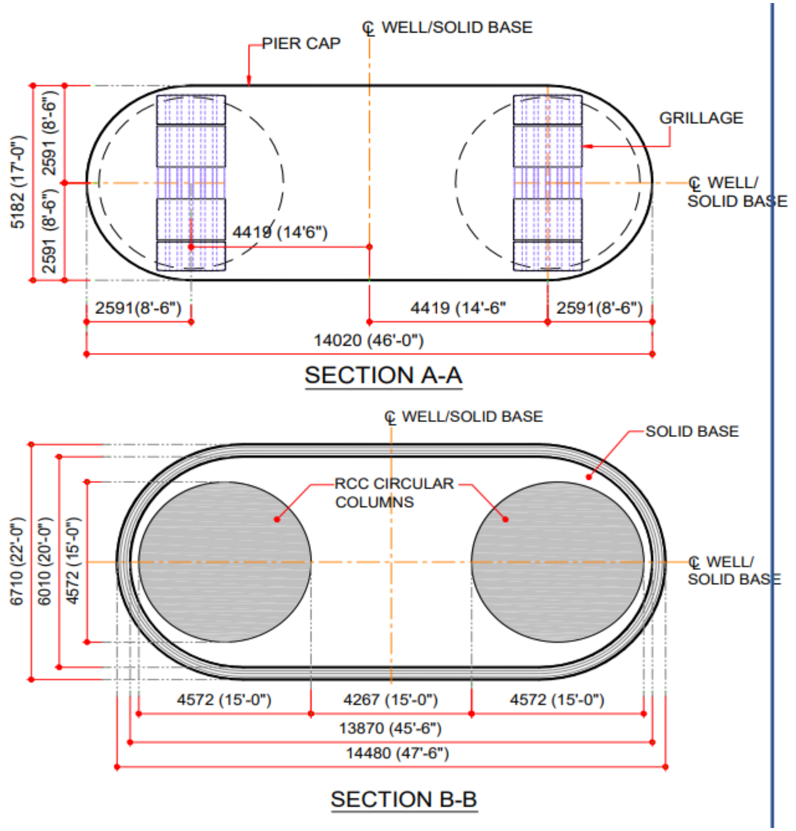
Public Works Department, Uttarakhand

ING-IABSE Workshop on “Design, Construction and Maintenance of Steel Bridges” , Dehradun, 19th & 20th October, 2024





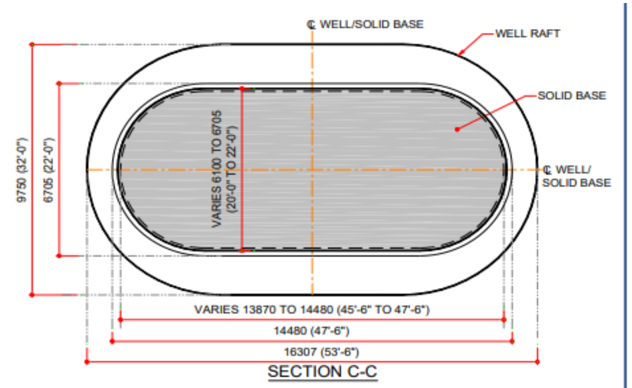
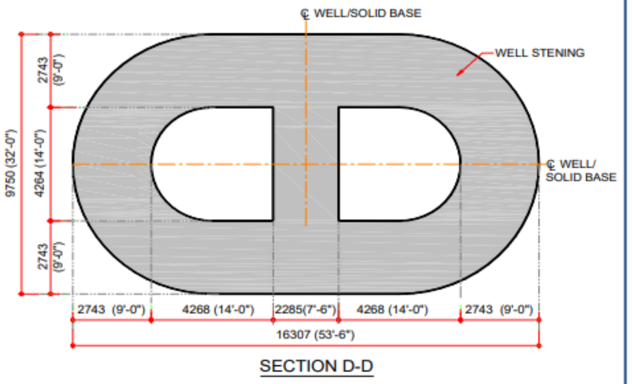
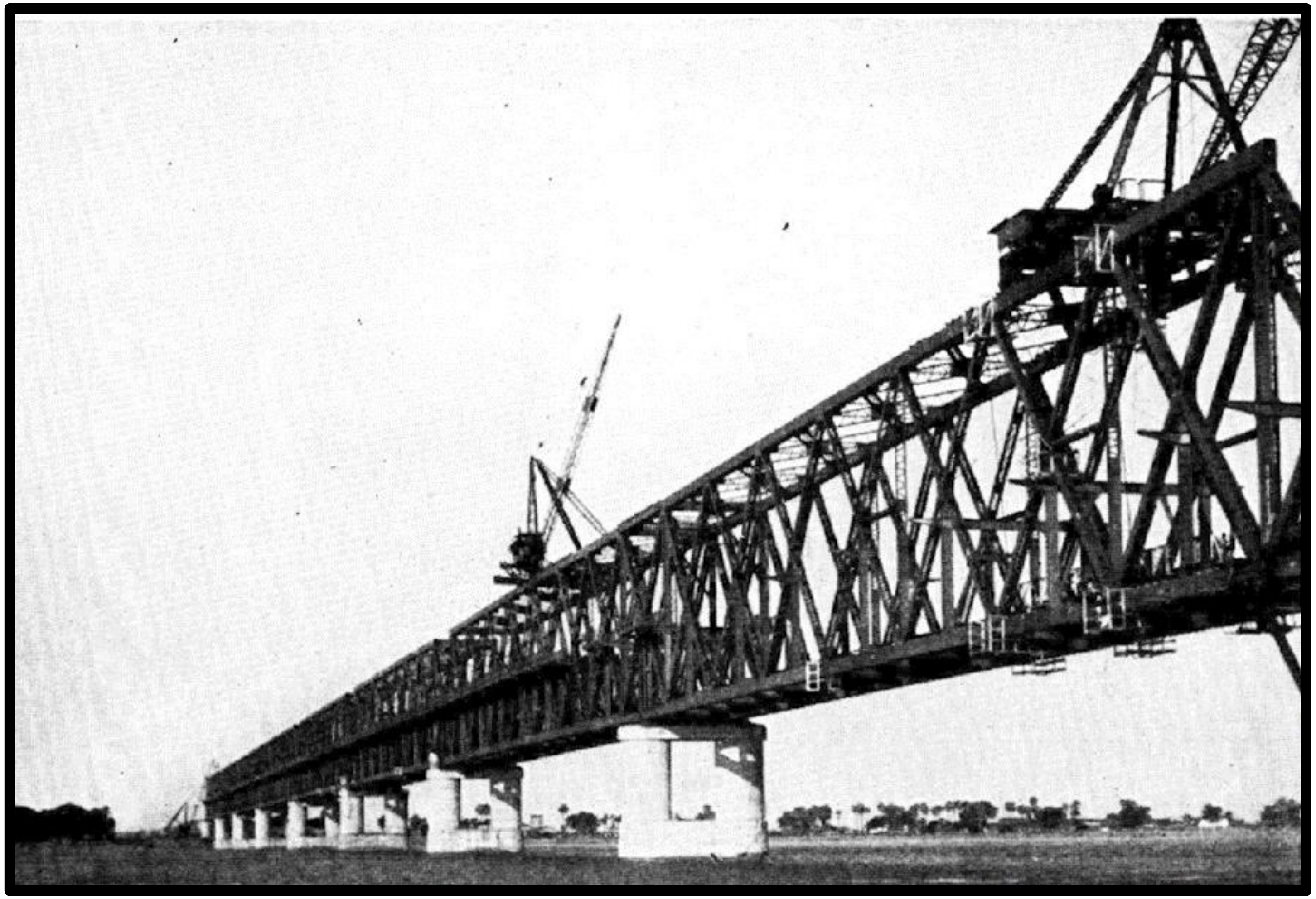


Fig. 1.4 : Typical PLAN at Pier Cap Level & at Pier Level (SECTION A-A, B-B & C-C)



- Double D well foundation – 9.75m x 16.3m in plan ad 54.8m deep, M20 concrete
- RCC twin column substructure – 4.57m diameter each, 8.84m apart, M20 Concrete

Salient features of the project
Cantilever erection



Cantilever erection photograph – Completion of each cantilever erection was hugely celebrated at site

Salient features of the project
Codes and standards followed in design

सत्यमेव जयते

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

BRIDGE RULES
(IN SI UNITS)

RULES SPECIFYING THE LOADS FOR DESIGN OF SUPER-STRUCTURE AND SUB-STRUCTURE OF BRIDGES AND FOR ASSESSMENT OF THE STRENGTH OF EXISTING BRIDGES

ADOPTED –1941
FIRST REVISION - 1964

First Reprinting - 1989
Second Reprinting - 2008
(Incorporating Correction Slips Upto 39)

ISSUED BY

RESEARCH DESIGNS AND STANDARDS ORGANISATION
LUCKNOW - 226011

For Official use only

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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

INDIAN RAILWAY STANDARD

CODE OF PRACTICE FOR THE DESIGN OF SUB-STRUCTURES AND FOUNDATIONS OF BRIDGES

(BRIDGE SUB-STRUCTURES & FOUNDATION CODE)

ADOPTED –1936
INCORPORATING A & C SLIP NO. 22, YEAR : 2003

ISSUED BY

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LUCKNOW - 226011

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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

INDIAN RAILWAY STANDARD

INDIAN RAILWAY STANDARD CODE OF PRACTICE FOR THE DESIGN OF STEEL OR WROUGHT IRON BRIDGES CARRYING RAIL, ROAD OR PEDESTRIAN TRAFFIC

(STEEL BRIDGE CODE)

ADOPTED –1941
INCORPORATING A & C SLIP NO. 17, YEAR : 2003

ISSUED BY

RESEARCH DESIGNS AND STANDARDS ORGANISATION
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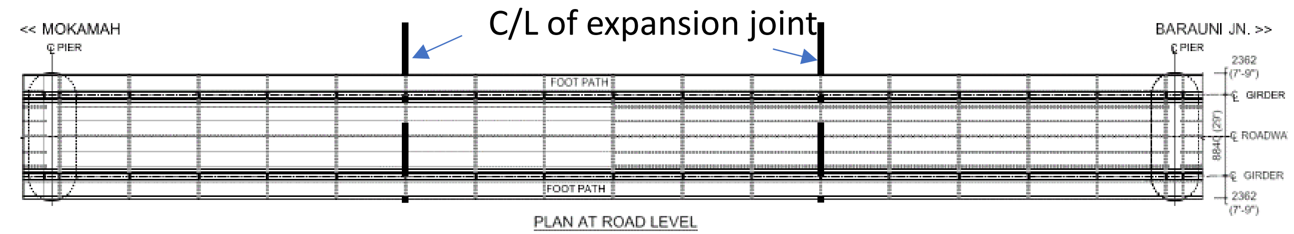
CONTENT :

History of repair
Crack in cross girder at expansion joint

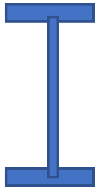
- In 2011, CSIR-SERC was engaged for structural audit
- Crack observed since 1992 at the junction of cross girder and rackers connection at the expansion joint location
- Investigation of CSIR reveals the reason behind crack is the eccentric loading
- Undulated and damaged road surface caused excessive vibration
- Repair measure was suggested by CSIR along with restricted loading



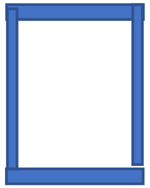
History of repair

Crack in cross girder at expansion joint

- Replacement of the damaged cross girders at the road level at stringer expansion joint location by providing box section instead of existing I section.
- Replacement of the damaged connection between the rakers and the cross girders at the stringer expansion joint location
- Repair of damaged stringer ends at the support location near stringer expansion joint location



Original cross girder



Proposed cross girder

Proposal of CSIR

History of repair
Crack in cross girder at expansion joint

- The damaged road cross girders at the stringer expansion joint location has been replaced by I section instead of proposed box section and the stringers are made continuous by removing the expansion joint

- This made the expansion at the road deck level redundant. However, the existing expansion joints at the deck level as such didn't have any purpose as the stringers at their continuous support are having unyielding connection and not allowed to move longitudinally over the cross girders

Repair done by ECR

History of repair

For 30m span

- Rail level cross girders repaired/ replaced and metalizing done for the new ones
- Rail level stringers top flange angle 125x125x12 replaced
- Rail level stringer top lateral bracing angle 75x75x10 replaced

For main span

- Existing cross-girder webs strengthened

CONTENT :

Original design load

1. Dead load of superstructure

Steel = 840 t

Track = 25 t

Concrete = 575 t

Services = 60 t

Total = 1500 t

2. Railway live-load

Broad guage standard main line, single track (BGML of 1926)

3. Highway live-load

24ft(7.32m) -wide roadway carrying a single lane of class AA or two lanes of class A highway loading.

New design load

1. Dead load of superstructure

- Steel = 840 t
- Track = 75 t
- Concrete = 575 t
- Services = 60 t

due to the change in sleeper from wooden to steel and the change in rail weight

Total = 1550 t

2. Railway live-load

Broad guage 25T loading - 2008

3. Highway live-load

24ft(7.32m) -wide roadway carrying a single lane of class AA/ Class 70R or two lanes of class A highway loading.

Original design load

4. Footway live-load

Two footways, 6ft(1.83M) wide carrying 40lb/sqft(195kg/sqm) for the design of main truss

5. Wind load

20 lb/sqft (100kg/sqm) with highway and footway live loads in the bridge.

6. Seismic load

Seismic coefficient Ah = 1/g = 0.1(for trans. & Longitudinal direction)

Seismic coefficient Av = 0.5 X 1/g = 0.05 (for vertical direction)

New design load

4. Footway live-load

Two footways, 6ft(1.83M) wide carrying 40lb/sqft(195kg/sqm) for the design of main truss

5. Wind load

20 lb/sqft (100kg/sqm) with highway and footway live loads in the bridge.

6. Seismic load

Seismic coefficient Aht = 0.0721(for transverse direction)

Seismic coefficient Ahl = 0.225(for longitudinal direction)

Seismic coefficient Av = 0.5 X 0.13 = 0.065 (for vertical direction)

Original design load

7. Braking force

Braking force on roadway is governed by class-A vehicle = 25 T

Braking force on railway due to BGML-1926 = 95 T

8. Racking force

The racking force as per IRS bridge rule code = 600 KG/M**

*(** The racking force to be considered for the design of lateral bracings of the railway deck only and not for main truss members)*

New design load

7. Braking force

Braking force on roadway is governed by class-70(W) = 40 T

Braking force on railway due to 25T loading -2008 = 182 T

8. Racking force

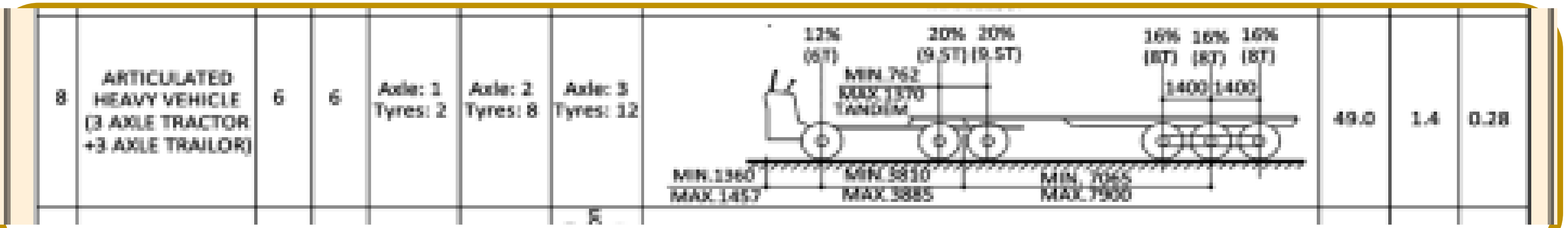
The racking force as per IRS bridge rule code = 600 KG/M**

*(** The racking force to be considered for the design of lateral bracings of the railway deck only and not for main truss members)*

Design Philosophy

- Working stress method has been adopted for the design check as IRS steel bridge code recommends the same
- DL, LL, Wind Load and Seismic load have been considered for the design check
- SV loading not considered, as the same is not being envisaged on the bridge. This will be ensured by regulation.
- Congestion factor has been considered for the new loading
- IRC SP37 commercial vehicle loading has been considered including the overloading factor – bumper to bumper with no IF and normal load position with IF

IRC SP 37 Loading



Governing Load Case

Table-2 Classification of Commercial Vehicles

CLASSIFICATION OF COMMERCIAL VEHICLES

Sr. No	TYPE Description	Type No.	Total No. of axles	Axle/Tyre Arrangement – Tractor – Front End	Axle/Tyre Arrangement – Tractor – Rear End	Axle/Tyre Arrangement – Trailor – Rear End	Configuration & Distribution of Total Load (Nominal GVW)	Nominal GVW (Tonne)	Recommended Overload Factor	Standard Deviation
1	LIGHT VEHICLE	1					TWO WHEELERS. THREE WHEELERS PASSENGER AND GOODS VEHICLES			
2	RIGID LIGHT COMMERCIAL VEHICLE	2A	2	Axle: 1 Tyres: 2	Axle: 1 Tyres: 2	–	50% (6T); 50% (6T); 1044, 3365, 1570; 5979	12.0	1.4	0.32
3	RIGID MEDIUM COMMERCIAL VEHICLE	2B	2	Axle: 1 Tyres: 2	Axle: 1 Tyres: 4	–	37% (6T); 63% (10.2T); 1260, MIN. 2515 MAX.4855, 1120; MIN. 4895 MAX.7235	16.2	1.4	–
4	RIGID HEAVY COMMERCIAL VEHICLE	3A	3	Axle: 1 Tyres: 2	Axle: 2 Tyres: 8	–	24%(6T); 38% (9.5T); 38% (9.5T); 1400 TANDEM; 1502, MIN. 3683 MAX.5182, 2540; MIN. 7725 MAX.9224	25.0	1.4	0.29
5	ARTICULATED HEAVY VEHICLE (2 AXLE TRACTOR +1 AXLE TRAILOR)	3B	3	Axle: 1 Tyres: 2	Axle: 1 Tyres: 4	Axle: 1 Tyres: 4	22% (6T); 39% (10.2T); 39% (10.2T); 1457, MIN.3023 MAX.3300, 4050; MIN.8530 MAX.8807	26.4	1.4	0.32
6	ARTICULATED HEAVY VEHICLE (2 AXLE TRACTOR +2 AXLE TRAILOR)	4	4	Axle: 1 Tyres: 2	Axle: 1 Tyres: 4	Axle: 2 Tyres: 8	16% (6T); 30% (10.2T); 27% (9.5T); 27% (9.5T); 700, 700; 1457, MIN.3023 MAX.3300, 4700, 1400 TANDEM; MIN.9880 MAX.10157	35.2	1.4	0.55
7	ARTICULATED HEAVY VEHICLE (2 AXLE TRACTOR + 3 AXLE TRAILOR)	5	5	Axle: 1 Tyres: 2	Axle: 1 Tyres: 4	Axle: 3 Tyres: 12	15% (6T); 25% (10.2T); 20% (8T); 20% (8T); 20% (8T); 1400 1400; 1457, MIN.3023 MAX.3300, 5350; MIN. 11230 MAX.11507	40.2	1.4	–
8	ARTICULATED HEAVY VEHICLE (3 AXLE TRACTOR +3 AXLE TRAILOR)	6	6	Axle: 1 Tyres: 2	Axle: 2 Tyres: 8	Axle: 3 Tyres: 12	12% (6T); 20% (9.5T); 20% (9.5T); 16% (8T); 16% (8T); 16% (8T); MIN.762 MAX.1370 TANDEM; 1400 1400; MIN.1360 MAX.1457, MIN.3810 MAX.3885, MIN. 7065 MAX.7900	49.0	1.4	0.28
9	MULTI AXLE HEAVY VEHICLE	Multiaxle	15	Axle: 1 Tyres: 2	Axle: 2 Tyres: 8	Multiaxle 4 Tyres each no. of axle (depending on design weight carried)	4% (6T); 6.5% (9.5T); 6.5% (9.5T); (6.9% x 12 (10.2T x 12no @ 1300c/c); 381, 381 TANDEM; 1457, 3810, 7900; 1300 (x11)	147.4	Not Applicable	–

NOTES

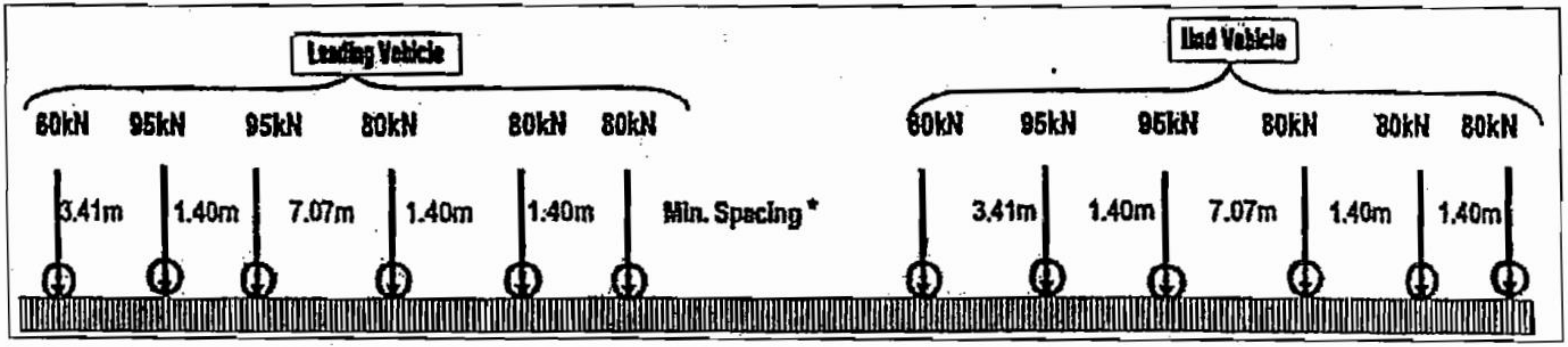
1 For Transverse spacing and types refer Fig. 2.

2 Recommended overload factors are based on recent surveys carried around in different cities on same stretches of National Highway/State Highway and are the mean overload factors. These can be modified as per local conditions.

3 Overload factor for design checks can be taken as recommended in Table-2 for long span bridges likely to carry more then one GVW class vehicle under consideration for maximum live load effect.For small spans carrying one vehicle the LL/DL ratio is high and effect of LL should be checked for overload factor of (1.4+1.65x standard deviation)

IRC SP 37 Loading

(1) GVW Class 49 Ton Vehicle

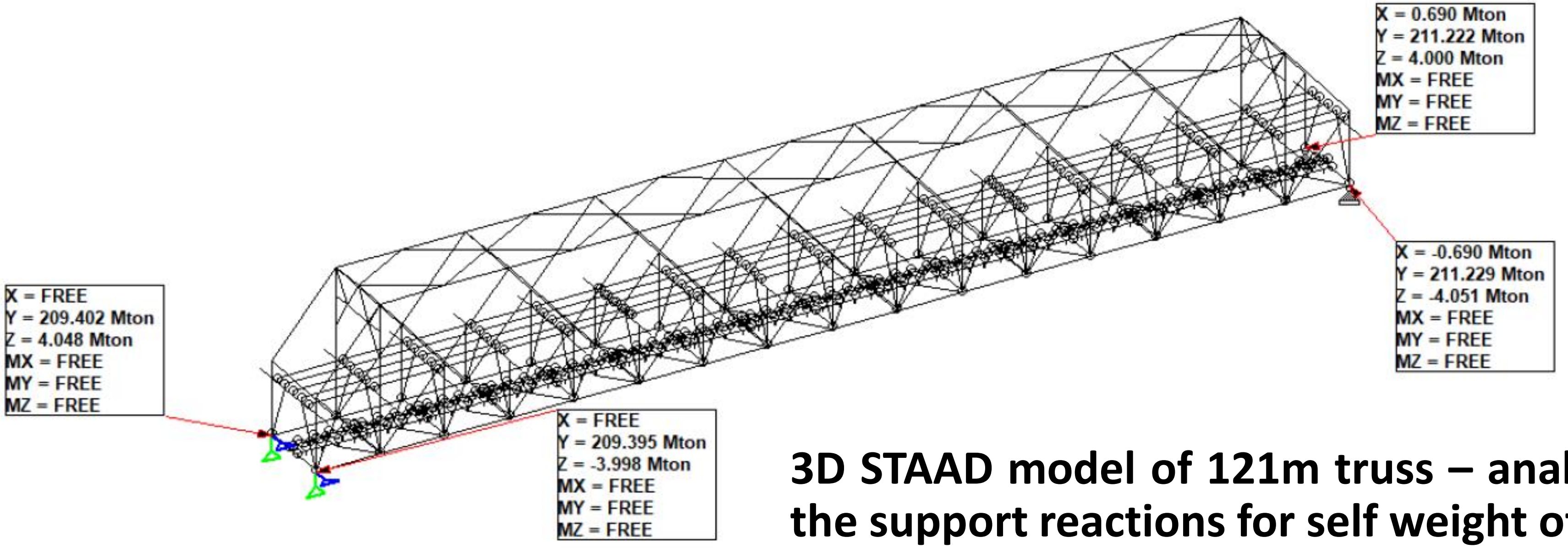


Minimum spacing between rear and front axles of two successive vehicles

For moving traffic condition	=	20.0 m (with impact)
For crowded/Traffic Jam condition	=	4.0 m (without impact)

Design Pholosophy

- 3D model of the truss has been prepared and analysed for all loads
- Analysis has been performed for the new loading and the design forces (Demand) are obtained which has been compared with the Capacity of the section. If the Demand vs Capacity is more than unity, overstressing is expected and the members are identified separately



3D STAAD model of 121m truss – analysis results showing the support reactions for self weight of structural steel

Overstressed Members

1) STRESS SUMMERY OF 121M SPAN (FOR NEW LOADING)

STRESS SUMMARY OF MAIN TRUSS MEMBERS:

MEMBER DESCRIPTION			ACTUAL STRESS (ton/sq. Inch)				PERMISSIBLE STRESS (ton/sq. Inch)				INTERACTION RATIO			
			COMB1*		COMB2*		COMB1*		COMB2*		COMB1*		COMB2*	
			Comp.	Tens.	Comp.	Tens.	Comp.	Tens.	Comp.	Tens.	Comp.	Tens.	Comp.	Tens.
DIAGONALS	D2	D2X		12.5		13.6		12.4		14.5		1.01		0.94
	D10	D10X		12.5		12.8		12.4		14.5		1.01		0.88
	D1,D1X, D1A & D1AX		10.3		11.2		10.1	12.4	11.8	14.5	1.02		0.95	
	D3	D3X		12.8		13.3		12.4		14.5		1.03		0.92

Members identified where Demand vs Capacity is more than unity and thus overstressing is expected

(Diagonals of 121m span OWG)

Overstressed Members

STRESS SUMMARY OF STRINGERS & CROSS GIRDERS:

MEMBER DESCRIPTION		COMB1			COMB2			PERMISSIBLE STRESS (ton/sq.inch)				INTERACTION RATIO			
		Shear Stress (ton/ sq.inch)	Bending Stress (ton/sq.inch)		Shear Stress (ton/ sq.inch)	Bending Stress (ton/sq.inch)		COMB1*		COMB2*		COMB1*		COMB2*	
			M_x	M_y		M_x	M_y	Shear	Bending	Shear	Bending	Shear	Bending	Shear	Bending
ROAD CROSS GIRDER	R3	4.9	6.6	4.3	5.2	7.3	4.4	5.5	9.5	6.4	11.08	0.89	1.03	0.82	0.96
	R5	5.2	6.7	4.5	5.3	7.7	4.6	5.5	9.5	6.4	11.08	0.94	1.06	0.83	1.01
	R7	5.2	6.6	5.5	5.3	7.8	5.7	5.5	9.5	6.4	11.08	0.94	1.15	0.83	1.11
	R9	5.1	6.4	5.6	5.3	7.5	5.6	5.5	9.5	6.4	11.08	0.93	1.14	0.83	1.08
	R11	5.2	6.7	5.6	5.3	7.5	5.7	5.5	9.5	6.4	11.08	0.94	1.16	0.83	1.09
	R13	5.2	6.8	4.1	5.4	7.2	4.1	5.5	9.5	6.4	11.08	0.95	1.03	0.84	0.93
	R15	4.9	6.7	4.1	5.7	8.2	4.2	5.5	9.5	6.4	11.08	0.90	1.02	0.89	1.02
ROAD STRINGER	S15	4.1	9.0	0.6	4.1	9.2	0.8	5.5	9.5	6.4	11.08	0.74	1.01	0.64	0.90
	S17	3.9	9.1	0.5	3.9	9.3	0.5	5.5	9.5	6.4	11.08	0.70	1.00	0.61	0.88
	S18	3.9	9.1	0.5	3.9	9.3	0.7	5.5	9.5	6.4	11.08	0.70	1.01	0.61	0.90
	S19	4.0	9.3	0.5	4.0	9.5	0.8	5.5	9.5	6.4	11.08	0.73	1.03	0.63	0.92
	S20	3.8	9.3	0.5	3.8	9.5	0.8	5.5	9.5	6.4	11.08	0.69	1.03	0.60	0.92
	S21	3.8	9.1	0.5	3.8	9.2	0.8	5.5	9.5	6.4	11.08	0.69	1.01	0.59	0.90
	S22	4.0	9.1	0.5	4.0	9.2	0.5	5.5	9.5	6.4	11.08	0.73	1.01	0.63	0.88

Members identified where Demand vs Capacity is more than unity and thus overstressing is expected

(Road cross girder and stringer of 121m span OWG)

Overstressed Members

2) STRESS SUMMERY OF 30M SPAN (FOR NEW LOADING)

NO MEMBER OF THIS BRIDGE IS OVER STRESSED

3) STRESS SUMMERY OF 19M SPAN (FOR NEW LOADING)

		Bending Moment (tm)				Load Combinations			Actual Stress (ton/sq.inch)		Perm. Stress (ton/sq.inch)		Interaction Ratio	
S.No.	Stringer	D.L	FPLL LL	Wind Load	Live Load	Comb-1	Comb-2	Section Modulus (inch^3)	Comb-1	Comb-2	Comb-1	Comb-2	Comb-1	Comb-2
1	S1	89.471	22.751	6.743	100.69	212.91	219.65	789.62	10.26	10.95	9.50	11.10	1.08	0.96

Members identified where Demand vs Capacity is more than unity and thus overstressing is expected

(Stringer of 19m span)

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Overstressed Members

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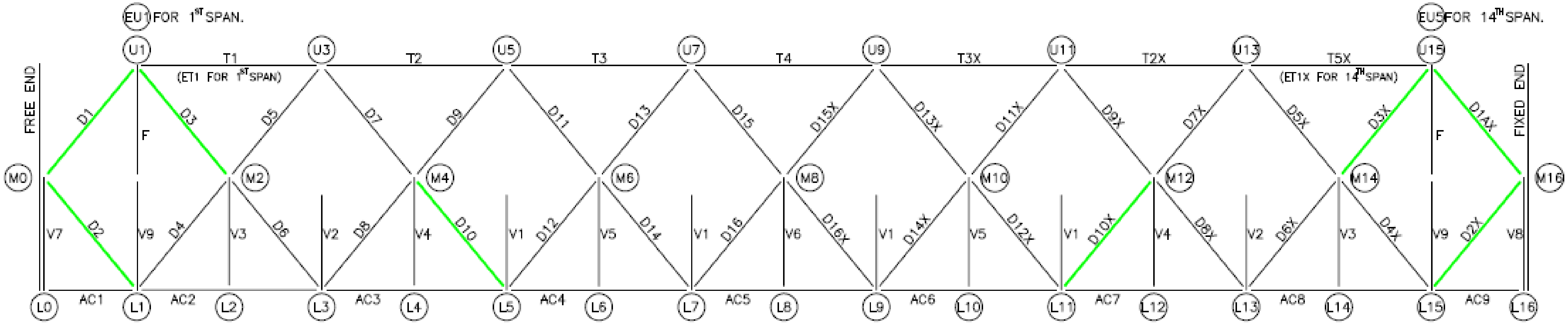
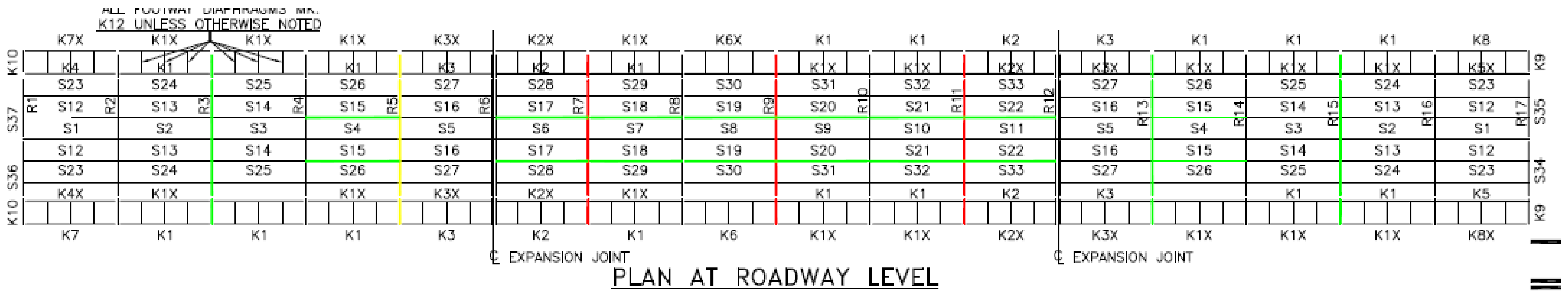




Members identified where Demand vs Capacity is more than unity and thus overstressing is expected (121m span)

Failure Range :		
1	upto 5) %	
2	(5-10) %	
3	(More than10) %	

Bearing Load – Old loading and New loading

COMPARISON OF BEARING LOADS FOR OLD AND PRESENT LOADING

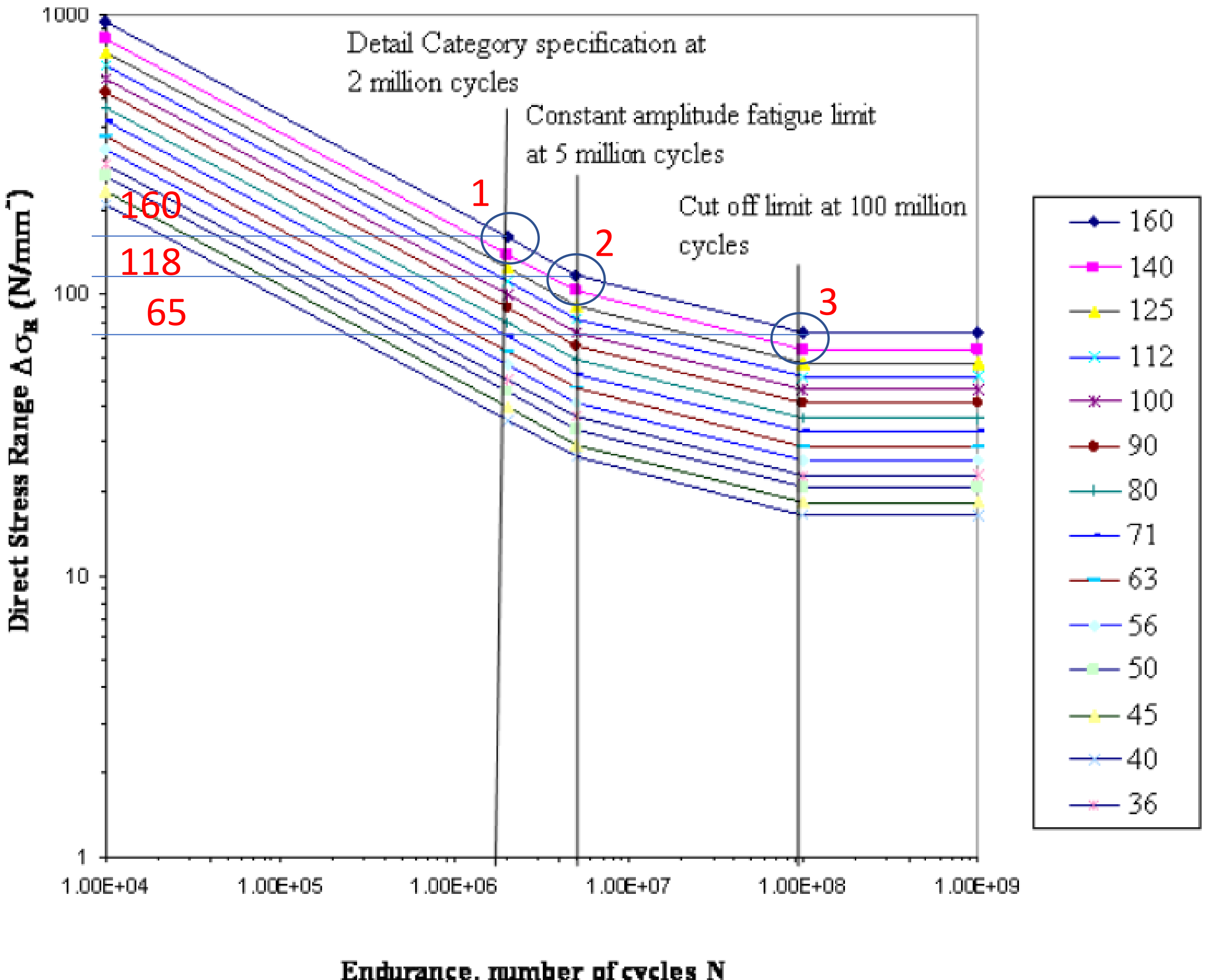
			OLD LOADING (t)		NEW LOADING (t)	
			LG	FX	LG	FX
NORMAL CASE	VERTICAL	MAX.	812	812	892	892
		PERMANENT	376	376	388	388
		MIN.	376	376	388	388
	TRANSVERSE		-	-	-	-
	LONGITUDINAL		-	58	-	114
WIND CASE	VERTICAL	MAX.	864	890	944	974
		MIN.	320	292	332	306
	TRANSVERSE		45	45	45	45
	LONGITUDINAL		-	282	-	338
SEISMIC LONG.	VERTICAL	MAX.	620	620	612	620
		MIN.	348	348	366	362
	TRANSVERSE		0	0	14	14
	LONG.		-	104	-	252
SEISMIC TRANS.	VERTICAL	MAX.	664	694	634	658
		MIN.	304	272	344	324
	TRANSVERSE		58	58	42	42
	LONG.		-	284	-	274

Assessment of Residual Fatigue Life

Structural assessment (Estimation of demand, capacity, Fatigue life)

Residual Fatigue Life of All Members of 121 m span		
S.No.	Member Description	Residual Fatigue Life
1	Top Chord	543 years
2	Bottom Chord	496 years
3	Diagonal Chord	167 years
4	Vertical Chord	500 years
5	Rail Stringer	90 years
6	Rail Cross Girder	1513 years
7	Connection between Stringer & Cross Girder: A. At central cross girder location B. Other location	Failed 90 years
8	Roadway Stringer	22 years
9	Road Cross Girder	150 years

S-N curve for direct stress



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Detail Category

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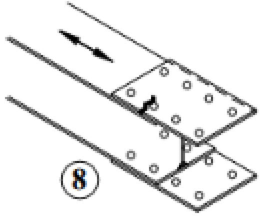
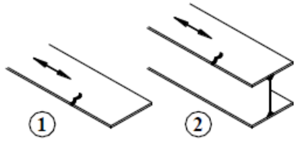
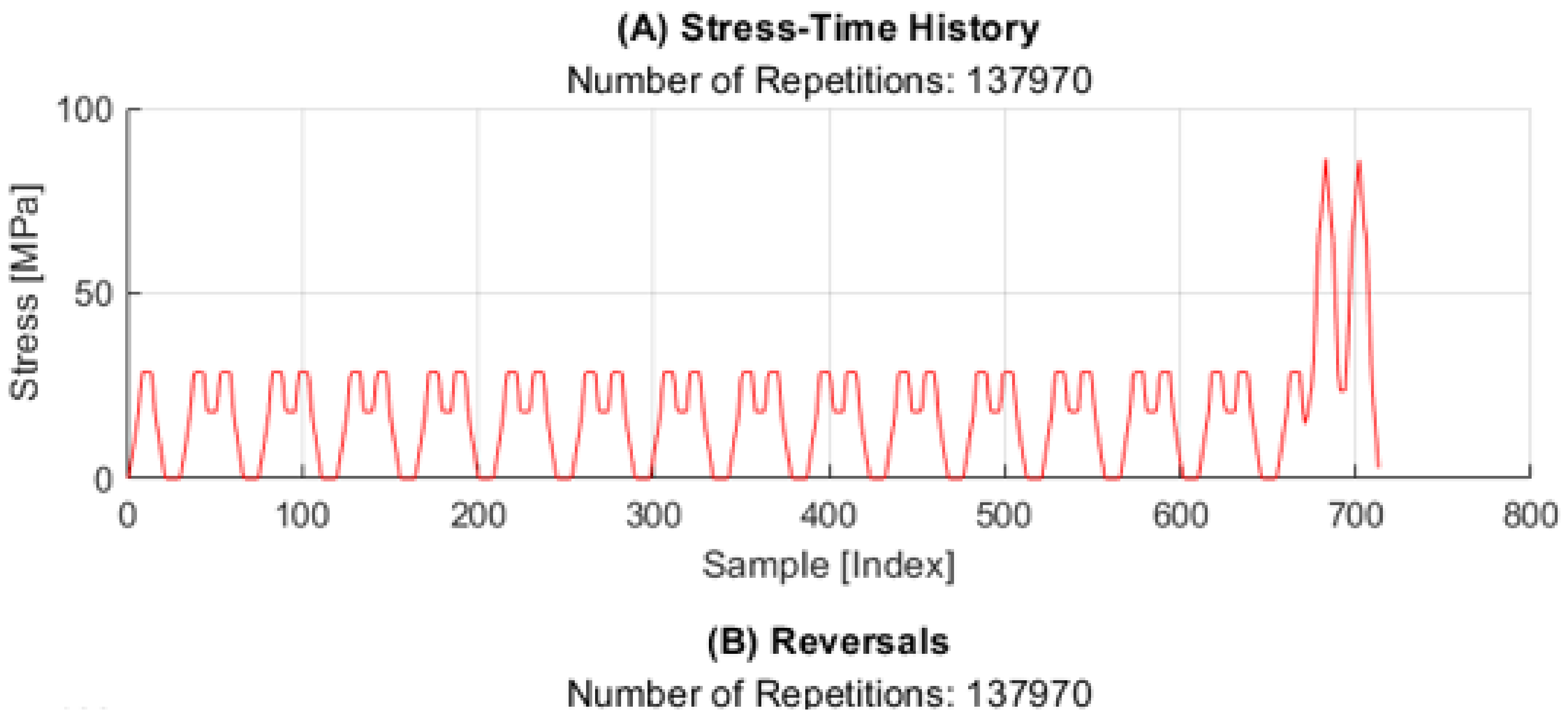
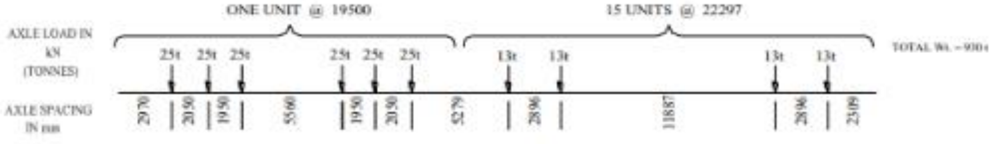
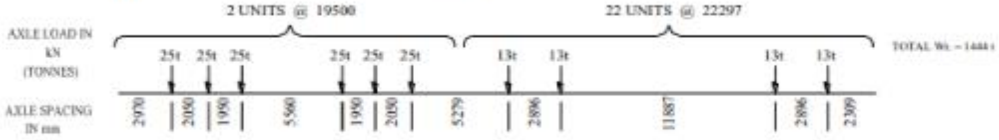
80		8) One sided connection with fitted bolts or rivets.	8) $\Delta\sigma$ to be calculated on the net cross-section.
160	NOTE: The fatigue strength curve associated with category 160 is the highest. No detail can reach a better fatigue strength at any number of cycles. 	Rolled and extruded products: 1) Plates and flats 2) Rolled sections	Details 1) to 2) Sharp edges, surface and rolling flaws to be improved by grinding until removed and smooth transition achieved.

Real life complex stress history



Fatigue Loading

Table 1 (b) Train Formation details in traffic Model for 25t. Loading-2008

Train type	Composition	Train Length Ist. to Last axle (m)	Total Weight (t)	Diagram
Type - 1	1L+15 ICF COACH (Non AC)	348.676	930	1. PASSENGER TRAIN ONE 25 t. LOCO + 15 ICF COACH NON AC 
Type - 2	2+22 ICF COACH (Non AC)	524.255	1444	2. PASSENGER TRAIN TWO 25 t. LOCO + 22 ICF COACH NON AC 

(Contd.)

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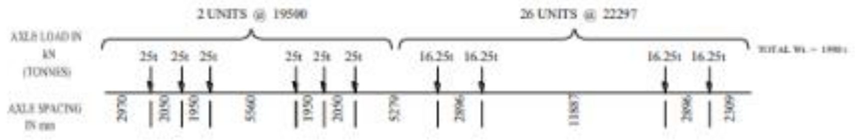
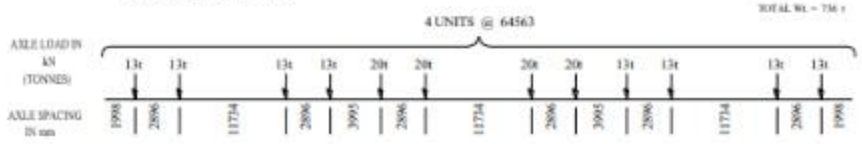
Fatigue Loading

Public Works Department, Uttarakhand

(Contd.)

Table 1 (b) Train Formation details in traffic Model for 25t. Loading–2008

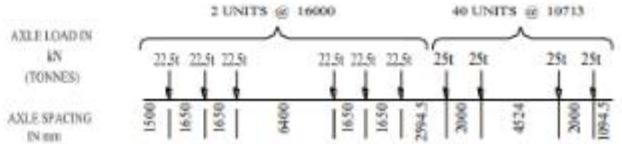
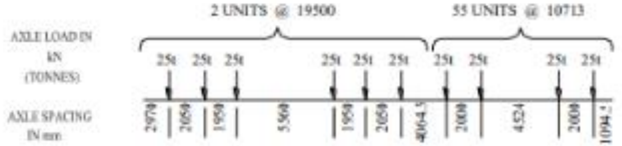
Train type	Composition	Train Length Ist. to Last axle (m)	Total Weight (t)	Diagram
Type - 3	2+26 COACH (AC)	613.443	1990	3. PASSENGER TRAIN TWO 25 t. LOCO + 26 COACH AC 
Type - 4	EMU 12	254.257	736	4. PASSENGER TRAIN EMU 12 (3x4 UNITS) 

(Contd.)

Fatigue Loading

(Contd.)

Table 1 (b) Train Formation details in traffic Model for 25t. Loading-2008

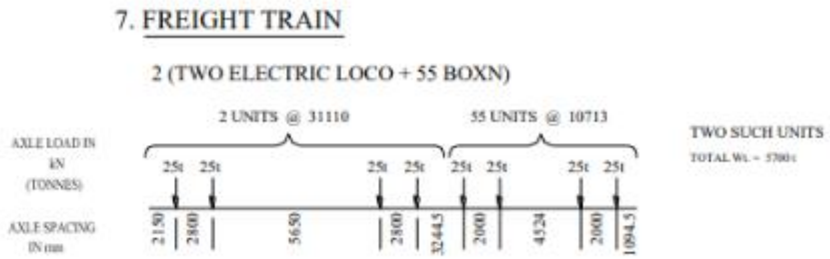
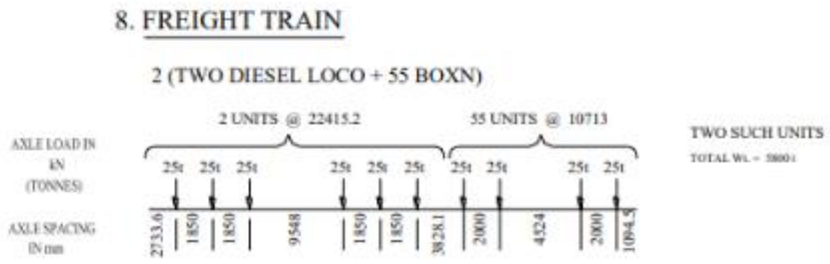
Train type	Composition	Train Length Ist. to Last axle (m)	Total Weight (t)	Diagram
Type - 5	2(22.5t)+40 BOXN	457.925	4270	5. FREIGHT TRAIN TWO 22.5T LOCO + 40 BOXN 
Type - 6	2(25T)+55 BOXN	624.15	5800	6. FREIGHT TRAIN TWO 25T LOCO + 55 BOXN 

(Contd.)

Fatigue Loading

(Contd.)

Table 1 (b) Train Formation details in traffic Model for 25t. Loading-2008

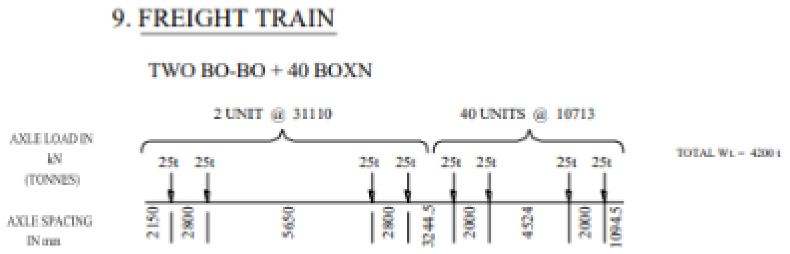
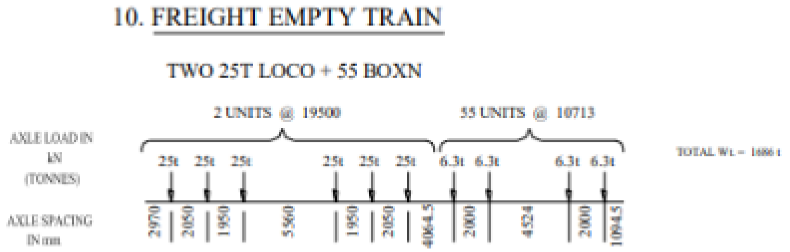
Train type	Composition	Train Length Ist. to Last axle (m)	Total Weight (t)	Diagram
Type - 7	2E(2+55 BOXN)	1236.33	11400	
Type - 8	2D(2+55 BOXN)	1262.62	11600	

(Contd.)

Fatigue Loading

(Contd.)

Table 1 (b) Train Formation details in traffic Model for 25t. Loading-2008

Train type	Composition	Train Length Ist. to Last axle (m)	Total Weight (t)	Diagram
Type - 9	BO-BO+40 BOXN	456.375	4200	
Type - 10	2(25T)+55 BOXN	624.15	1686	

(Contd.)

Traffic Model for 25t loading

Appendix G-I

Table 1(a) – Traffic Models for 25t Loading

Type of Train	Train No.	Train Composition	Weight per train (t)	GMT/ Train	Class of Traffic							
					Heavy Freight Traffic (100 GMT)		Mixed Traffic Lines with Heavy Traffic (70 GMT)		Sub Urban Traffic (60 GMT)		Mixed Traffic Lines with Light Traffic (40GMT)	
					No. of Trains	GMT	No. of Trains	GMT	No. of Trains	GMT	No. of Trains	GMT
Passenger	1	1+15ICF COACH NON AC	900	0.33	3	1.0	6	2.0	-	-	5	1.7
	2	2+22 ICF COACH NON AC	1400	0.51	2	1.0	10	5.1	7	3.57	5	2.6
	3	2+26 COACH AC	1700	0.62	-	-	14	8.7	7	4.34	-	-
	4	EMU12	700	0.26	-	-	-	-	200	52.0	-	-
Freight	5	2(22.5T)+40 BOXN	4270	1.56	2	3.1	-	-	-	-	4	6.24
	6	2(25T)+55 BOXN	5800	2.12	8	16.96	4	8.48	-	-	9	19.08
	7	2E(2+55 BOXN)	11540	4.21	10	42.1	6	25.21	-	-	1	4.21
	8	2D(2+55 BOXN)	11600	4.23	8	33.84	5	21.15	-	-	1	4.23
	9	Bo-BO +40 BOXN	4200	1.53	2	3.06						
Freight empty	10	2(25T)+55BOXN	1686	0.61	-	-	-	-	-	-	1	0.61
	11	2(22.5T)+40 BOXN	1278	0.47	-	-	-	-	-	-	2	0.9
Total					35	101.06	45	70.64	214	59.91	28	39.57

Cycle counting method (Reservoir method)

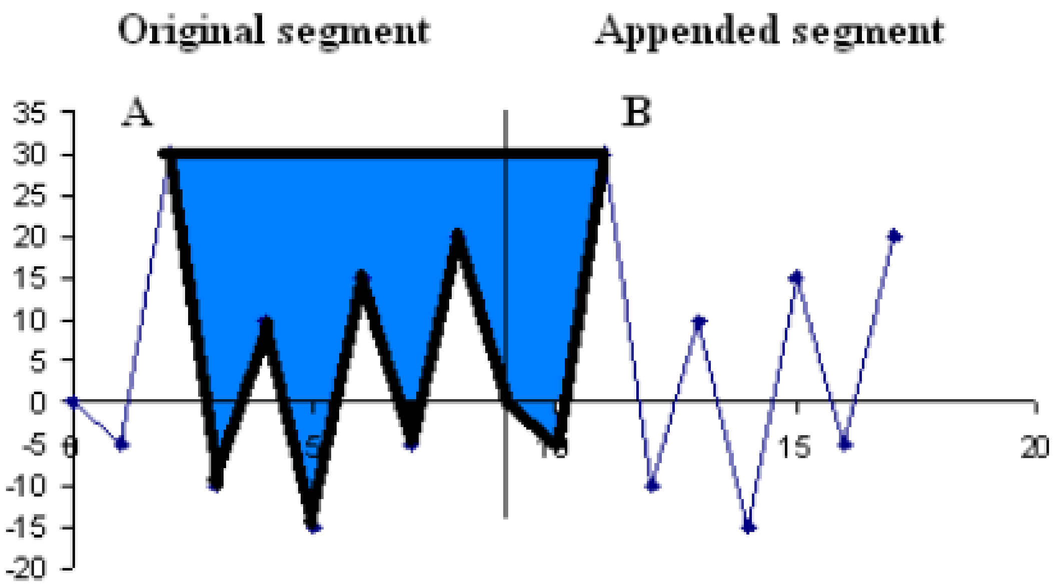


Figure A.3 Original and appended stress history

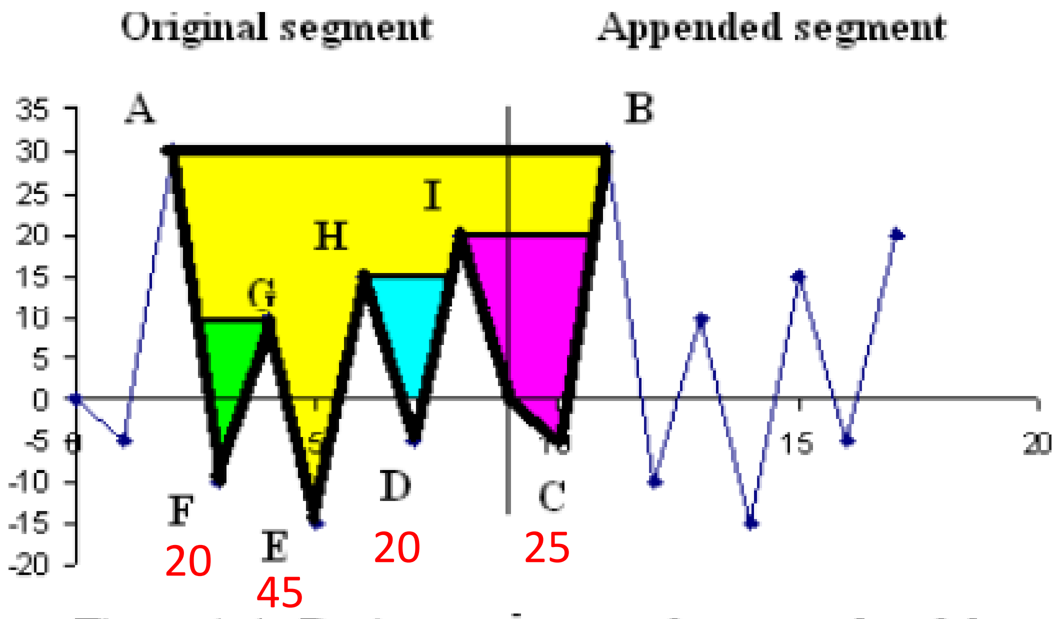


Figure A.4 Drainage sequence from troughs of the reservoir

13.2.1.3 A cumulative damage assessment may be made using:

$D_d \leq 1$ where $D_d = \sum \frac{n_i}{N_i}$

Appendix G-III

Cycle counting Methods

Calculation of Damage accumulation by Palmgren – Miner’s rule

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Cycle counting method (Reservoir method)

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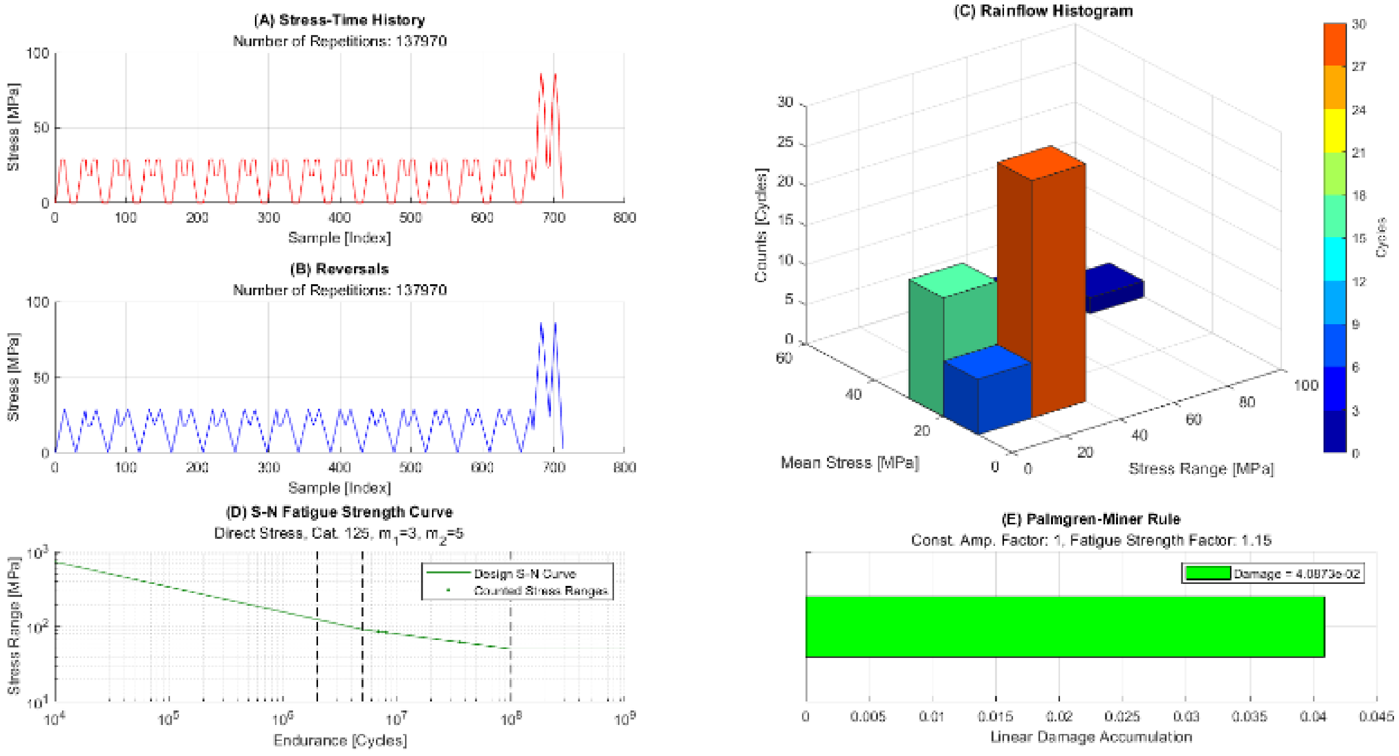
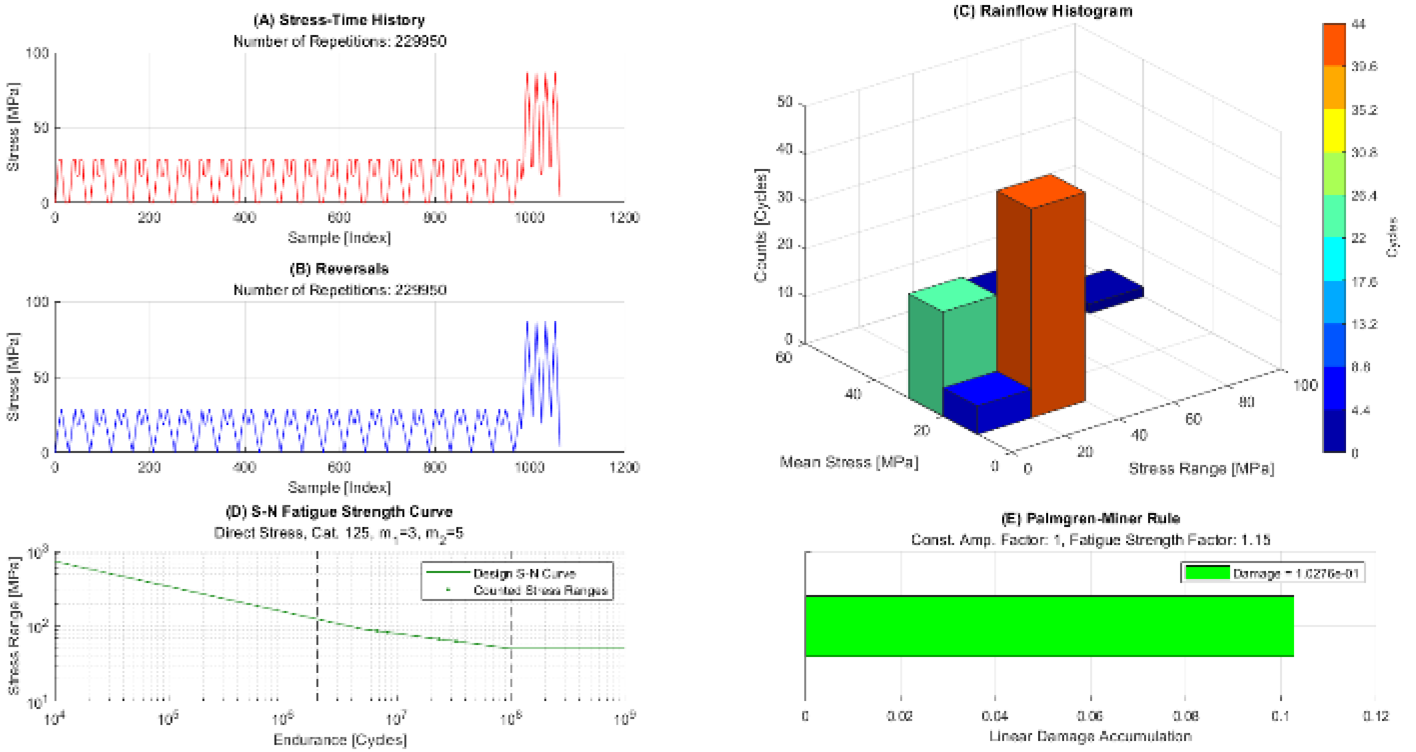


Fatigue assessment by cumulative damage method

Analysis results through MATLAB programme – Simply supported rail stringer – Direct stress for Train type 1

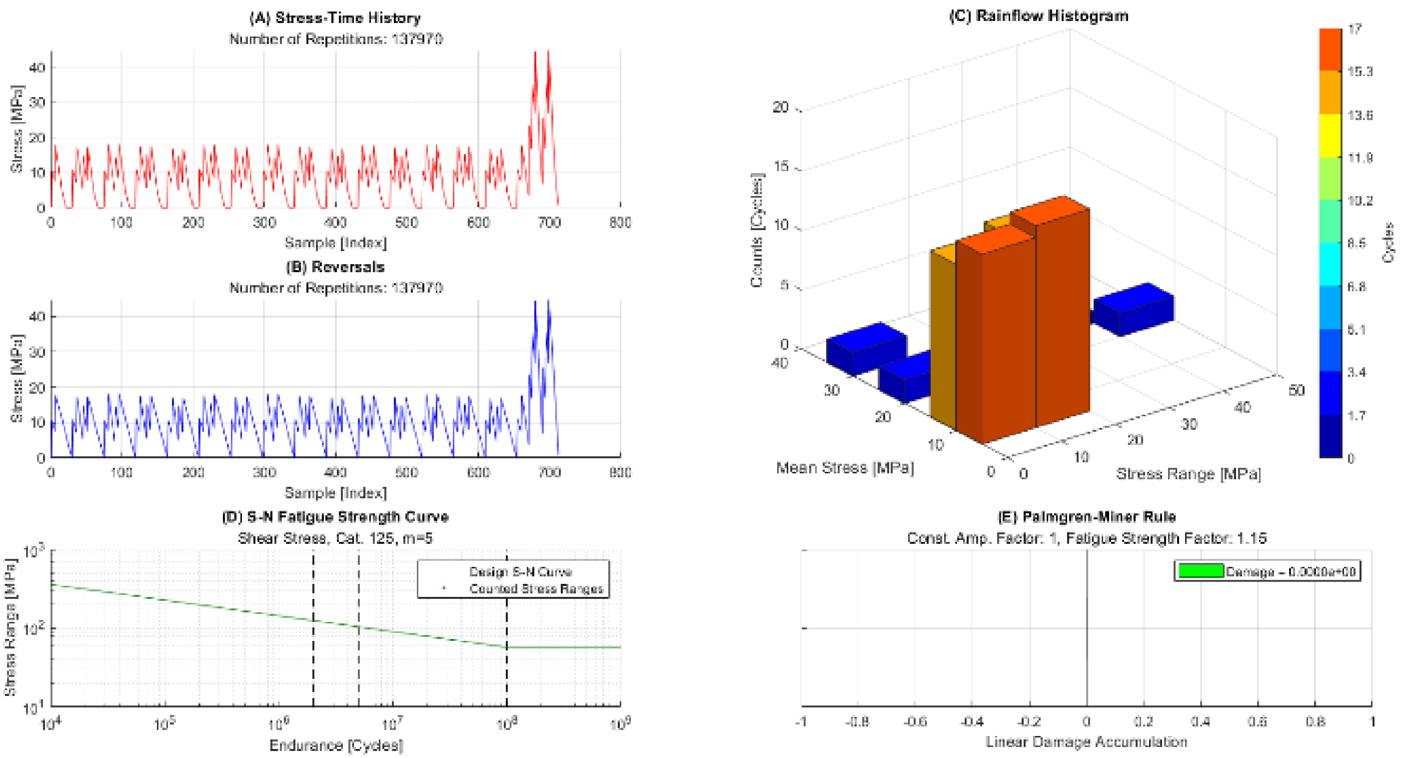
Cycle counting method (Reservoir method)



Fatigue assessment by cumulative damage method

Analysis results through MATLAB programme – Simply supported rail stringer – Direct stress for Train type 2

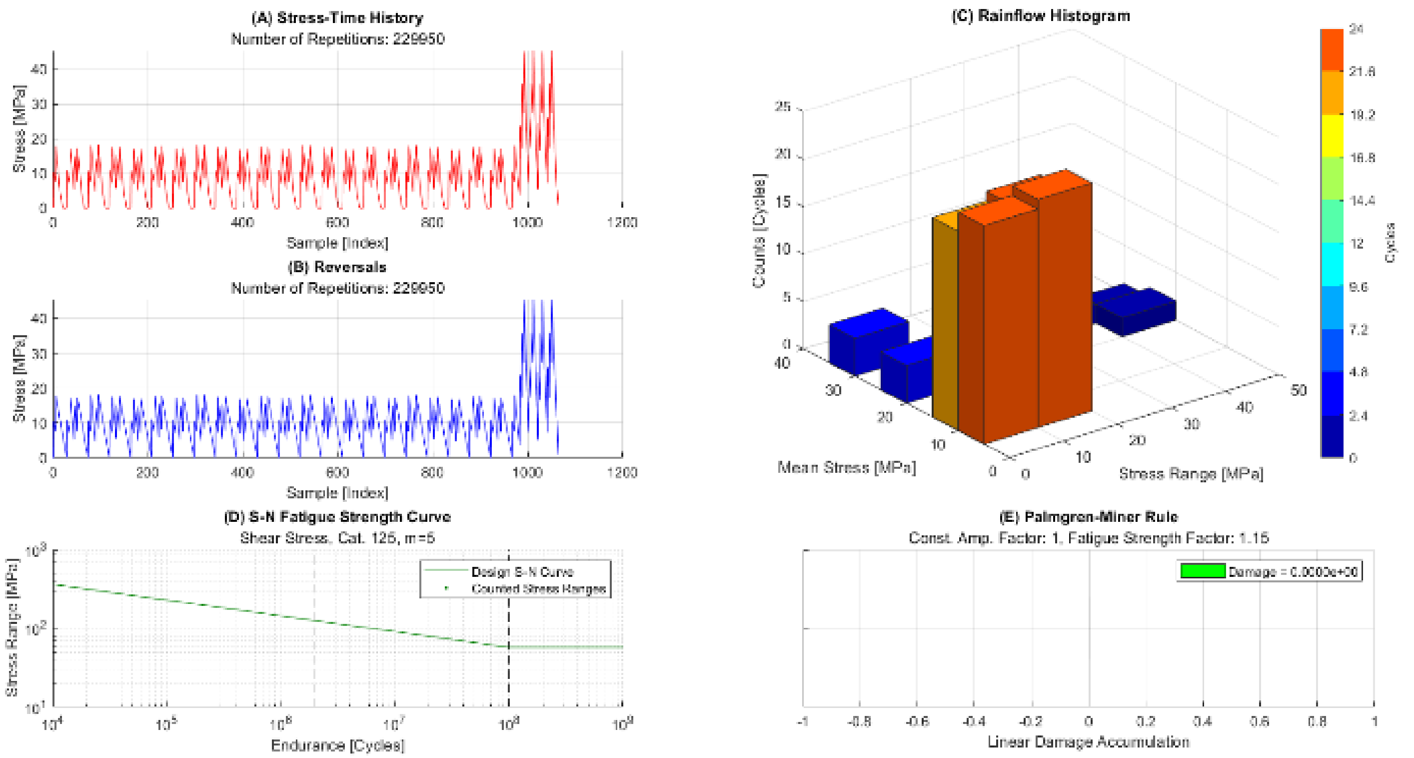
Cycle counting method (Reservoir method)



Fatigue assessment by cumulative damage method

Analysis results through MATLAB programme – Simply supported rail stringer – Shear stress for Train type 1

Cycle counting method (Reservoir method)



Fatigue assessment by cumulative damage method

Analysis results through MATLAB programme – Simply supported rail stringer – Shear stress for Train type 2

Appendix G-I
Table 1(a) – Traffic Models for 25t Loading

Type of Train	Train No.	Train Composition	Weight per train (t)	GMT/ Train	Class of Traffic: Heavy Freight Traffic (100 GMT) No. of Trains	GMT	Mixed Traffic Lines with Heavy Traffic (70 GMT) No. of Trains	GMT	Sub Urban Traffic (60 GMT) No. of Trains	GMT	Mixed Traffic Lines with Light Traffic (40GMT) No. of Trains	GMT
Passenger	1	1+15ICF COACH NON AC	900	0.33	3	1.0	6	2.0	-	-	5	1.7
	2	2+22 ICF COACH NON AC	1400	0.51	2	1.0	10	5.1	7	3.57	5	2.6
	3	2+26 COACH AC	1700	0.62	-	-	14	8.7	7	4.34	-	-
	4	EMU12	700	0.26	-	-	-	-	200	52.0	-	-
Freight	5	2(22.5T)+40 BOXN	4270	1.56	2	3.1	-	-	-	-	4	6.24
	6	2(25T)+55 BOXN	5800	2.12	8	16.96	4	8.48	-	-	9	19.08
	7	2E(2+55 BOXN)	11540	4.21	10	42.1	6	25.21	-	-	1	4.21
	8	2D(2+55 BOXN)	11600	4.23	8	33.84	5	21.15	-	-	1	4.23
	9	Bo-BO +40 BOXN	4200	1.53	2	3.06						
Freight empty	10	2(25T)+55BOXN	1686	0.61	-	-	-	-	-	-	1	0.61
	11	2(22.5T)+40 BOXN	1278	0.47	-	-	-	-	-	-	2	0.9
Total					35	101.06	45	70.64	214	59.91	28	39.57

Cumulative damage in the member:				
Simply supported Stringer - Midspan & supoort section				
Service life of the btridge =			63	years
Average traffic as per record =			22	GMT
Detailed category =			125	Mpa
Cumulative damage as per Palmgren-Miner's rule				
	Flexure	Shear	Flexure	Shear
Type 1	0.0409	0.0000	0.0409	0.0000
Type 2	0.1027	0.0000	0.1027	0.0000
Type 3	0.1253	0.0000	0.1253	0.0000
Type 6	0.1031	0.0005	0.1196	0.0005
Type 7	0.1298	0.0007	0.1480	0.0009
Type 8	0.1820	0.0013	0.2111	0.0015
Cumulative damage for 70GMT traffic				
			0.7476	0.0029
Cumulative damage for recorded traffic				
			$D_{d\sigma}$	$D_{d\tau}$
			0.2349	0.0009
Consider future traffic =			50	GMT
Fatigue life of the member will be				
	90		years	

Fatigue assessment by cumulative damage method

Summary of cumulative damage assessment result – Simply supported rail stringer

Cycle counting method (Reservoir method)

Danapur Division - Traffic Density (Annual & Cummulative GMT)

Section	Hathidah(HTZ) link-Rajendrapul(RJO)		
Km	3.83 - 8.50		
Line	SL		
Year	Annual GMT↓	Year	Annual GMT↓
1981-82	2.67	2002-03	13.47
1982-83	3.625	2003-04	13.608
1983-84	4.865	2004-05	13.46
1984-85	5.68	2005-06	12.55
1985-86	5.58	2006-07	12.62
1986-87	6.363	2007-08	12.62
1987-88	6.495	2008-09	73.639
1988-89	17.66	2009-10	99.864
1989-90	18.477	2010-11	98.55
1990-91	23.083	2011-12	108.697
1991-92	19.184	2012-13	82.782
1992-93	19.053	2013-14	83.293
1993-94	23.191	2014-15	85.629
1994-95	23.495	2015-16	65.481
1995-96	21.567	2016-17	18.210
1996-97	25.058	2017-18	39.120
1997-98	23.457	2018-19	39.120
1998-99	23.362	2019-20	39.120
1999-00	21.547	2020-21	31.840
2000-01	21.547	Total	1281.000
2001-02	21.547		

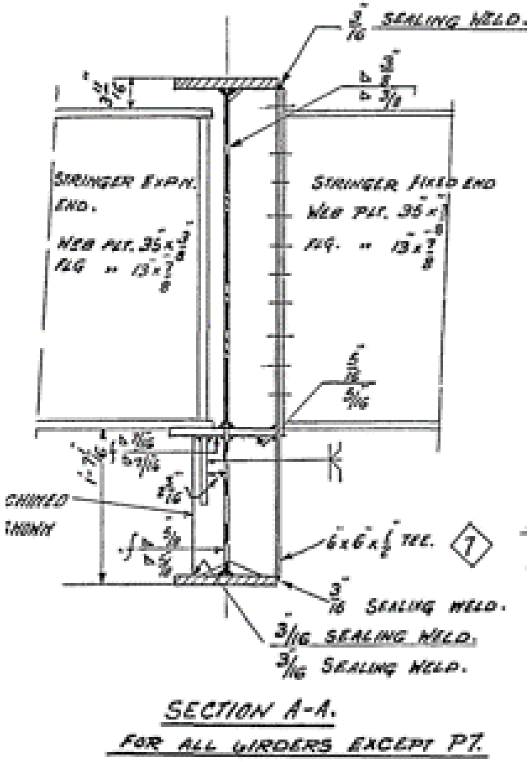
Total including loading from 1959 to 1981 @ 5 GMT, The average value comes to 22 GMT

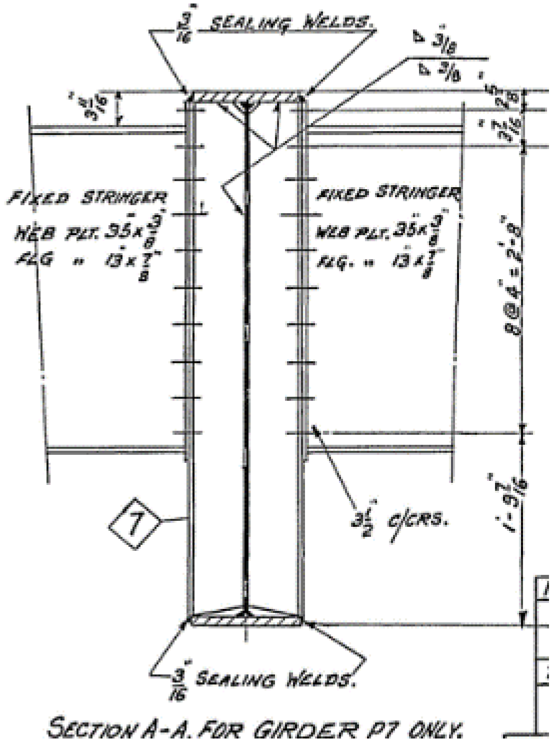
*Note: Annual GMT data of Year 2019-20 has not been provided by the Statistical deptt/ECR/HJP

So, Annual GMT of year 2019-20 has been assumed of Year 2018-19,

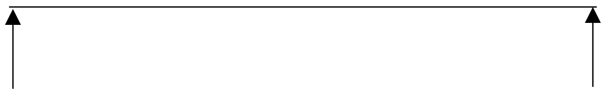
Train loading history of the bridge – as recorded by ECR

Stringer connection behavior in fatigue

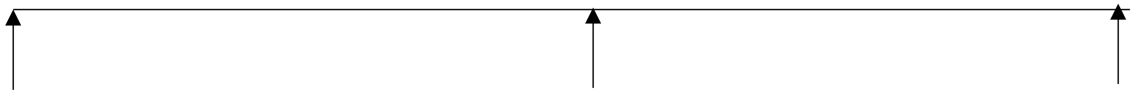




Stringer behaviour based on end connection detail

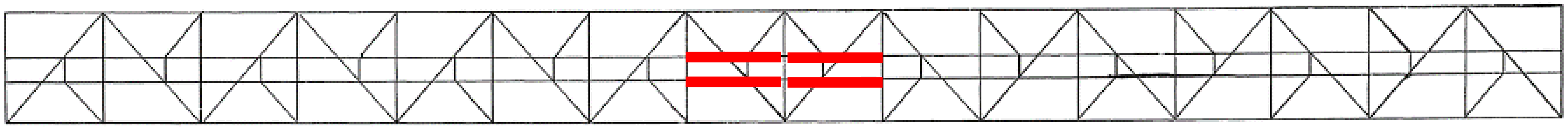


Simply supported Stringer



Two span continuous stringer

Stringer behaviour based on end connection detail

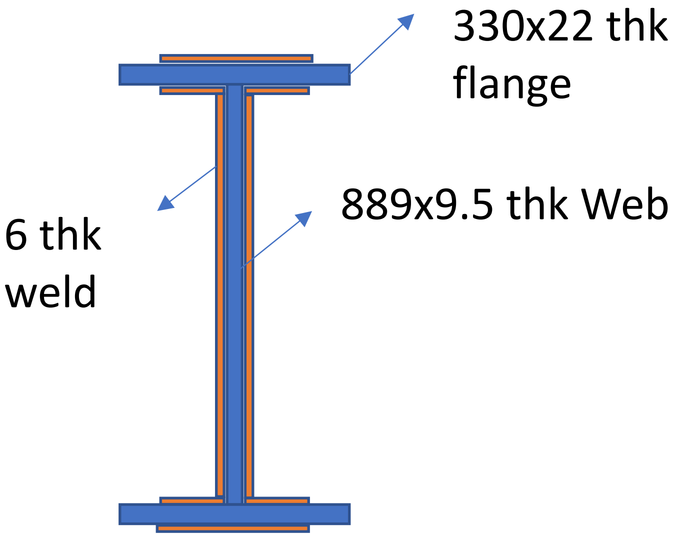


Plan at Rail level

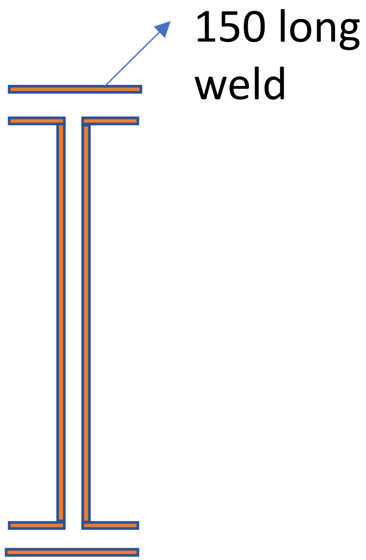
ING - IABSE

Stringer connection behavior in fatigue

Public Works Department, Uttarakhand



View of Cross section of Stringer including weld with face plate



View of Stringer weld with face plate

Thickness of web of Stringer = 9.5 mm
Thickness of weld at web = 8.4 mm
Ratio of shear area = 1.13

Section property comparison between Stringer section and Stringer welded connection with face plate

Stringer connection behavior in fatigue

Cumulative damage in the member:						
2 span conctinuous Stringer - Support connection (weld)						
Service life of the btridge =			63	years		
Average traffic as per record =			22	GMT		
Detailed category =			80	Mpa		
Cumulative damage as per Palmgren-Miner's rule						
	Flexure	Shear	Flexure	Shear		
Type 1	0.9380	0.0337	0.9380	0.0337		
Type 2	2.0560	0.0785	2.0560	0.0785		
Type 3	4.5000	0.1250	4.5000	0.1250		
Type 6	1.4300	0.1830	1.6588	0.2123		
Type 7	1.8240	0.2610	2.0794	0.2975		
Type 8	1.6900	0.2590	1.9604	0.3004		
Cumulative damage for 70GMT traffic						
			13.1926	1.0475		
Cumulative damage for recorded traffic						
			$D_{d\sigma}$	$D_{d\tau}$	$D_{d\sigma} + D_{d\tau}$	
			4.1462	0.3292	4.4754	>1
Consider future traffic =			50	GMT		
Fatigue life of the member will be						
			years			

Interesting observation – as per theoretical calculation the crack in this connection should have occurred before 2005. Crack has been observed at site on 2011.

Summary of cumulative damage assessment result – Two span continuous rail stringer – at weld connection with face plate

Stringer connection behavior in fatigue

Modification of Stringer connection with cross girder undertaken by ECR

Summary of residual fatigue strength

Residual Fatigue Life of All Members of 121 m span		
S.No.	Member Description	Residual Fatigue Life
1	Top Chord	543 years
2	Bottom Chord	496 years
3	Diagonal Chord	167 years
4	Vertical Chord	500 years
5	Rail Stringer	90 years
6	Rail Cross Girder	1513 years
7	Connection between Stringer & Cross Girder: A. At central cross girder location B. Other location	Failed 90 years
8	Roadway Stringer	22 years
9	Road Cross Girder	150 years

Residual Fatigue strength assessment shall be done by testing of sample of the members at the laboratory of the CSIR-SERC, Chennai

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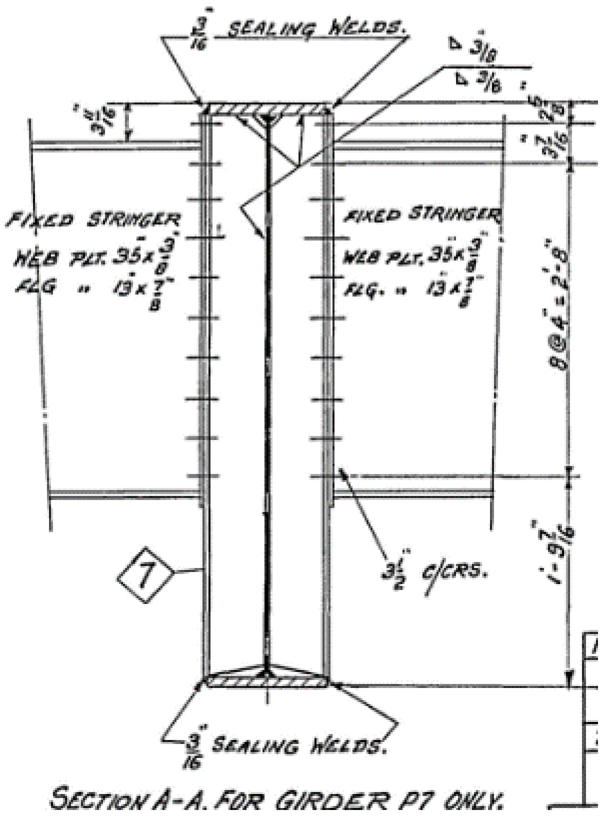
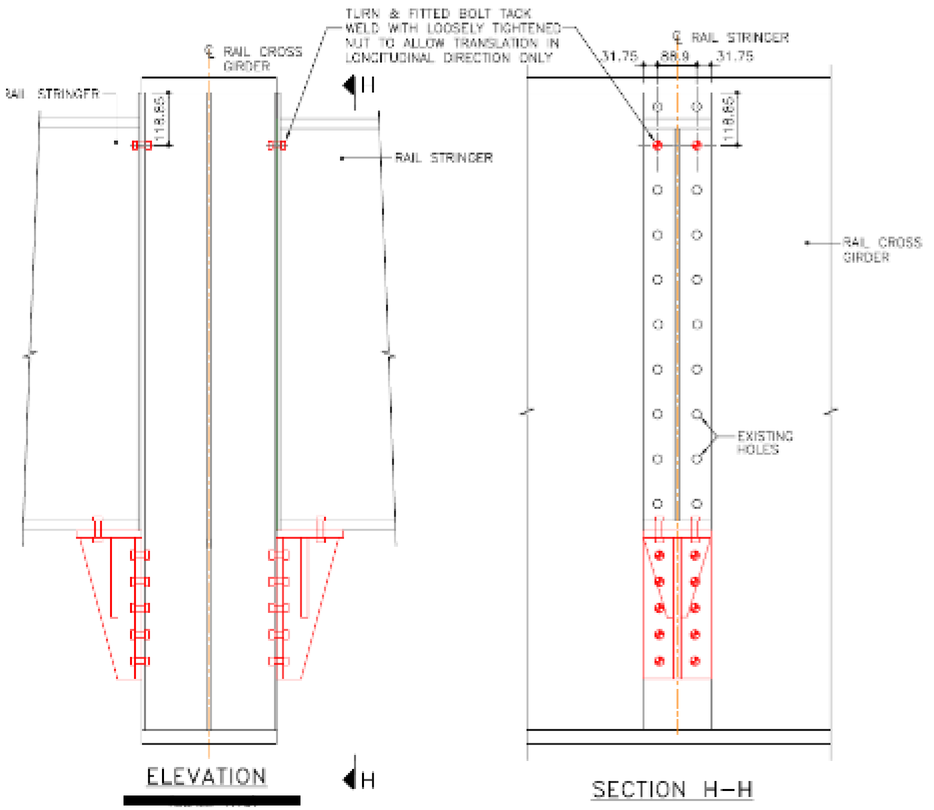
5. STRUCTURAL INTERVENTION PROPOSED
6. SUMMARY & CONCLUSIONS

Requirement of Structural intervention

- All members at the railway level are adequate for the revised loading
- All members at the road level are adequate for the revised loading only if Class 70R loading is excluded from roadway load.
- All the truss members are adequate for the new loading if Class 70R loading is excluded from roadway loading
- It has been decided by ECR that class 70R loading need not be considered in the design check of the bridge. There will be restrictions and regulation in the passage of vehicles
- With the above condition only the members that are already damaged have been proposed to be repaired/ replaced which are listed below:
    - In the main span the rail level stringer connection with the central cross girder where crack in the weld connection appeared and was later replaced by rivets with cleat angle by ECR
    - In the 30m approach span, diagonal crack appeared in the upper part of the web of the railway stringer near the support
    - Inclined members of portal frame above road level have been damaged due to heating by oversized vehicle
    - Road way RCC deck has been damaged and the entire deck is being relayed

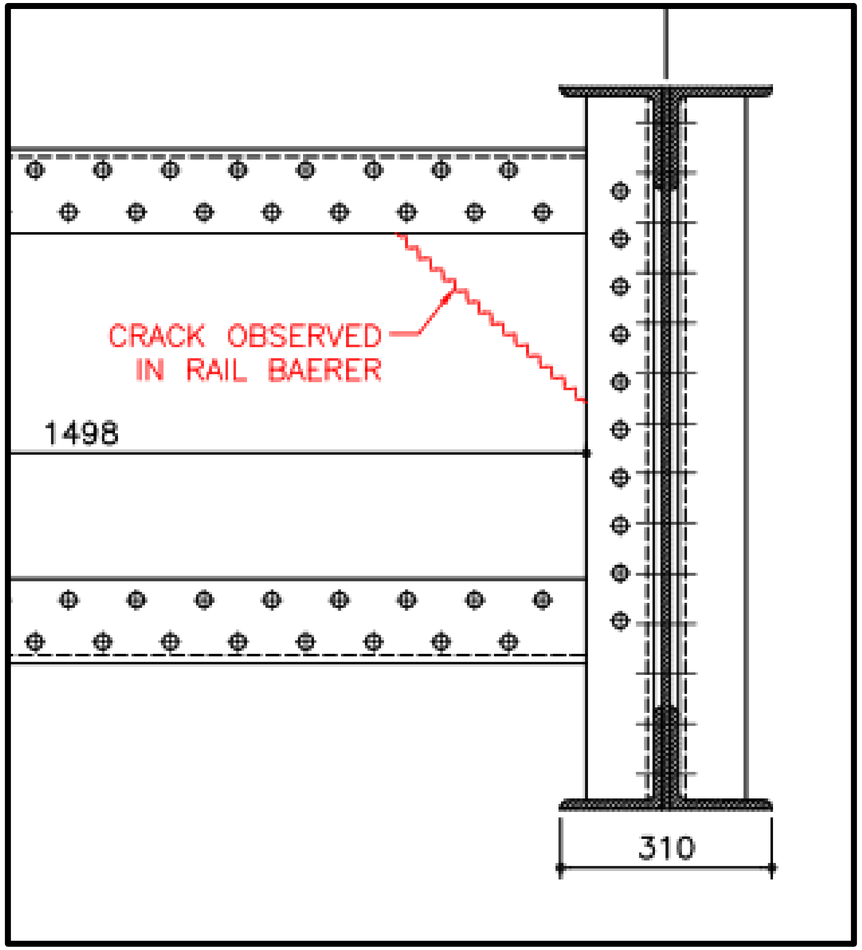
Railway main span continuous stringer



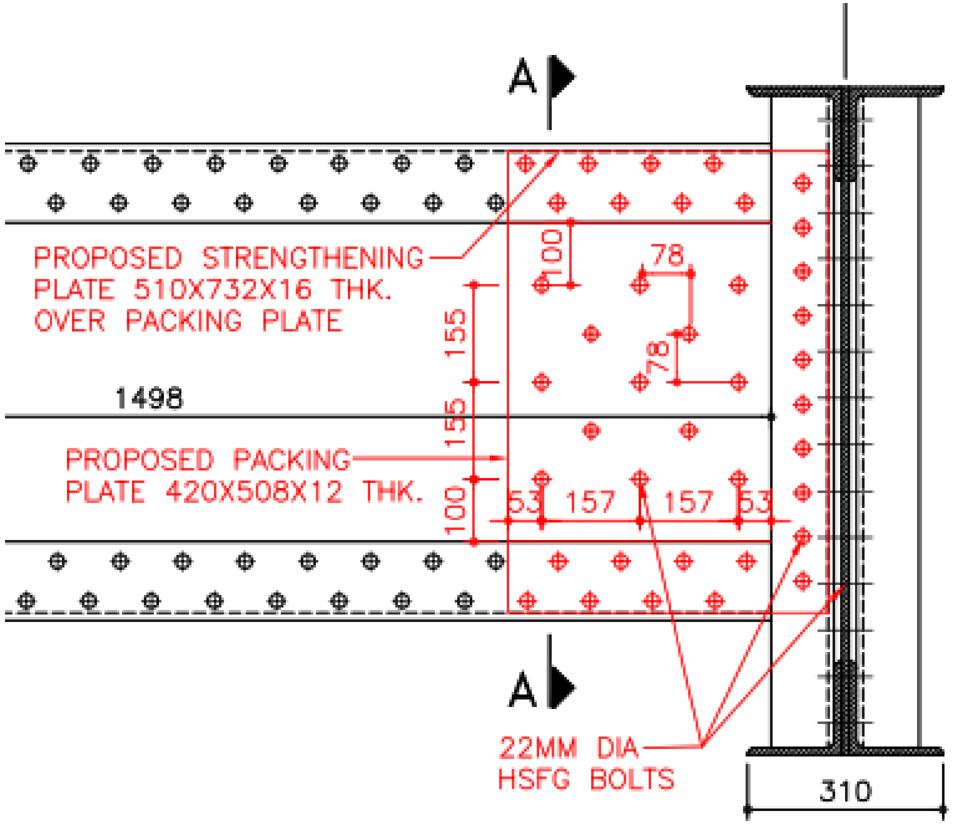


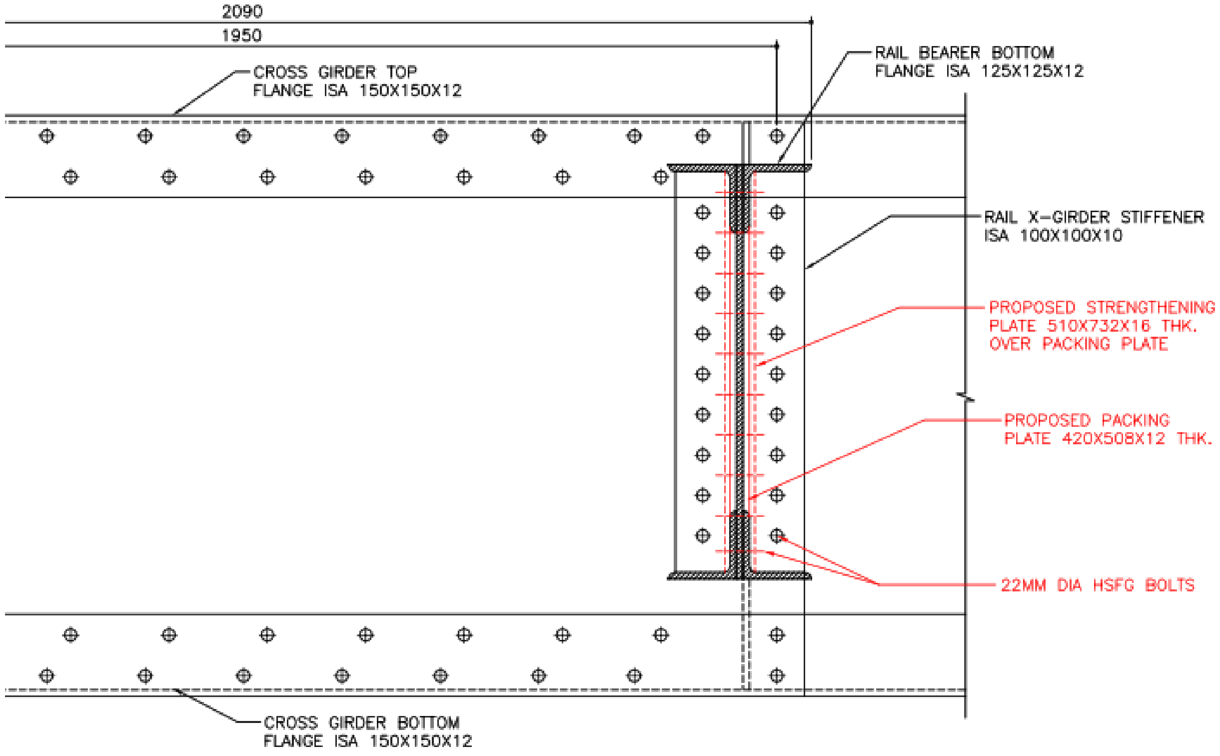
Repair scheme of railway continuous stringer at central cross girder location – by removing the moment connection

Railway 30m span stringer



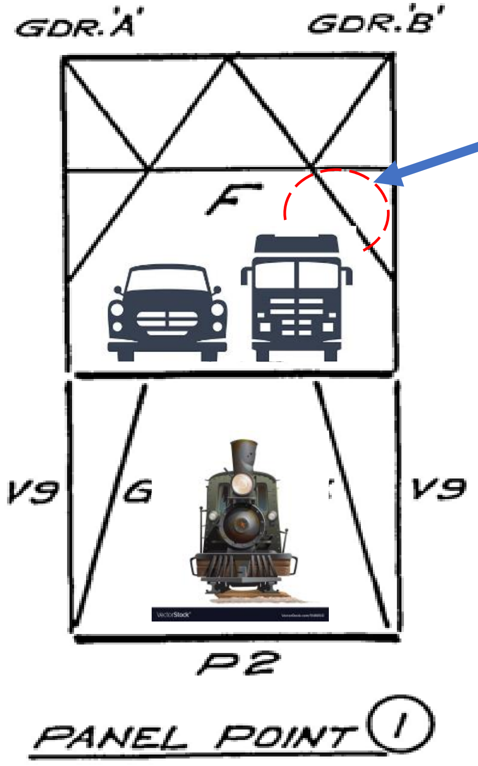
Railway 30m span stringer



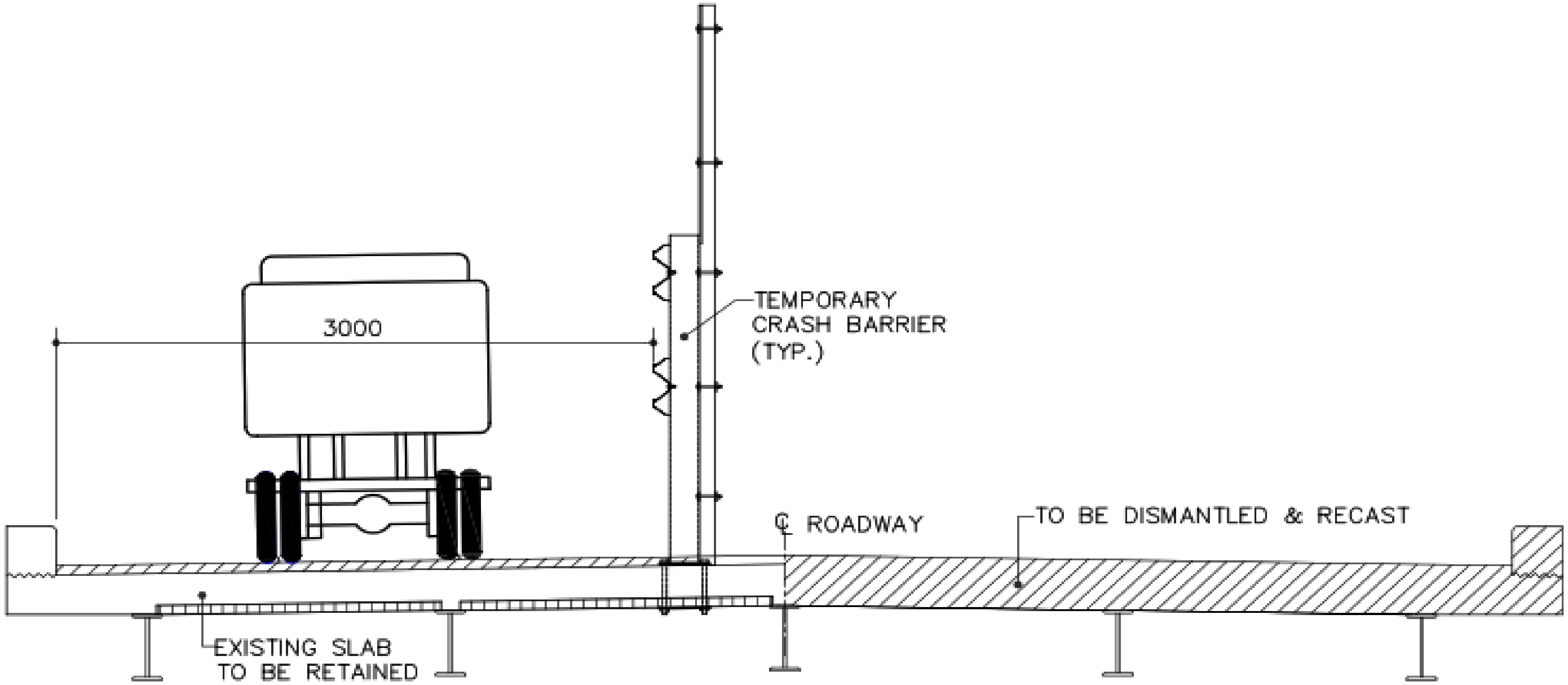


SECTION A–A
(SCALE 1:10)

Bending of inclined member of portal frame due to hitting of oversized vehicle



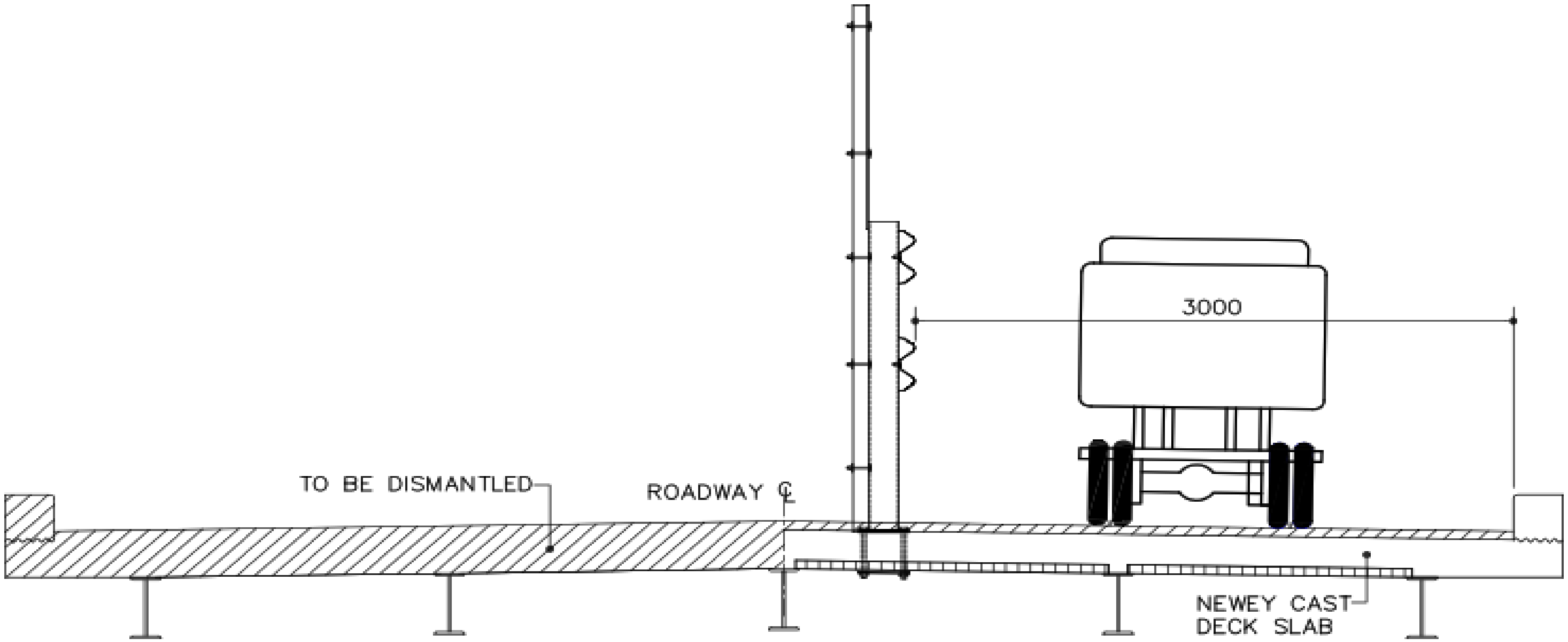
Relaying of deck slab



Stage 1

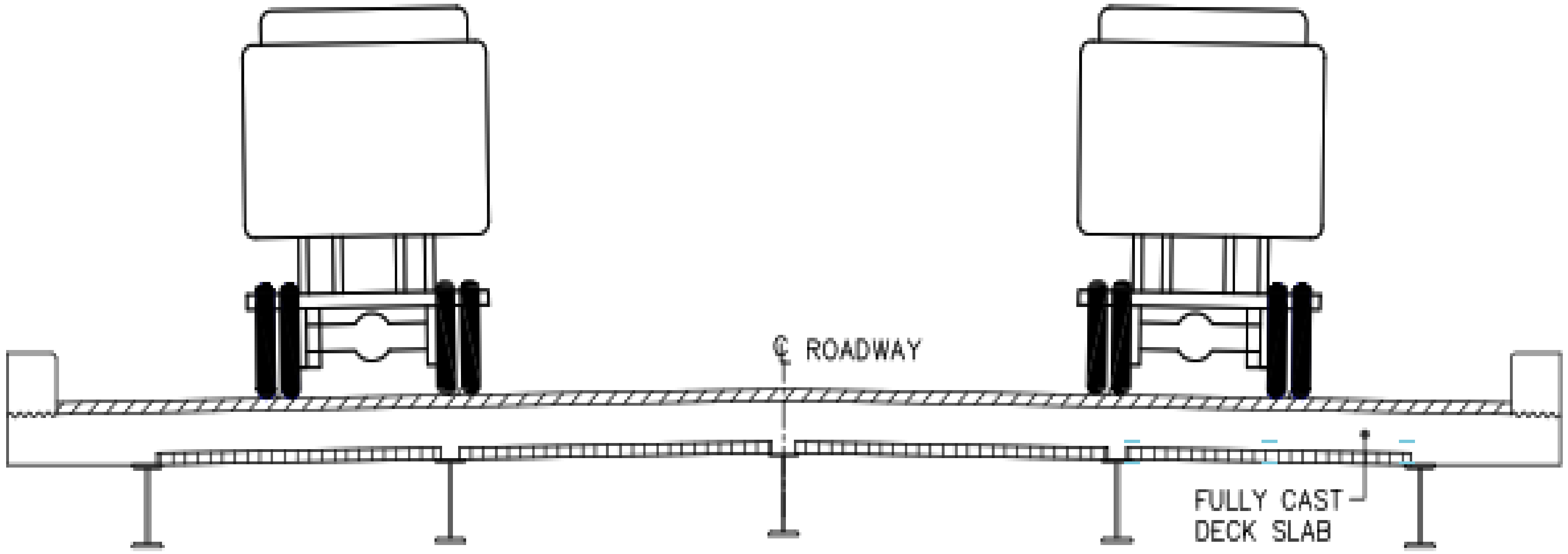
Relaying of deck slab

Relaying of deck slab



Stage 2

Relaying of deck slab



Stage 3

CONTENT :

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Status of Superstructure after Rehabilitation

Original loading

- Railway loading- Broad guage standard main line, single track **(BGML of 1926)**
- Highway loading - Single lane of class AA or two lanes of class A highway loading.
- **Original wind/ Seismic load**

All members are adequate

New loading

- Railway loading- Broad guage 25T loading - 2008
- Highway loading - single lane of Class 70R or two lanes of class A highway loading.
- New wind/ Seismic load

All members are adequate except road way cross girders and stringers

Revised new loading

- Railway loading- Broad guage 25T loading - 2008
- Highway loading - Two lanes of class A loading or any commercial vehicular load as defined in IRC SP37
- New wind/ Seismic load

All members are adequate

Summary and Conclusion

- Working for Repair and Rehabilitation of Mokama Bridge was a huge learning experience on many counts. Following are some of them :

  a. Learnt how important it is for Engineers to write articles about the project they are involved in, for the sake posterity and for future repair / rehabilitation / retrofit.

  b. Learnt what all information should be included in AS-BUILT Drawings in a project.

  c. Huge learning on determination of fatigue service life of elements.

Status of Superstructure & Bearings

Residual fatigue strength is adequate for all the members except at two locations due to the connection issue where crack has been observed

- **Location 1 - Cracks appeared in the weld of stringer connection at the <u>central cross girder location of all spans due to fatigue failure</u>. Repair has been proposed**
- **Location 2 – Diagonal cracks appeared at web of the shore span 30m stringer near the support. Repair has been proposed**

Inclined members of portal frame has been bent due to hitting of oversized vehicles. Replacement of the members have been proposed. <u>Height restriction shall be imposed at the road level by ECR</u>

Relaying of the entire deck concrete is being done

Bearings are being replaced for the Main Trussed Bridge

Status of Substructure & Foundation

- Substructure and foundations are safe with the new loading

- It has been decided by ECR that the following load will be considered for design on the bridge
    - MBG train loading ...25T loading - 2008
    - IRC Class A-2 Lanes or Class AA or Commercial vehicles given in IRC-SP 37 modified as per the amended version

Summary and Conclusion