Workshop
on
“Design, Construction and Maintenance of Steel Bridges”

Forensic Investigation of Bowstring Girder during Construction

Presentation

By

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19-20 October, 2024
Dehradun

Organized by

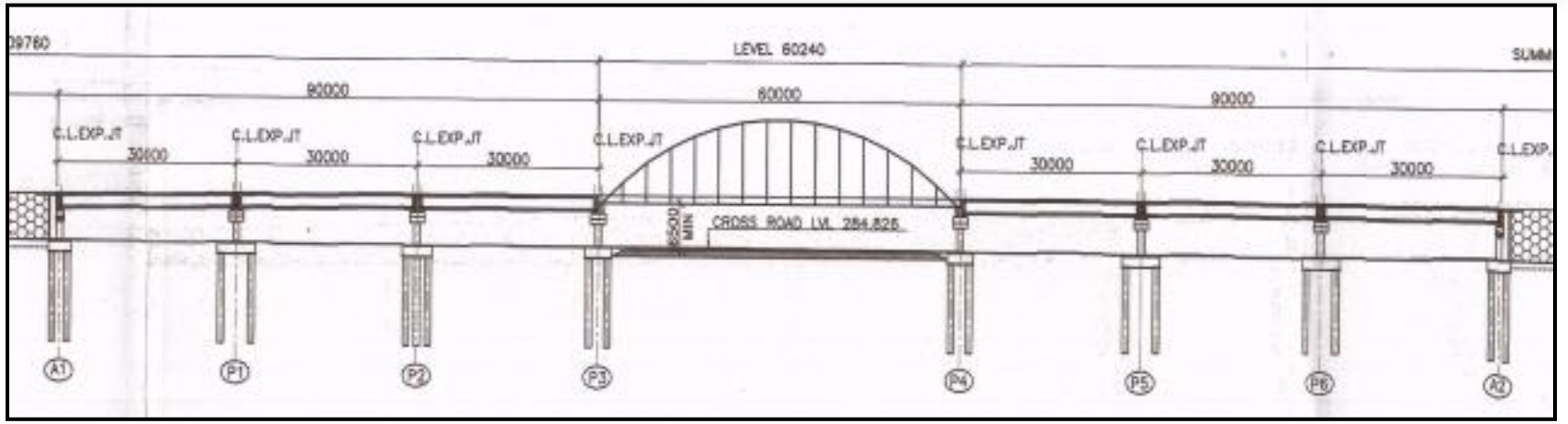
ING–IABSE
Indian National Group of the IABSE

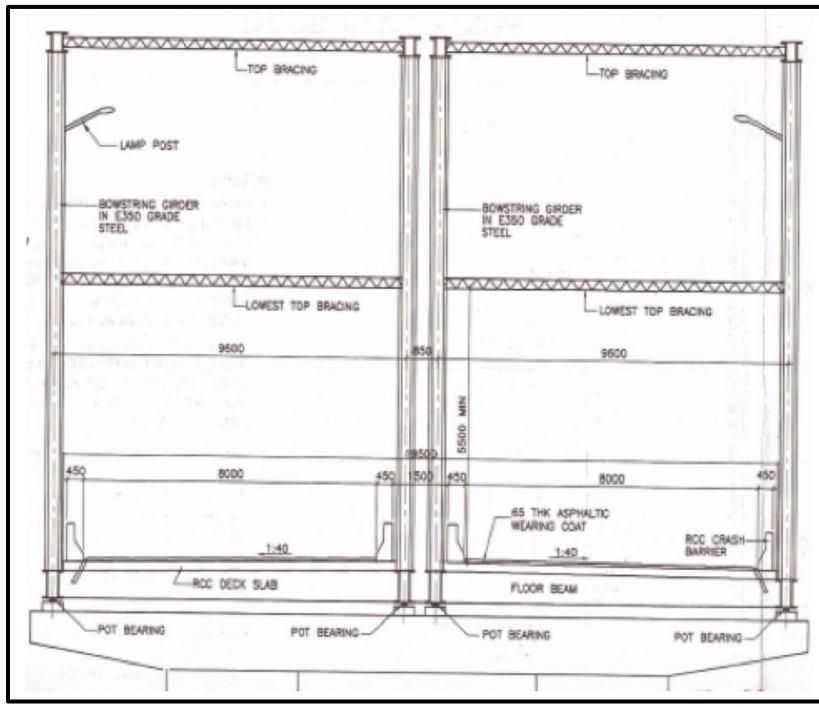
Supported by:

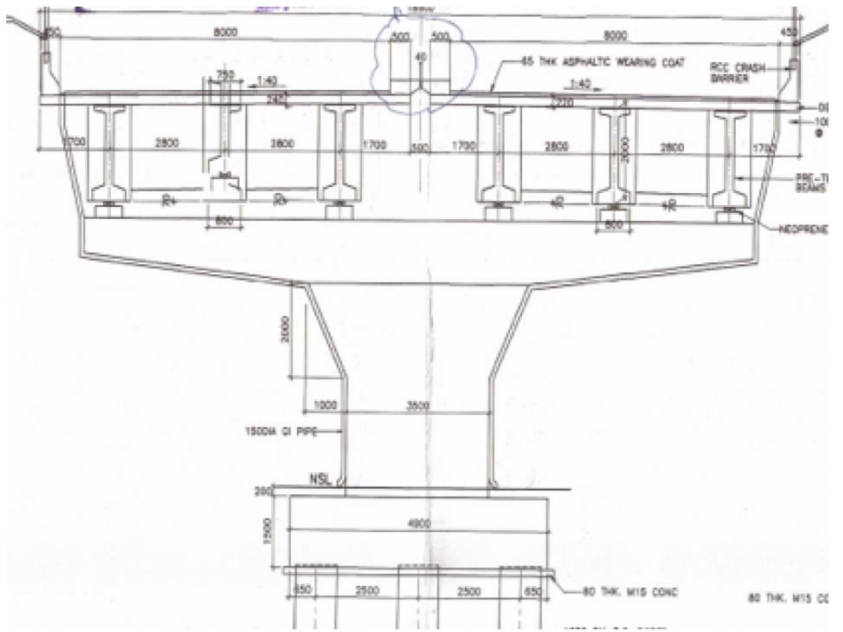
UTTARAKHAND
Public Works Department, Uttarakhand

Background

- The grade separator has 2 independent carriageways (LHS & RHS) catering for 2 lanes each with the overall deck width of around 8.5m.
- LHS including PSC girder superstructure and Bow string arch bridge super structure is already completed and traffic is commissioned.



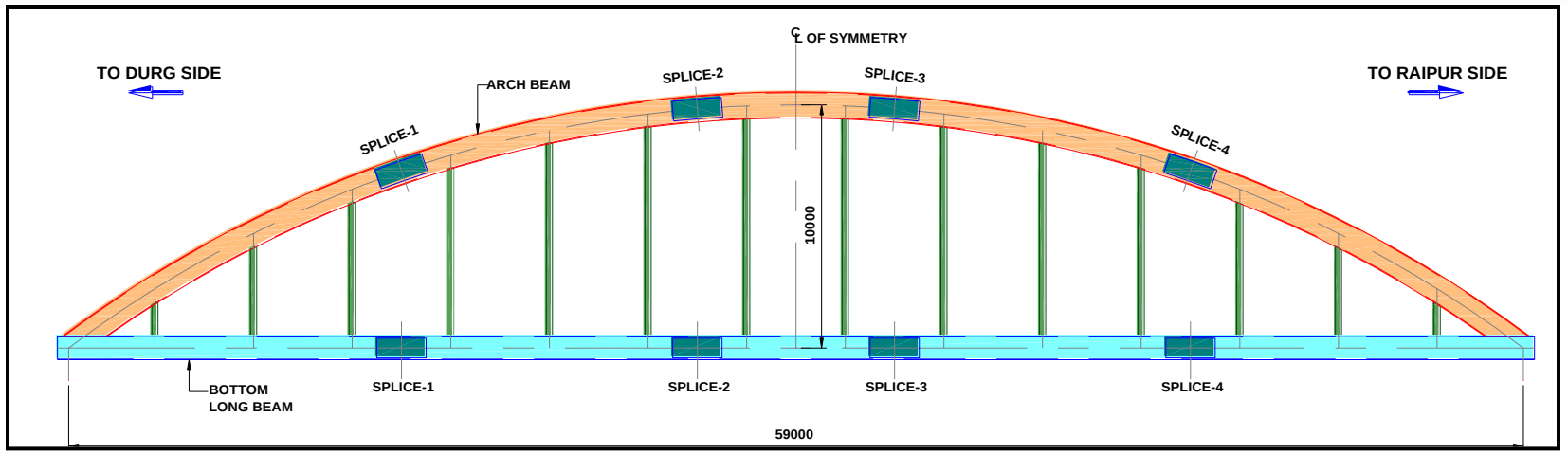




Background

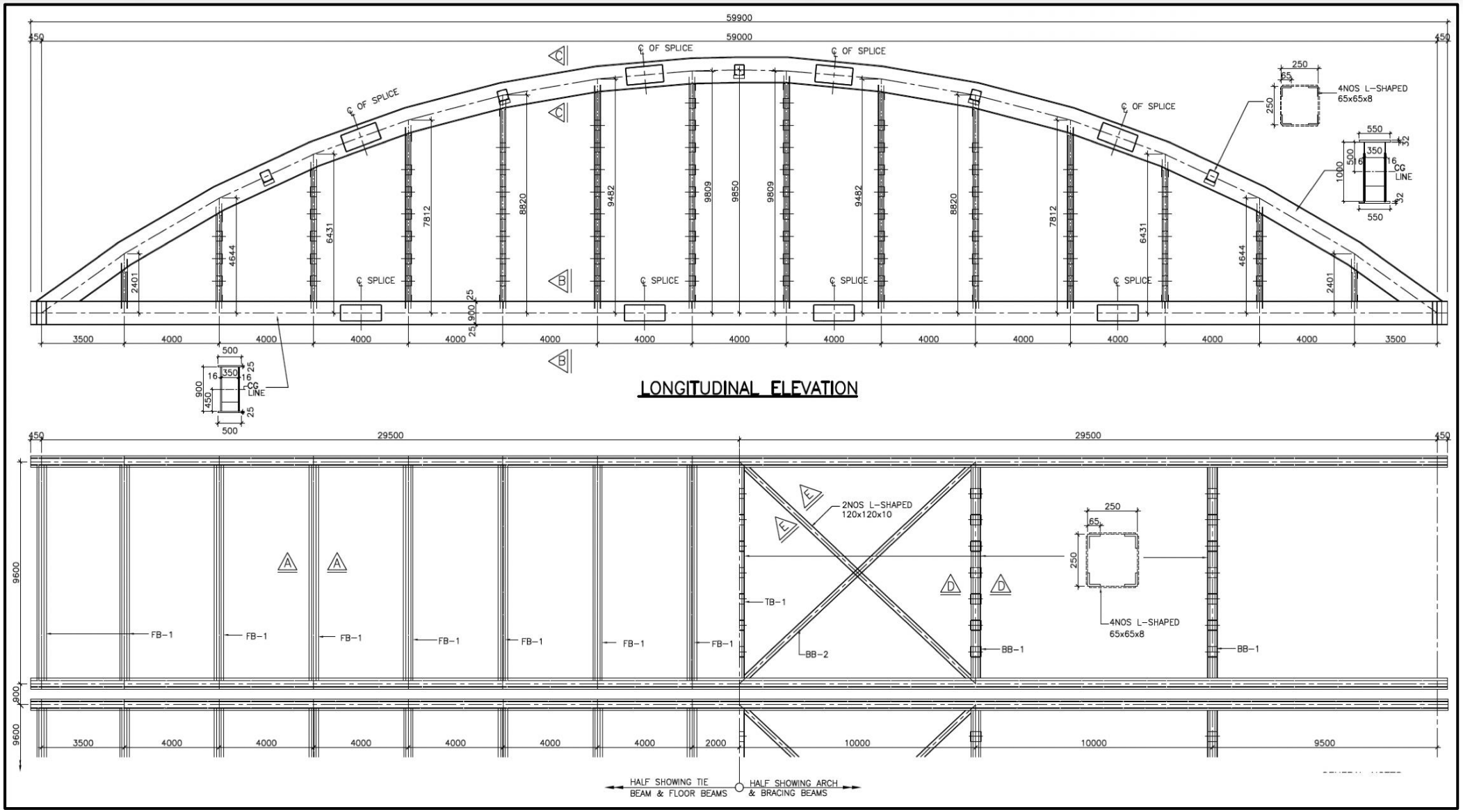
- During the erection, one of the arch ribs and bottom tie chord of RHS which is towards median side adjacent to already commissioned LHS arch bridge was found to be distorted beyond tolerance limits.
- On either side, the approaches were ready for commissiong. Only the deck slab was to be cast on floor beams.
- At the time of appointment of forensic expert, the distortion in the arch rib was corrected to certain extent but the acceptability of the same was in question.

Background


TO DURG SIDE
TO RAIPUR SIDE
℄ OF SYMMETRY
ARCH BEAM
SPLICE-1
SPLICE-2
SPLICE-3
SPLICE-4
10000
BOTTOM
LONG BEAM
SPLICE-1
SPLICE-2
SPLICE-3
SPLICE-4
59000

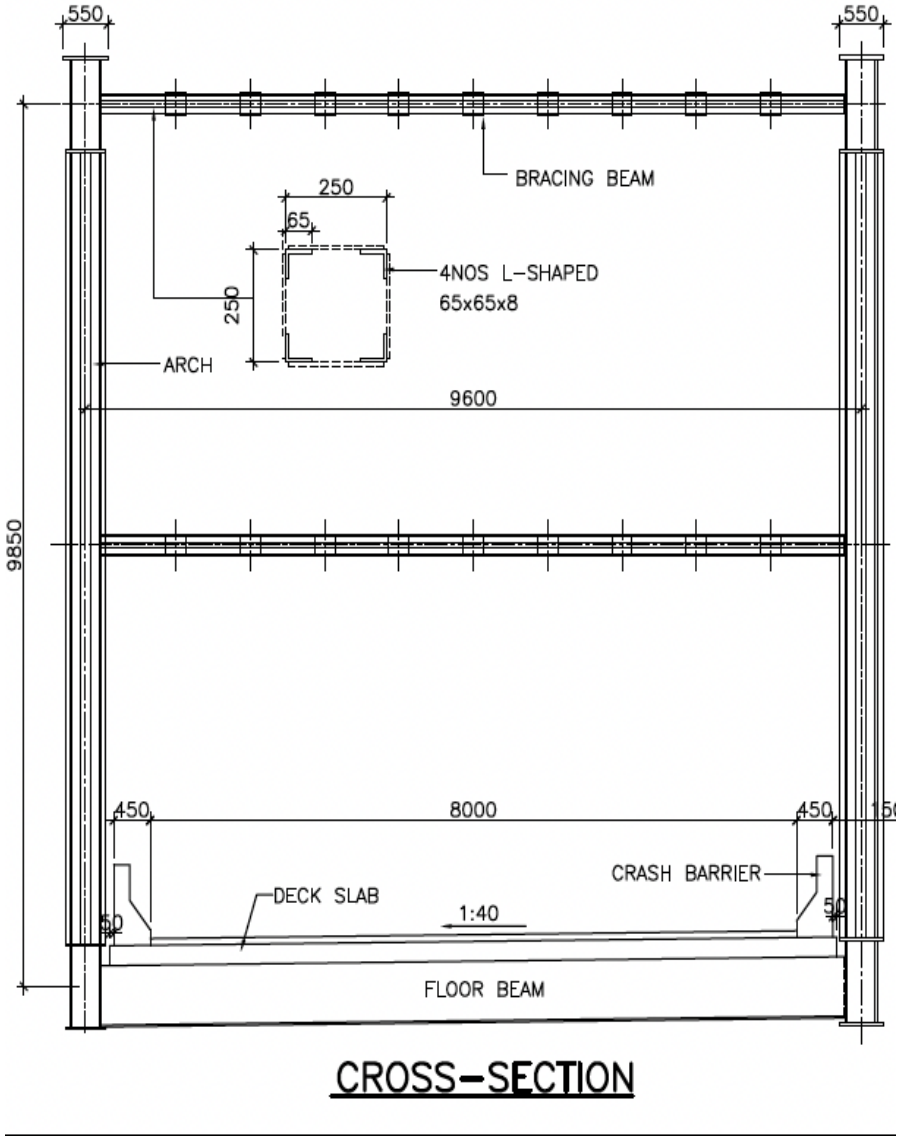
Structural Concepts

- The structural concept of the tied arch adopted is conventional.
- The arch ribs & bottom chord is made up of 5 box segments each fabricated at factory and spliced at 4 locations by in situ welding.

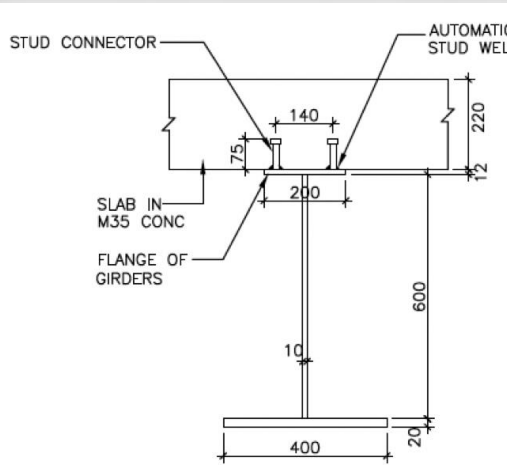


Structural Concepts

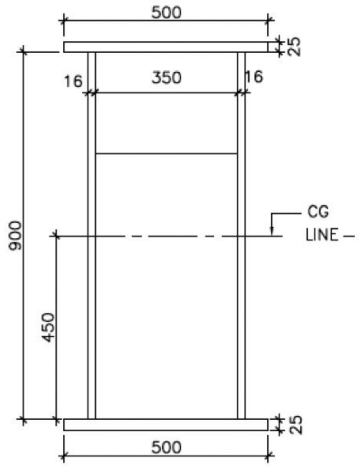
- The plate girder floor beams spaced at 4m c/c is connected to bottom chord by 22 dia. HSFG bolts of grade 10.9.
- 16 dia. shear studs welded by shot guns are spaced at 110 c/c in 2 rows on floor beams.
- **The original design was carried out by simple 2D analysis.**



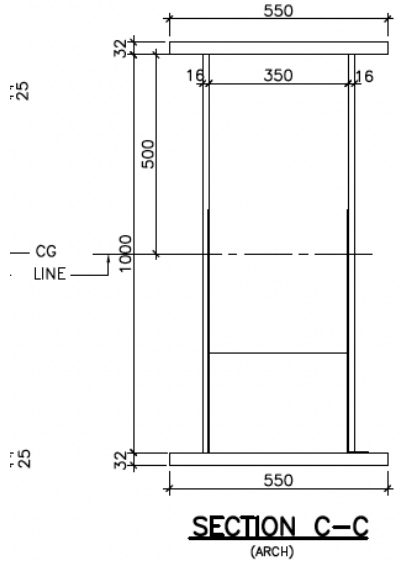
CROSS-SECTION



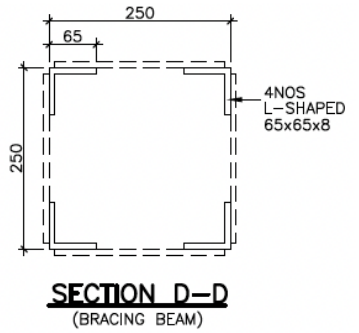
SECTION A-A
(FLOOR BEAM)



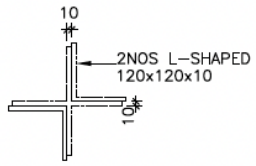
SECTION B-B
(TIE BEAM)



SECTION C-C
(ARCH)



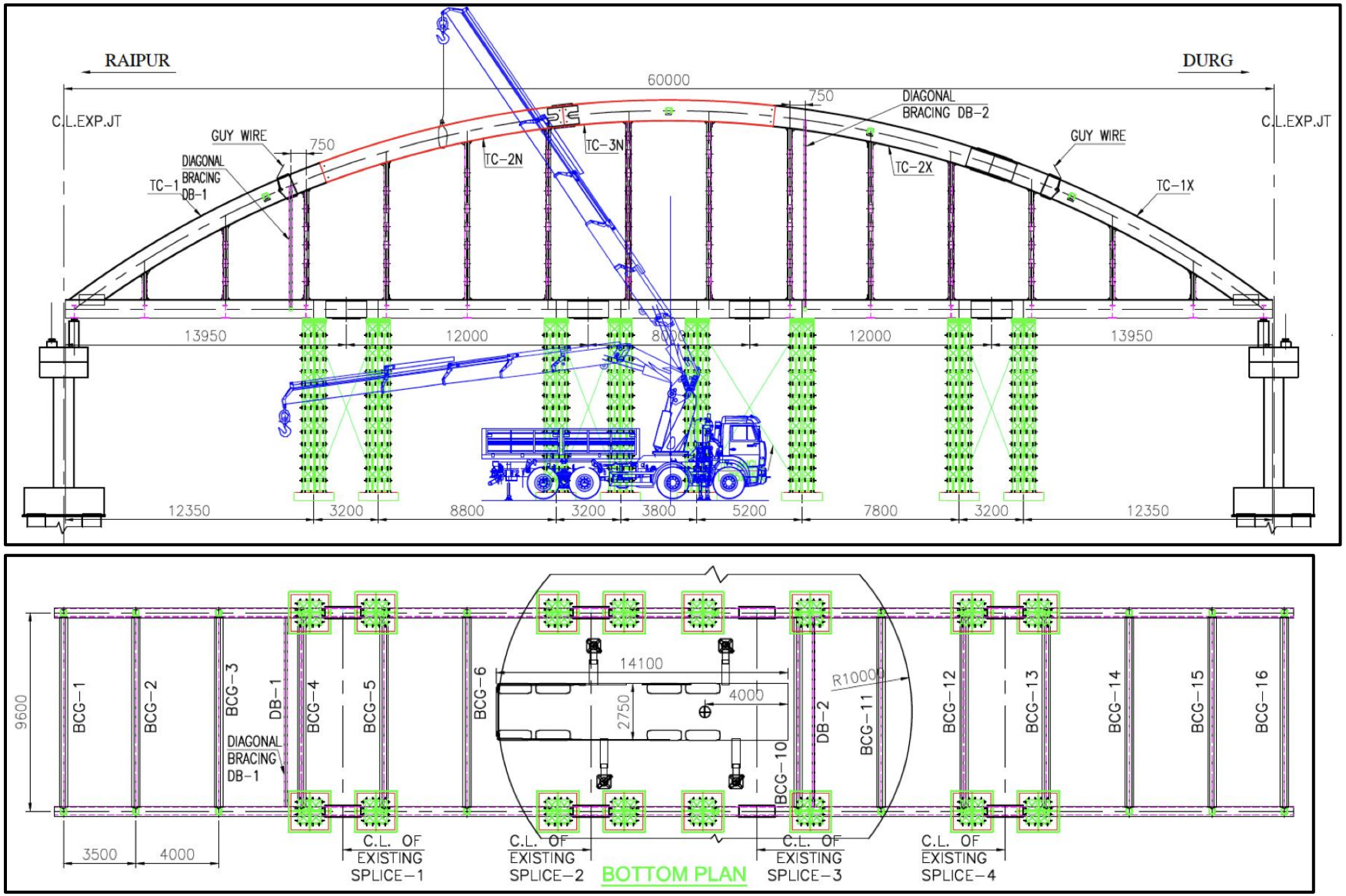
SECTION D-D
(BRACING BEAM)



SECTION E-E
(BRACING BEAM)

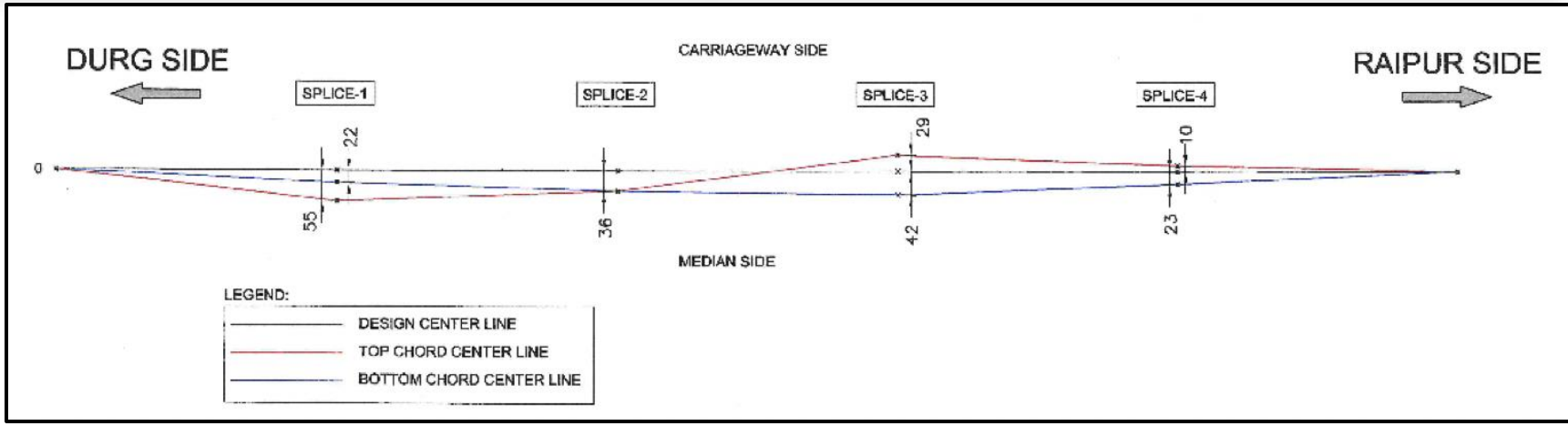
Fabrication & Erection

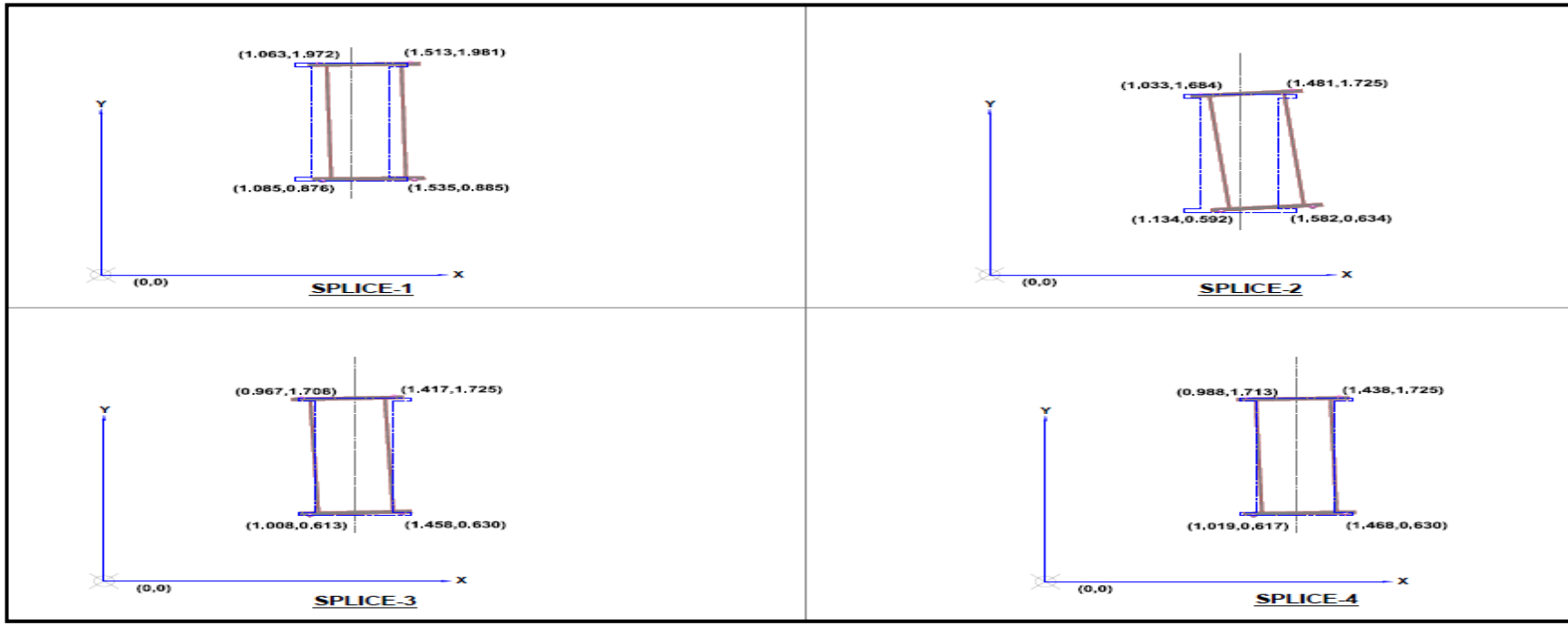
- Fabrication & Erection were carried out during Covid period.
- Fabrication was carried out at nearby fabrication facility.
- The fabricated segments were transported to the location.
- The erection was done by conventional method using cranes on Ground Supported Staging.



Distortion in the arch Rib.

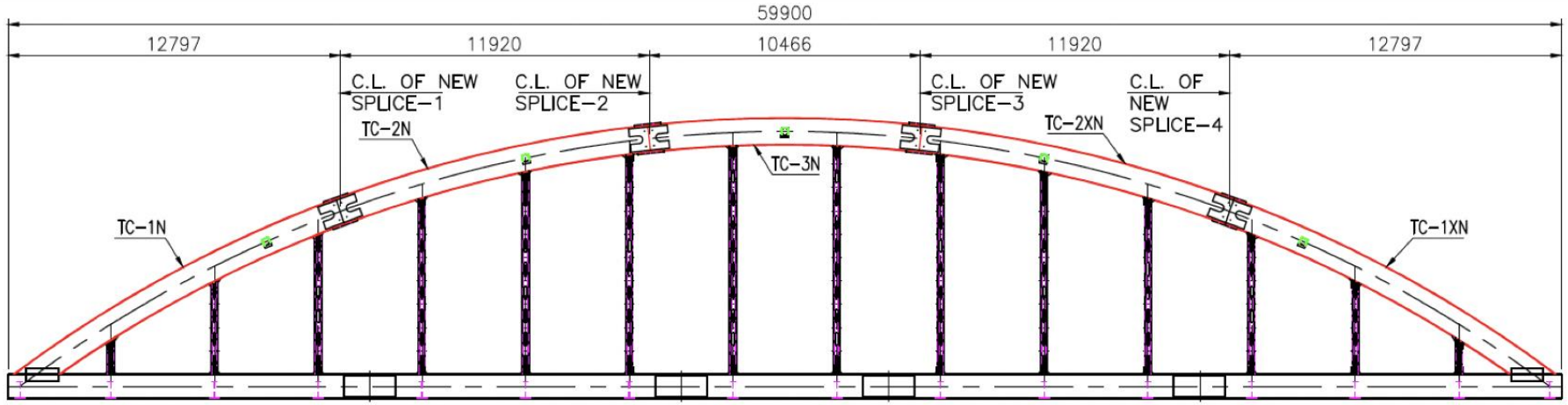
- Distortion in the alignment of one of the arch ribs and Bottom chord was detected during inspection.
- The distortion in the arch rib & the Tie chord were much beyond the permissible limits mentioned in IRC : Sp-104 and IRC : 24-2010.



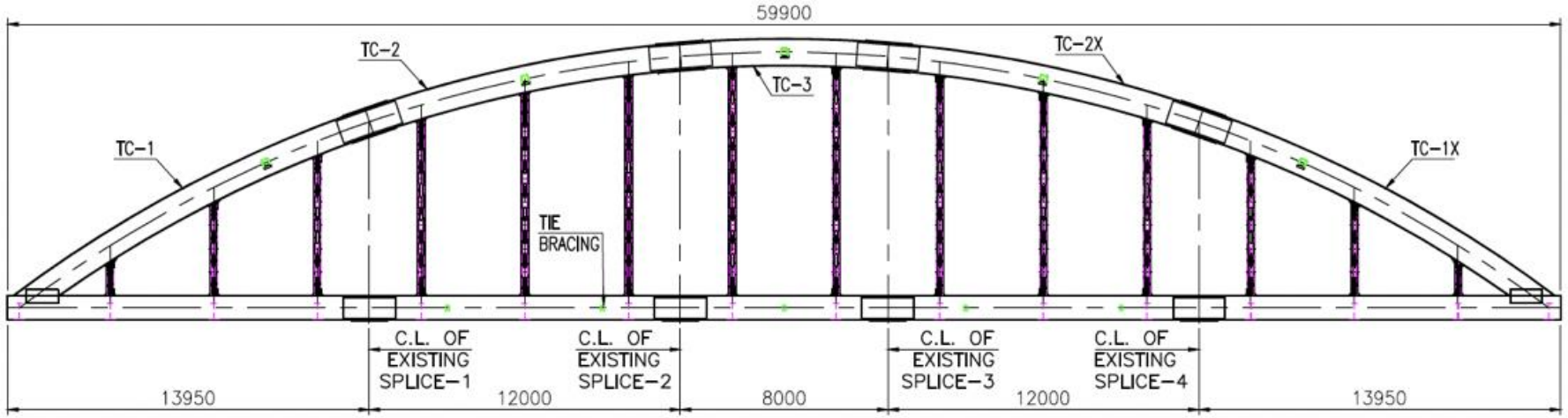


Rectification of Distortion in the arch Rib

- The segment TC3 was most distorted.
- All 5 segments of the arch rib TC-1 to TC-3 & TC-1X to TC-2X were replaced with newly fabricated segments.
- The shape (dumble) & location of splices were changed
- Distortion was brought under the permissible limits.



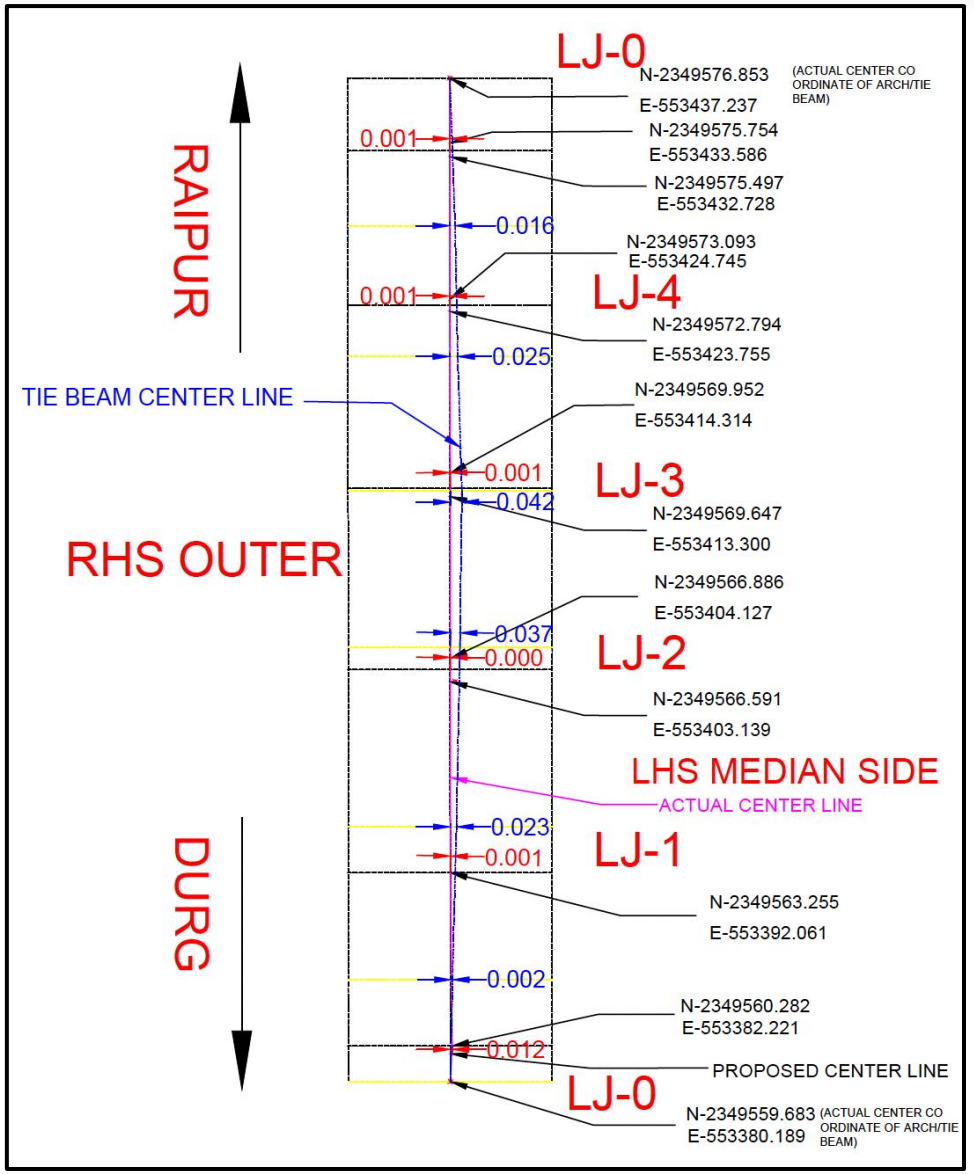
Replaced arch ribs & modified splice location & shape.



Original splicing in the arch rib

Tie Beam rectification

- After the rectification of the Arch ribs and Tie beam, the deviations from the designed positions at splice joint locations were around 10mm for the arch rib which was well within the tolerance limits of 15mm.
- However, for the Tie beam, the deviations at splice joints were varying from 23mm to 42mm which are beyond permissible tolerance limits, could not be rectified due to working space availability.
- In case of such non-conformities where the tolerance limits have exceeded in steel, excessive bulging takes place in concrete, etc. non-linear analysis for design verifications is normally adopted.
- However, linear elastic 3D analysis is carried out in this case to verify for the design adequacy.



Observations on 3D analysis

- In the original design, 2D linear elastic analysis was carried out.
- However, in the revised design taking into considerations the non conformities, 3D analysis was carried out.
- In the 3D analysis especially for Bottom Chord/Tie Beam, the utilization ratio was 0.99 vis-à-vis 2D analysis of 0.73.
- This difference may not be because of the non-conformities as they are not very significant.

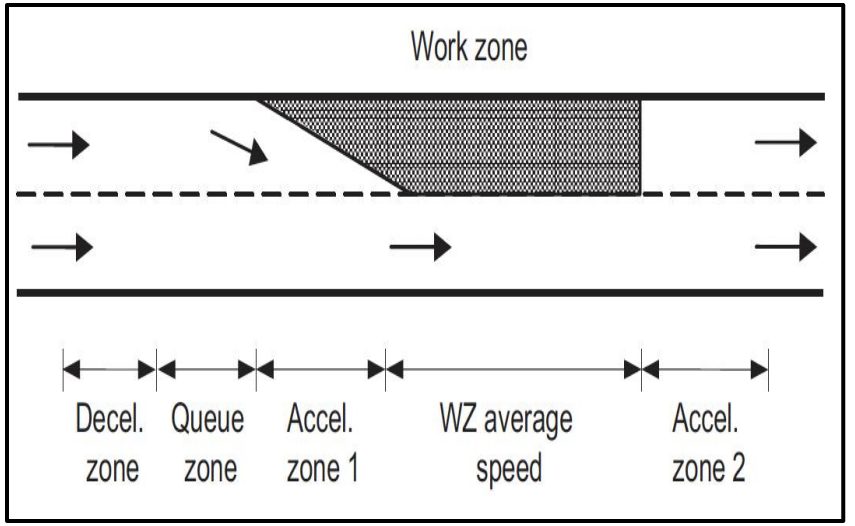
Sr. No.	Component of Bow String Girder	Utilization Ratio as per Approved Design & Drawing of Bow String Girder	Utilization Ratio as per 3D analysis submitted by the contractor
1)	Tie Member / Bottom Chord	0.73	0.99*
2)	Arch Member / Top Chord	0.70	0.75
3)	Vertical Member / Suspender	0.64	0.72
4)	Cross / Floor Beam	0.74	0.74

Summary of findings

- The RHS arch rib was not trial assembled at fabrication yard as such the fabrication defects were not rectified before the erection of the segments.
- The arch ribs are compression members which require proper milling/machining and trial assembled segments for proper alignment which was not done
- For such sensitive structures, 3D analysis should have been done in the first place. The 3D analysis accounting for deficiencies imply the utilisation ratio is almost 99%.
- In the original design by 2D analysis for the bottom chord, the utilisation ratio was 0.73. When the 3D analysis was done for the original design, the utilisation ratio was 0.95.

Impact on Sustainability

- The fly over is ready for commissioning after the casting of the deck slab.
- If the flyover has to be dismantled and reconstructed, there will be huge additional carbon foot print in terms of :
  - ✓ Dismantling & transportation of dismantled members
  - ✓ Fabrication and erection of new bowstring girder bridge
  - ✓ Heavily traffic to be allowed on already commissioned LHS, leading to traffic jams, acceleration, deceleration ,etc.



Impact on Sustainability

- On the basis of the 2 D analysis, already another 3 bowstring girder bridges in the same package were fabricated and erected including the one on LHS which is commissioned for traffic.
- It is found that if the 3D analysis was done in the original design, the utilization ratio would have been higher than 0.95.
- In view of this, if strengthening of the bottom chord is recommended, on the assumption that utilisation ratio is very high, the same has to be carried out for other 3 flyovers which are already fabricated and erected.

Expert Recommendations

- In a situation like this where the design and construction is not in accordance with the sections of the standard, IRC :24 recommends load testing.
- In this case, the design shows that the structure is safe despite crossing the tolerance limits of 15mm in bottom chord.
- The decision also had to be made keeping in view the ramification on other 3 flyovers which are already in position and impact on sustainability.
- However, as a measure of abundant precaution after completion of the bridge, the load testing as per IRC code was recommended.

IRC:24-2010

ANNEX-F

DESIGN ASSISTED BY TESTING

F1. Need for Testing

Testing of structures, members or components of structures is not required when designed in accordance with this standard. Test may be accepted as an alternative to calculation or may become necessary in special circumstances.

Testing on of a structural system, member or component may be required to assist the design in the following cases:

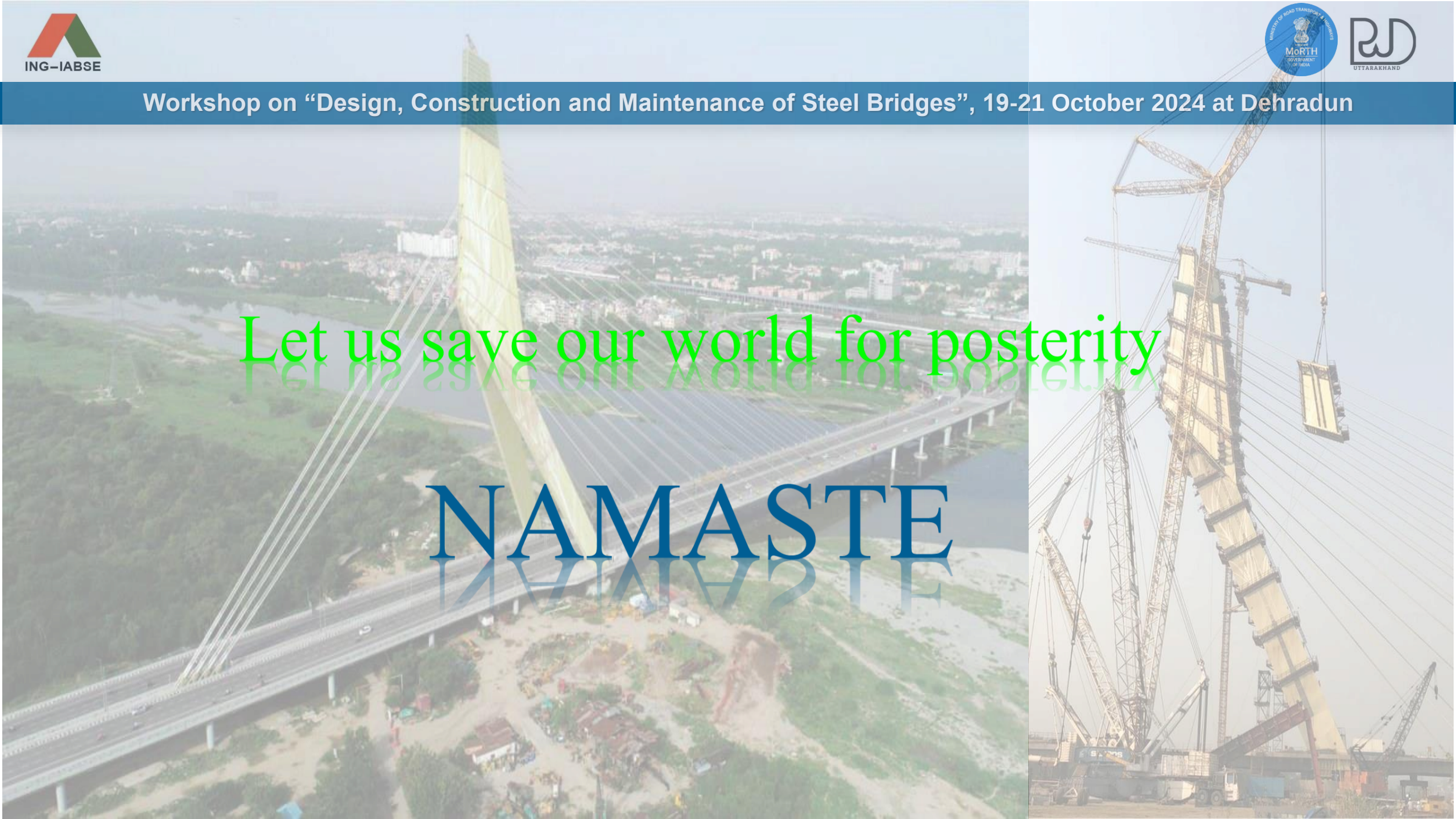
a) When the calculation methods available are not adequate for the design of a particular structure, member or component, testing shall be undertaken in place of design by calculation or to supplement the design by calculation;

b) Where rules or methods for design by calculation would lead to uneconomical design, experimental verification may be undertaken to avoid conservative design;

c) When the design or construction is not entirely in accordance with sections of this standard, experimental verification is recommended;

d) When confirmation is required on the consistency of production of material, components, members or structures originally designed by calculations or testing;

e) When the actual performance of an existing structure capacity is in question, testing shall be used to confirm it;



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