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WORKSHOP ON DESIGN, CONSTRUCTION, AND MAINTENANCE OF STEEL BRIDGES

DEHRADUN 19-20 OCTOBER 2024

LECTURE ON "SUSTAINABLE USAGE OF STEEL IN BRIDGES"

BY

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LECTURE ON "SUSTAINABLE USAGE OF STEEL IN BRIDGES"

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A Civil Engineering graduate from Bengal Engineering College (now a center of excellence as IIEST), he is a Fellow of a large number of Professional Institutions like the Institution of Engineers (India), the Institution of Civil Engineers (UK), International Association of Bridge and Structural Engineers (IABSE), and he contributes extensively to professional publications, including Codes of Practice for IRC and BIS.

He has authored a book on "Engineering Aspects of Howrah Bridge at Kolkata" published by CRC press and co-authored a book on Vidyasagar Setu published by IAStructE.

Preamble

- Bridges are for connectivity
- They connect two locations/communities/clusters or just two locales separated by barriers
- Bridge is not just a structure, they link people and places
- They become an identity for a city, and sometimes a country
- Sydney Harbour Arch Bridge reminds one of Australia and the Golden Gate Suspension Bridge of San Francisco and Howrah Bridge, of course, of Kolkata.

Bridges as Identity

Benefits of Steel usage

Steel is a welcome material for use in Bridges

- Steel has high strength in tension and compression
- It has low weight arising from its high strength
- It has the corrosion disadvantage which is addressed by corrosion-resistant material and improvement of protective layers with longevity
- Being elastic it is not subject to sudden failure
- Post-failure inspection and analysis offer future lessons

Quality Assurance

- Steel is a manufactured material and therefore easy to control the quality
- Factory produced materials are fabricated to reach final shape in controlled environment
- Equipment for construction are preplanned and can meet safety requirements.

Development of Design

- Bridges are essentially structures designed to carry moving loads.
- The stress in members keep on changing with the change in load intensity.
- The components of a structure and the joints are therefore prone to fatigue conditions.
- In a steel structure, the design of joints for varying stresses during all stages of construction and serviceability deserve special care.

Evolution of Design principles – learning from failures

- Structural forms and limitations for shape and thickness have changed with progress in engineering knowledge.
- Failures have happened whenever engineering practice has moved ahead of existing knowledge.
- Some examples are presented for clarity.

Tacoma Narrows Bridge, USA, 1940

- **The Tacoma Narrows Bridge collapsed due to the aerodynamic instability of the bridge deck, totally unexpected by designers and planners.**

- **The engineering fraternity had grossly underestimated the importance of the aero-dynamic study of bridge decks of suspension bridges.**

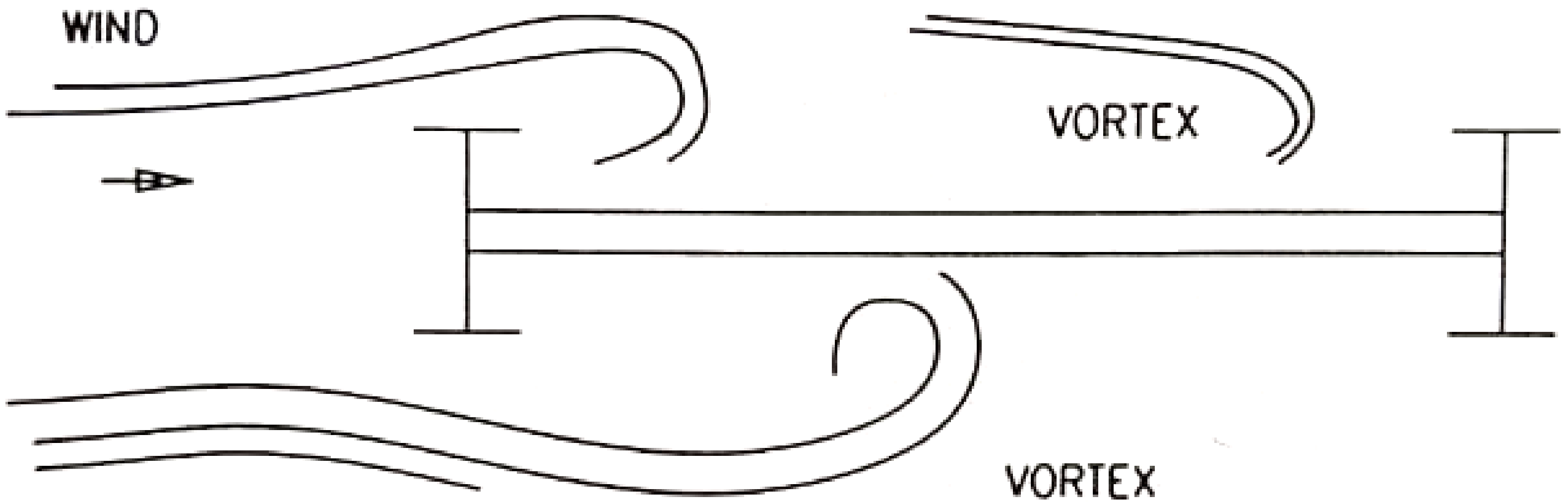
- **When it was opened to traffic on 1 July 1940, the Tacoma Narrows Bridge, over the beautiful Puget Sound in Washington State, was considered one of the most graceful, slender, and streamlined Suspension Bridges in America.**

Tacoma Narrows Bridge, USA, 1940

- **From the day of completion the bridge showed unusual undulations in moderate windy conditions.**

- **Four months after it was opened to traffic, after an hour in a moderately high wind at about 68 km/hr., the span suddenly went “into an alarming series of rolls and pitches”, one side of the road dipped and the other side rose, as a rippling wave traveled the length of the span. After some time, some of the suspension hangers gave way, and first, a length of the deck of about 180 m fell into the river, followed by the remainder of the deck.**

Tacoma Narrows Bridge, USA, 1940



[VIDEO]

Lessons Learned

- For any major bridge on flexible support like cables, it is obligatory to examine the Aerodynamic Effects on the Bridge Structure.

Another catastrophic failure

- This 2.6 km long bridge across Yarra river, with a cable-stayed span of 336 m, and side spans of 112m composite box girders, one of which collapsed during construction, resulting in a large number (35) deaths, and many serious injuries. It is remembered as the worst industrial accident in Australia.

- Crossing the river at a height of 58 m the multi-cellular box had a deck 37.3 m wide, accommodating 8 lanes of traffic initially (now been converted to a 10-lane bridge).

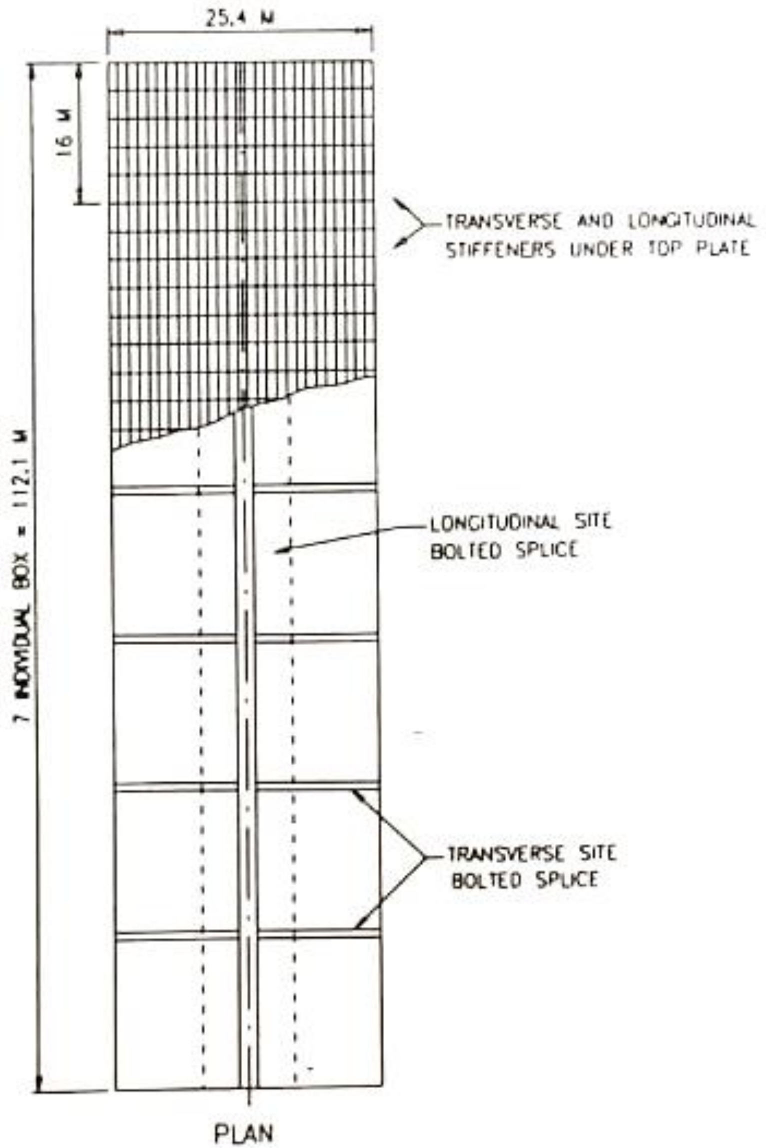
Westgate Bridge, Melbourne, Australia – Present picture

Westgate Bridge Failure, Melbourne, Australia

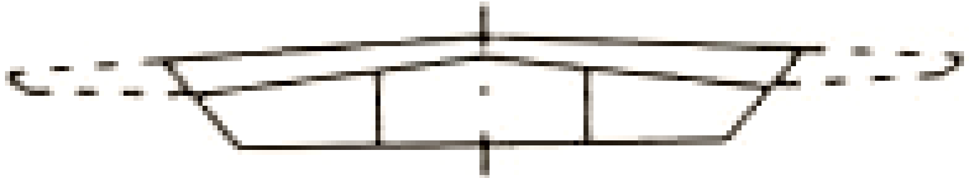
- **The 112 m box girder was made up of 7 trapezoidal box units of 16 m long each, prefabricated in two halves with longitudinal splice, to be completed with HSFG bolts during erection, and formed with thin (maximum thickness of 22 mm) plates.**

- **The half boxes were being erected by cantilever method to be spliced by bolts and the failed span showed a misalignment of 114 mm (4.5 inch) between the two halves.**

Westgate Bridge, Melbourne, Australia



Westgate Bridge, Melbourne, Australia



CROSS SECTION

Westgate Bridge, Melbourne, Australia

Westgate Bridge Failure, Melbourne, Australia

- **Designers located in UK were contacted for guidance, and constructors were advised to weigh down the higher half with 10 concrete blocks each weighing 8 tons. This weight caused the partially bolted span to buckle.**

- **The construction team was advised by the design team to restore the buckle by opening the HSFG bolts as the half box snapped back the span collapsed bringing down 2000 tons of steelwork into the river with a severe explosion.**

Lessons Learned

- Economy of cost and materials should never precede concerns with safety.
- Thin-walled box girders were a new introduction in bridge engineering and risks were taken without fully understanding the behaviour of inplane buckling of steel.
- Effective communication between designers and contractors is an essential requirement and cannot be carried out through phone calls alone.

Epilogue

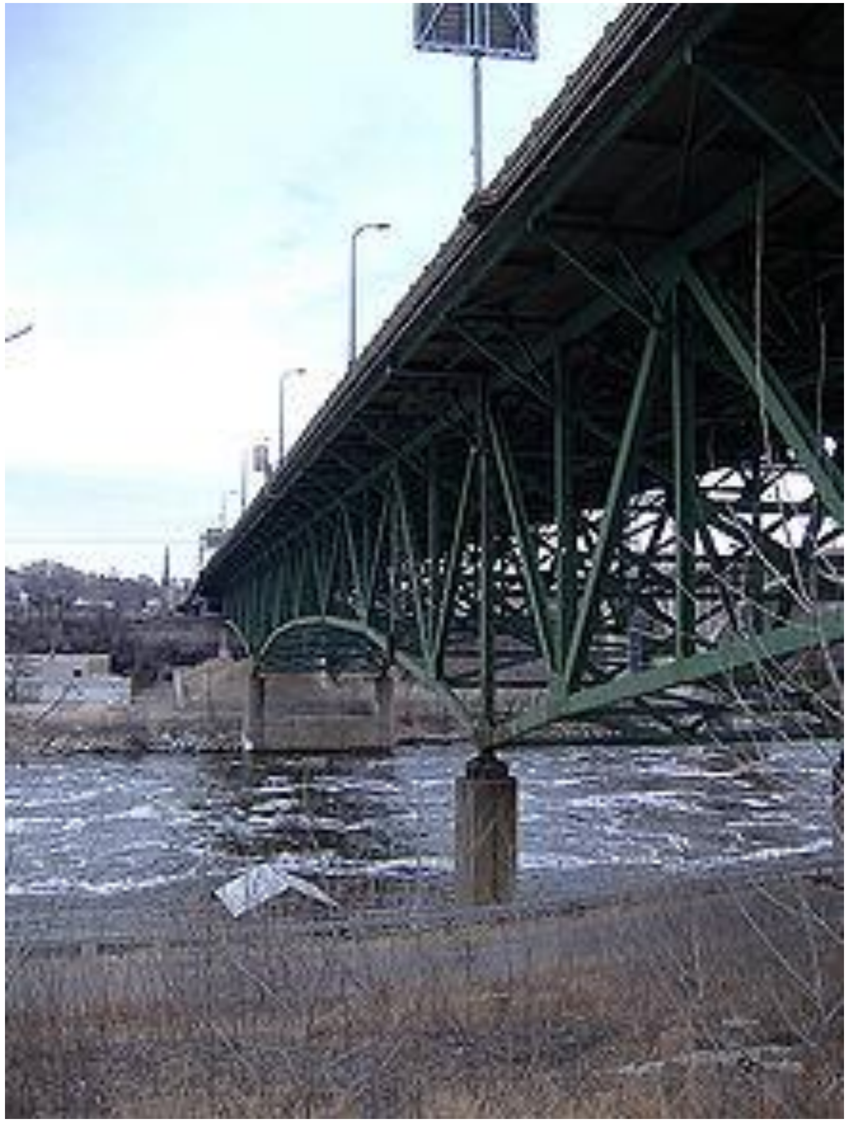
- This failure preceded by another failure of a cantilevered box girder during erection at Milford Haven in the UK a few months back, and two more in Europe across the Danube and Rhine, shook the conscience of bridge designers and authorities across the world.
- British Government appointed a high-level Technical Committee under Dr. Merrison, a Scientist, that went into the fundamentals of steel behaviour in buckling and the need for appropriate detailing. In plane buckling of skin plates of box girders was taken care of in their recommendations.
- The recommendations are built in design codes across the world and thankfully no further box girders have yet ever collapsed.

Minnesota Bridge, USA, 2007

Failure from mistaken conclusions

- The trussed Arch Bridge across the Mississippi River collapsed In August 2007 in a busy hour, killing 13 persons and injuring about 150.
- Carrying 8-lane traffic, the bridge had been under scanner of special inspection since 1993.
- Opened In 1967, the bridge was first rated "Structurally Deficient" in 1990.

Minnesota Bridge, USA, 2007



Minnesota Bridge, USA, 2007

Minnesota Bridge, USA, 2007

- A University of Minnesota study in 2001 found distress at x-girder ends and unanticipated out-of-plane distortion causing stress cracking.

- The study team commented on the lack of redundancy in the truss system.

- They suggested regular inspection, structural health monitoring, and use of strain gauges, though considered not likely to be affected by "fatigue'

Minnesota Bridge, USA, 2007

- **In 2005, the Bridge was again rated "Structurally Deficient" and in need of replacement.**
- **Two subsequent inspections in 2006 and 2007 found progress in cracking and replacement was planned by the government in 2020.**
- **Safety rating of the bridge was lowered to 50 out of 100, but termed to have met "minimum tolerable limits to be left in place as it is".**

Minnesota Bridge, USA, 2007

- **In December 2006, a rehabilitation project was planned initially but canceled in January 2007.**
- **Repair work was started and was in progress, closing 4 out of the 8 lanes.**
- **When the bridge collapsed in August 2007 there were 260 tons of construction material on the deck.**

Minnesota Bridge, USA, 2007

Minnesota Bridge, USA, 2007

- **The reasons for failure as concluded by the investigation team were –**
  - **Gusset thickness Inadequate.**
  - **Overloading of Bridge due to uncontrolled overlay.**
  - **Inadequate detailing at the end of cross girders.**

All consultants and contractors involved in the original design and subsequent repair plan were heavily fined and blacklisted.

Vivekananda Road Flyover, Kolkata, 2016

- **The most remarkable failure of a bridge structure, that shook the conscience of engineers across the country happened in Kolkata in March 2016.**

- **Failure happened during the casting of the deck slab across a busy road and with traffic in operation – the damage was restricted because it occurred during early hours.**

- **The failure compelled the technocrats to have a close look at the structure under construction as shown in some of the following slides.**

Vivekananda Road Flyover, Kolkata, 2016

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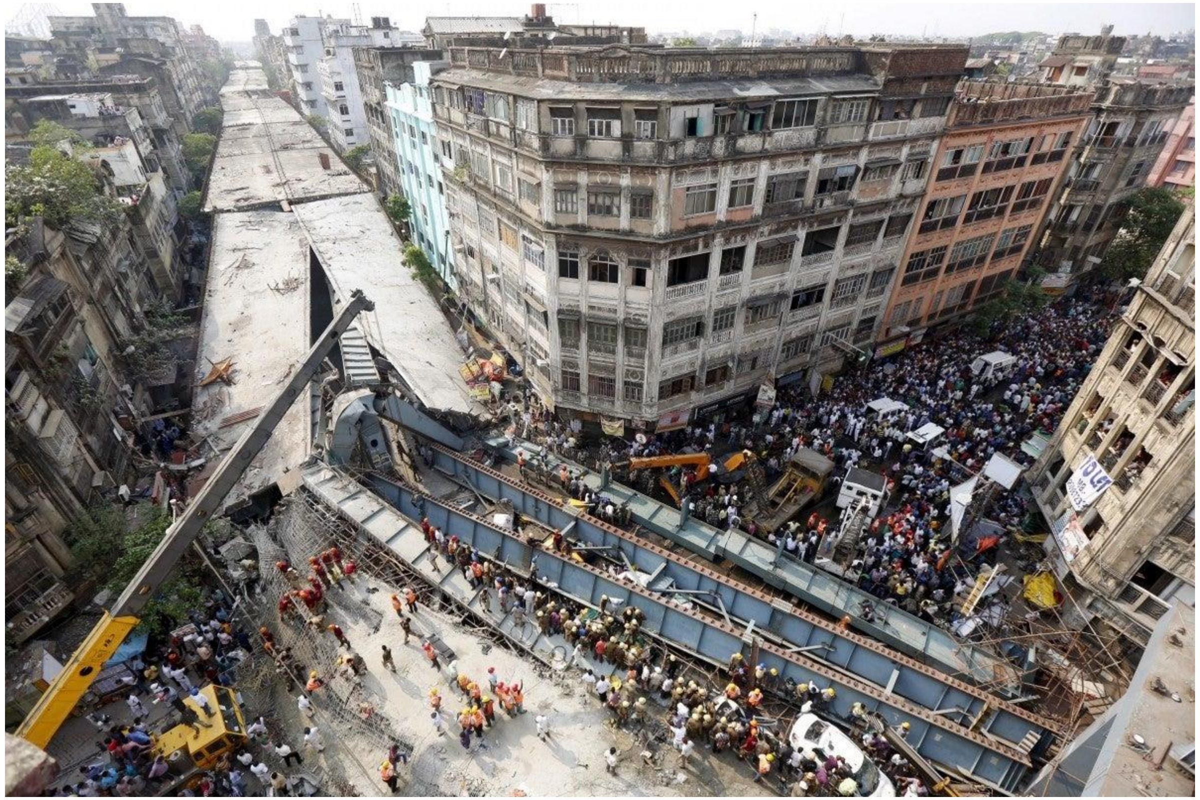

Vivekananda Road Flyover, Kolkata, 2016

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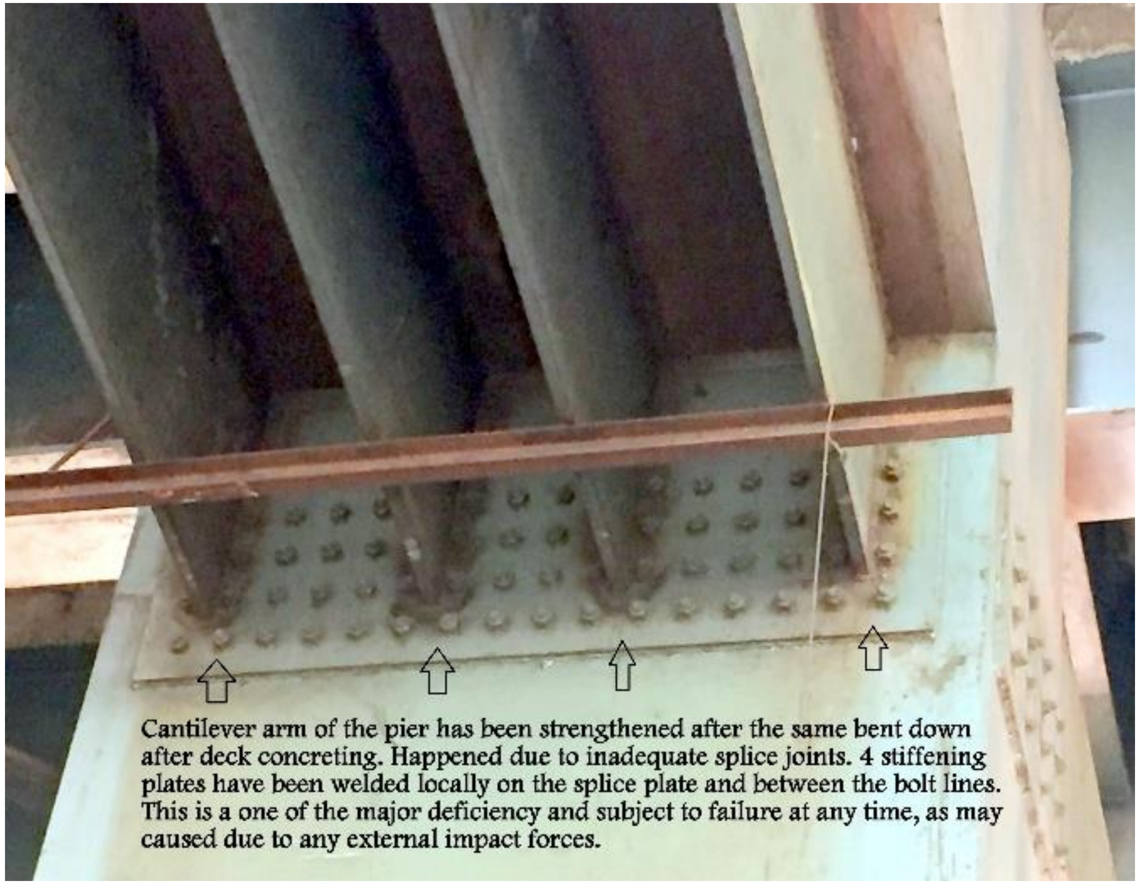

Vivekananda Road Flyover, Kolkata, 2016

The Learnings

- **Authorities need to be careful when selecting contractors and designers for any important project.**

- **Past experience and proven capability of the organization as also the responsible professionals have to be given weightage during the selection of designers and implementation agencies. The lowest cost should not be the prime criteria.**

The Learnings (Contd……)

- For EPC contracts, the employer must examine the capability and past experience of the consultant and the key personnel.

- Proof checking should not be reduced to a "stamping" process. A client should be alert during the implementation of the project and make sample checks of work being done. QAQC exercise should be extended to design work as well.

The difference in Indian Approach to a failure

- Globally, a major failure attracts review by authorities, often by an independent group of specialists, and the proceedings are accessible to interested professionals.

- The results and the recommended changes in future design basis are shared widely. The learnings are incorporated in future design rules.

- In India, till now, the investigation are carried out by departmental team away from public knowledge. The reports are kept confidential and the community / the professional bodies of engineers are not allowed to participate and reap the benefit.

THIS NEEDS CHANGE

Importance of Regular maintenance and Structural Health Monitoring

- **Every structure is different and deserves a custom-designed Inspection and maintenance plan.**
- **Only the bridge designer can produce the appropriate plan with method and schedule for inspection.**
- **Structural Health Monitoring of all improvement bridges at important locations by installing recordable/automated fixtures during construction and the serviceability period is an essential necessity.**
- **These should be mandated to ensure important structures' safe, sustainable life to avoid disruption from sudden failures.**

Conclusion

The key to the sustainability of structures are:

- **Development of SHMS by designer even before construction is done**
- **Ensure regular inspection and follow-up action by deploying a dedicated team and funds**
- **Review of design and follow-up action whenever the design basis is changed**

Thank You