Analysis And Strengthening Of Simple RC Bridge Girder

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Introduction

Bridges are avital part of the road transportation system used toovercome obstacles like rivers, canal, and roads. Among all bridges in the world, the percentage of simple reinforced girder is above 80%. In this chapter, the effectiveness of strengthening a simple RC girder of a bridge has been discussed.In this study, a finite element model of a rectangle RC beam girder has been addressed on various parameters with and without fibre wrapping. In this chapter, the potency of different layers of fibre wrapping was also analysed with ANSYS's help and different results were discussed before and after strengthening the girder. Finally, the strengthening of a delaminated bridge girder prescribed fibre wrapping with varying layers has been performed. Static and dynamic load testing of girder before and after strengthening was executed at site.Deflection, Natural frequency produced at different loading conditions is being discussed. The bridge girder's plasticity has been calculated in terms of deflection recovered when the load was removed.
A specimen bridge was selected to perform this investigation. The superstructure of this bridge has three concrete girders with a reinforced concrete deck slab. Substructure consists of simple RC piers, abutment, and the type of foundation is a pile foundation. **(Fig. 1)**

Type of Bridge – Simply supported RC bridge

Type of Superstructure – 3 numbers of RC Girders with RC Deck Slab.

Type of Substructure – Reinforced Concrete Piers and Abutments

Type of Foundation – Pile Foundation

Total Length of Bridge – About 70 m

Seismic Zone – Zone IV

Fig 1: A view of damaged bridge.

1. Background

The superstructure was found in a very distressed condition. There were various wide cracks found at multiple locations in girder No. 1 and 4. These cracks were very severe, wide and active and were very detrimental for structural strength and safety of the bridge.The concrete cover was found delaminated at multiple locations as shown in **Fig. 2**.The reinforcements were exposed badly due to delamination of concrete cover. It was found that there were no concrete present between reinforcing bars. The section was almost hollow at several locations at the bottom due to present of voids between reinforcing bars. This must have resulted as adequate compaction of concrete between congested reinforcing bars might have not ensured at the time of construction. The flexural cracks were very wide and present in the full depth of girder indicating that the girder has lost its flexural strength completely. There were wide shear cracks also. The concrete was found badly damaged and some parts are just hanging with the girders and about to fall.

Fig.2 : Severely deteriorated girder, wide cracks, loose concrete, exposed reinforcement

Fig 3: Severe deterioration in Concrete

Fig 4: Efflorescent effect on Concrete and cracks in interior girder

The longitudinal RC girders of superstructure were found in a severe distressed condition in span No. 1 and 4. There were wide structural cracks present in the girders. These cracks were originating from bottom and going up to top of girders as clearly shown in **Fig.2.** These were flexural cracks, which are wide and active. These girders seemed to have lost their flexural strength considerably and needed immediate strengthening.The concrete cover of bottom flanges of girders were found severely delaminated at multiple locations as shown in **Fig.3.** The reinforcing bars are provided at the bottom flange in layers. It was found that there are voids between the reinforcing bars provided in different layers. This must had occurred due to inadequate compaction done at the time of construction. The voids between the reinforcing bars can be easily seen in the **Fig. 4.** As the reinforcement has been provided in layers without ensuring proper gaps and adequate compaction was not done so that reinforcement could be properly covered by concrete, a Large number of voids created inside layers of reinforcement. It is clear from the **Fig. 2** that the cover is about to get separated in a larger length. This indicates that the delamination of cover has already been started or has tendency to start in future. It must happen because there are voids between reinforcing bars which can be noticed where the cover has already been separated,Hence the cover should be tested for its integrity with the structure and all loose cover should be removed.

Reinforcement should be exposed and cleaned properly with anti-corrosive paint. New cover should be provided by doing micro concreting.Carbon fiber reinforced polymer, CFRP system should be used for strengthening of longitudinal RC girders. Flexural and shear capacity can be enhanced by using this state-of-art globally accepted technology. Since the section has lost its strength in flexure and shear. The strength of RC girders in flexure can be enhanced by providing carbon fiber laminates at the bottom face of bottom flange and shear strength can be enhance by providing U wrapping of carbon fiber sheet.

2. Anlytical Analysis of Bridge

The T beam girder consists of 3 T beams of effective span 16.5m each spaced at 2.5 m c/c from each other. The girder supports a 2 lane road and hence has been loaded in both the lanes symmetrically with 6 axles of 7.8t, 11.5t, 11.5t, 11.55t, 11.55t and 7.9 t on one lane. The contact area of tyres with the girder surface has been considered according to IRC 6: 2016, Class A loading as 250mm X 500mm for 11.5t and 11.55t axles, and 200mm X 380mm for 7.8t and 7.9t axles. Self weight of the girder has also been considered by applying standard earth gravity in ANSYS environment. The weight of the pavement has been applied as a pressure load of intensity 1875 Pa (considering unit weight of the pavement as 25kNm-3), distributed on the top surface of the girder.

For meshing, SOLID 187 element has been used for the girder, supports and CFRP strips, while SOLID 186 element has been used for the GFRP strips on the side of the girder. The default element size is 957.98mm while for the CFRP and GFRP strips element size has been taken as 100mm because of their thin profiles. The CFRP strips have been generated with the help of tetrahedron meshing. The axle loads have been applied with the help of contact blocks of dimensions same as that of ground contact dimensions of tyres and thickness of 50mm. They are also simulated with the help of SOLID 186 elements. As a result, the simulation is carried out with 35,014 elements and 151,574 nodes.

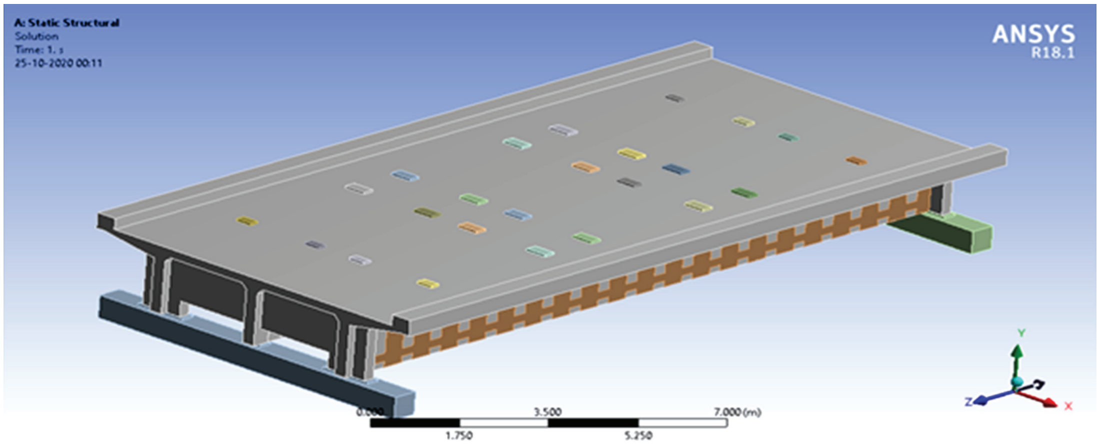

Fig. 5: Modelling of deck slab using ANSYS

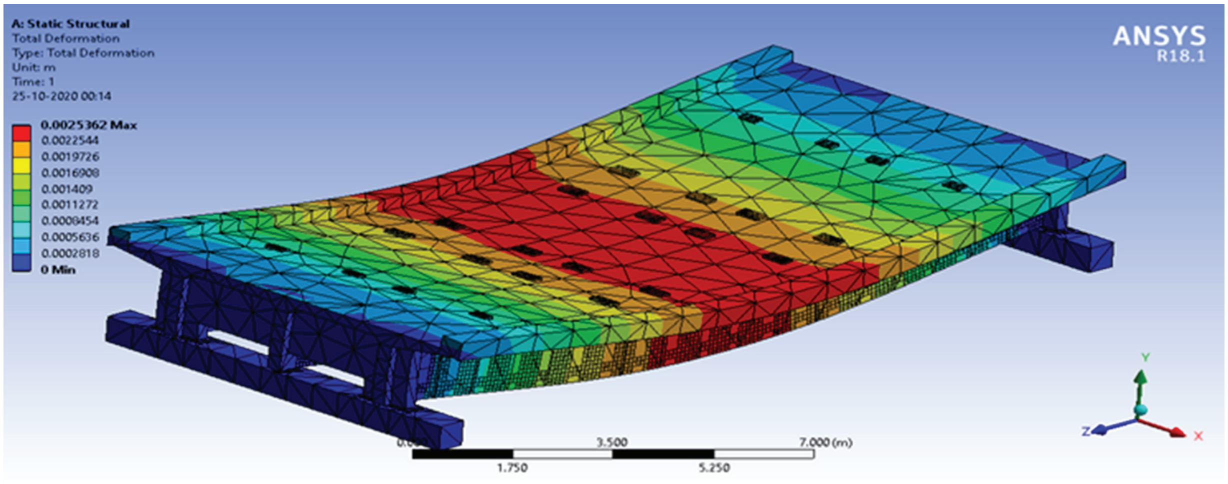

Fig. 6: ***Total deformation of deck slab under static loading***

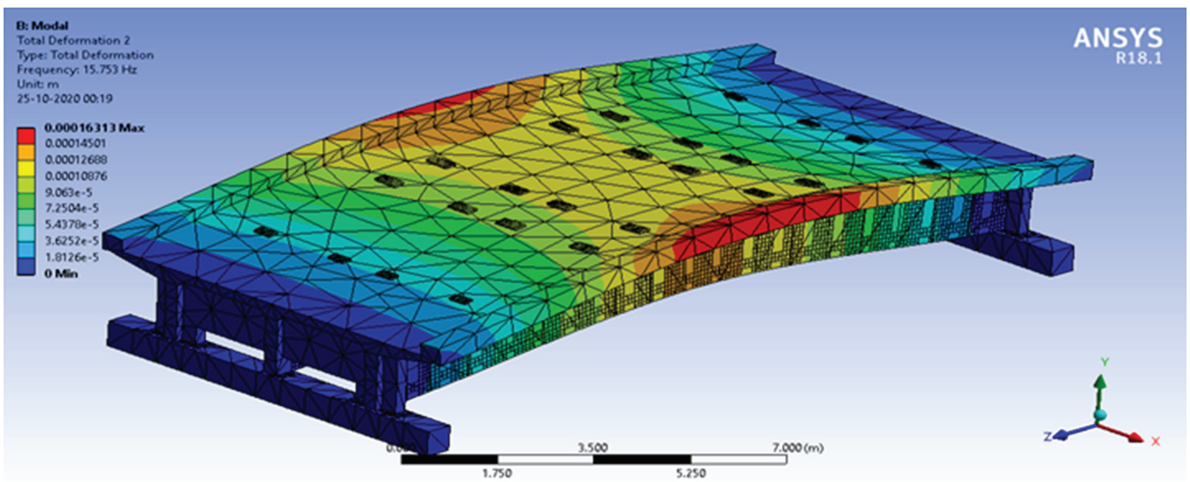

Fig. 7: ***Total deformation of deck slab under dynamic loading loading (frequency 15.75 Hz)***

3. Strengthening Scheme

Following procedure have been adopted for repair and strengthening of Distressed RC girders.

1. Strengthening of girders of span 1 and 4 were done by using Carbon fiber reinforced polymer, CFRP system. Flexural capacity was enhanced by providing two 100 mm wide 1,4 mm thick carbon laminates at bottom face of bottom flange of each RC girders as shown in **Fig 8,9 and 11.**
2. Shear capacity were enhanced by providing single layer of 400 GSM Carbon fibre U wrap 500 mm wide 800 mm c/c as shown in **Fig 8, 9,10.**
3. Span 2 and 3 were repaired by micro concrete and cement/epoxy grouting. No strengthening work with CFRP has been done on girders of this span.

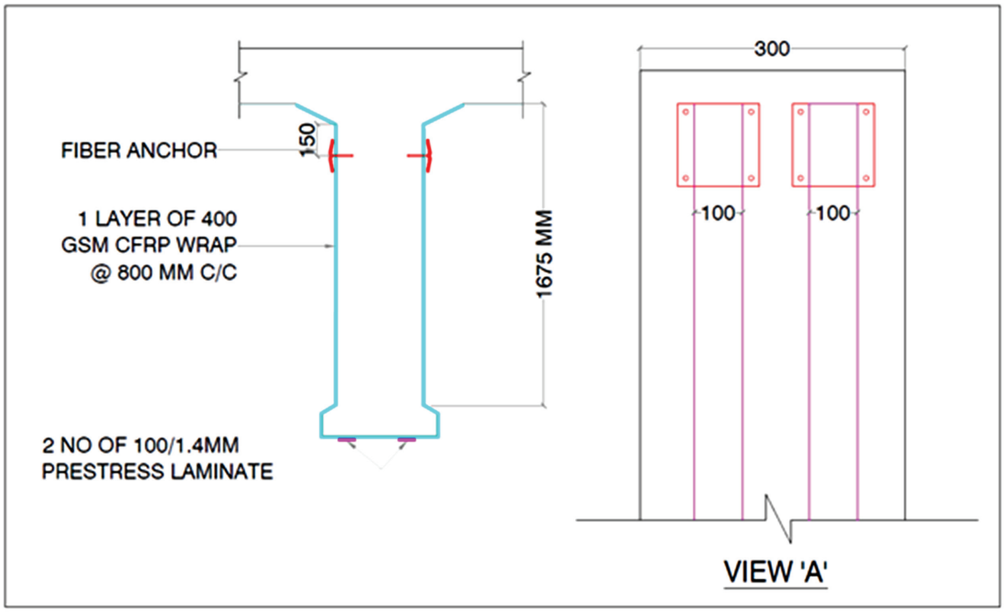

Fig. 8: Strengthening of Girder with FRP Laminate and U-wrap (Sectional Elevation)

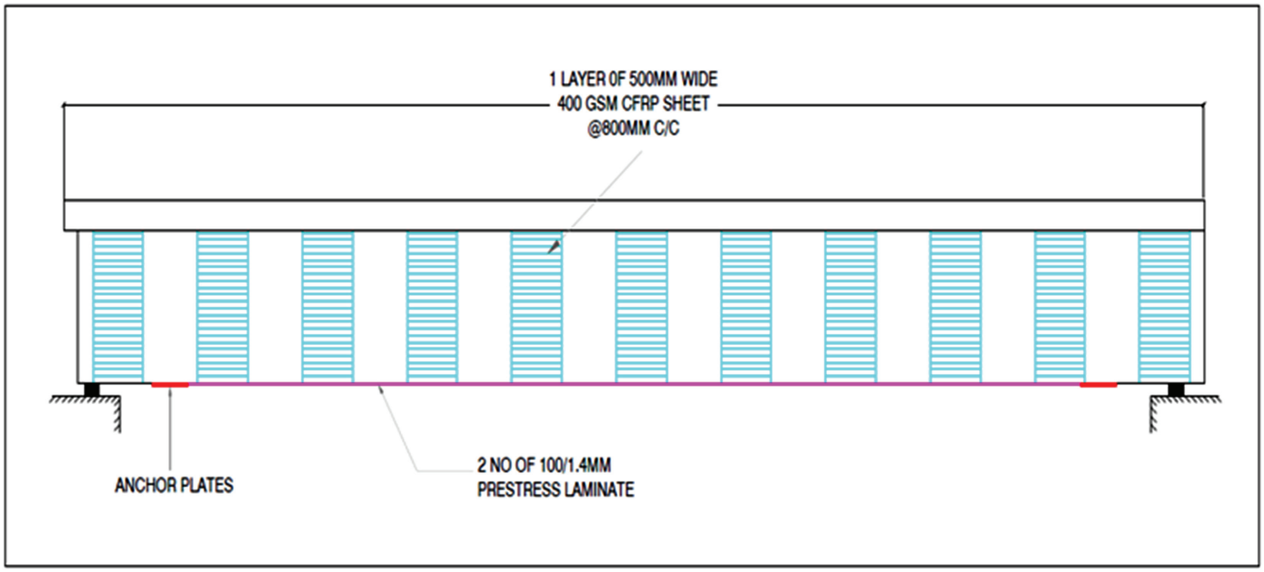

Fig. 9: Strengthening of Girder with FRP Laminate and U-wrap (Side Elevation)

Fig. 10: Exposed Reinforcement and Anti-corrosive paint

Fig. 11: RC girders Strengthened by CFRP System

4. Cases and Arrangement of Load

Static and dynamic load tests were performed to know the behavior of girders in flexure under vehicular load. The load tests have been carried out by placing the vehicles at different locations of deck to capture the behavior of all girders for maximum loaded critical conditions. The trucks were placed back to back as shown in **Fig 13-15**, to generate maximum absolute bending moment and deflection in the girders.

The deflection at center were measured below each girder for every load combination by installing LVDTs at Center of girders as shown in **Fig.-12**. Recovery were also measured after placing the loads and removing them after sufficient time. Combination of four and two loaded trucks each weighing approximately 31 tonnes were used for load test as under

Case I: Static Load Test with Two Truck

Two truck were used for performing static load test on all four spans of bridge with three load positions

- **Centre Loading :** The trucks were placed back to back at centre as shown in **Fig-13,14** to create maximum bending moment in central girder as the maximum load is coming directly over this girder.
- **Left Lane Loading :** The trucks were placed back to back on the left lane. In this case the maximum load is coming on left girder.
- **Right Lane Loading :** The trucks were placed back to back on the right lane. In this case the maximum load is coming on right girder.

Case II: Static Load Test with Four Truck

Four trucks were placed back to back symmetrically on the deck as shown in **Fig-7** for span 1 and 4 which were strengthened by using carbon fiber reinforced polymer in both bending and shear.

Case III: Dynamic Load Test with Two Truck

Dynamic Loading – Two loaded trucks, each weighing 31 tons passed in 2 different lane.

Position of axle loads loaded test trucks used for static loading and their values are shown in **Fig. 12 to 15** for a set of two/four trucks placed back to back.

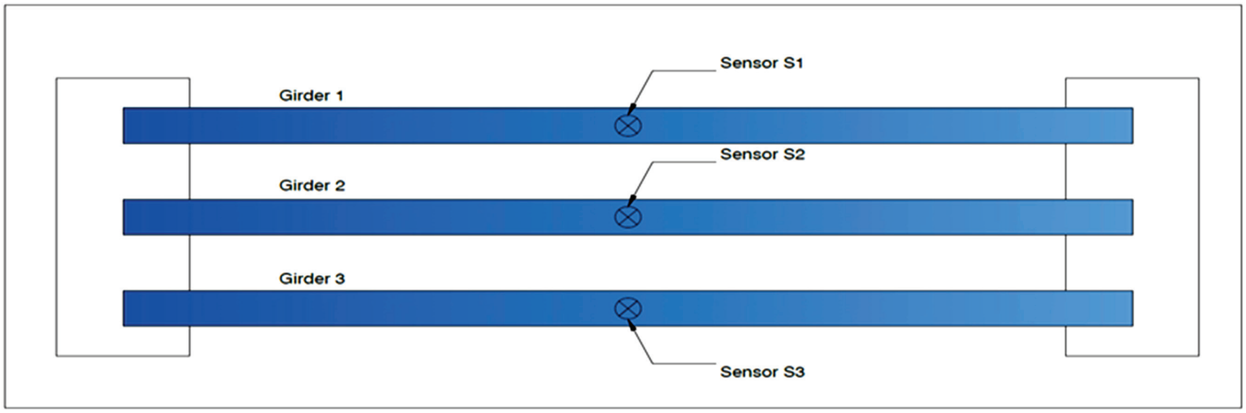

Fig 12: Arrangement of Sensors (LVDTs) at the center of each girder

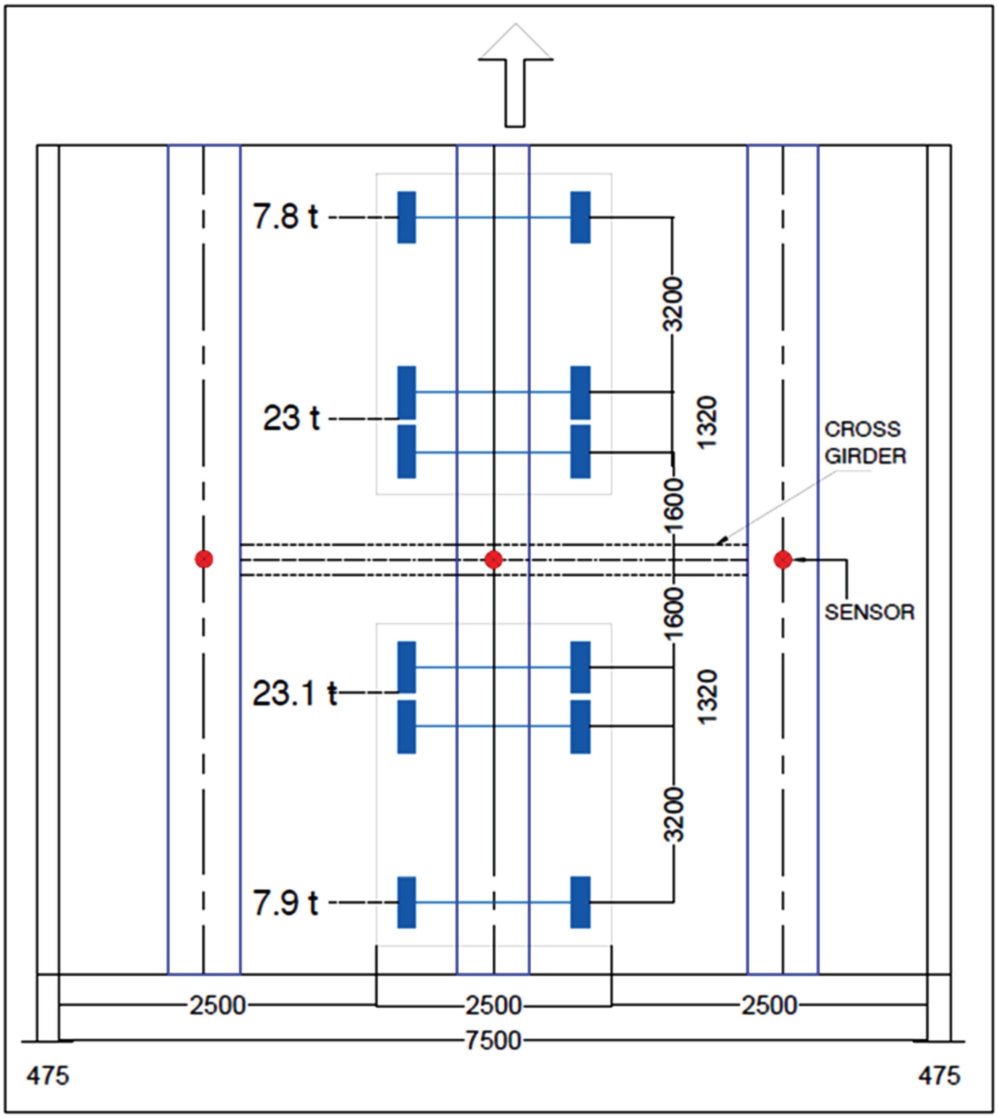

Fig 13: loading arrangement of axle load

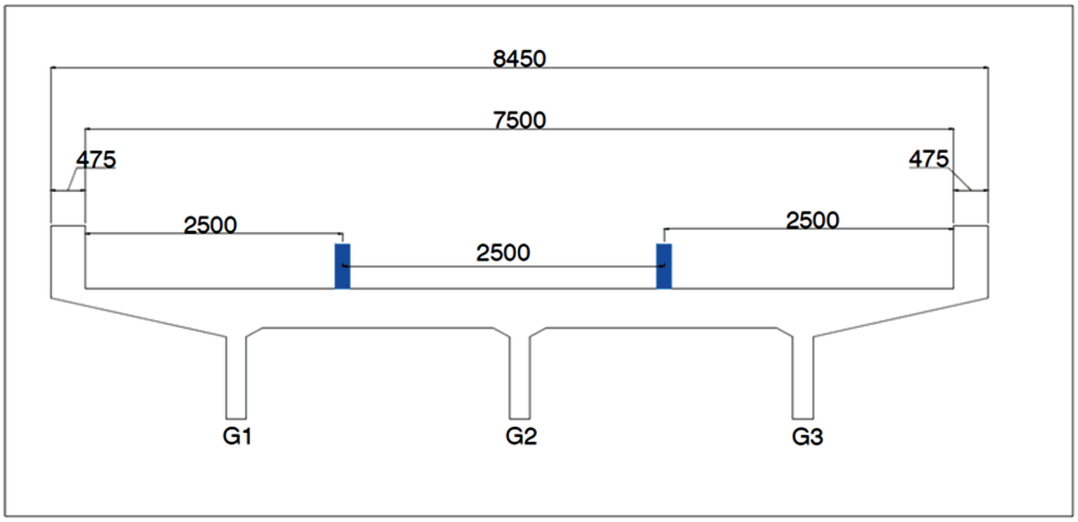

Fig 14: Arrangement and Axle Load of Two trucks for center

Fig 15: Loaded Trucks placed for Static Load Testing

5. Results and Discussion

1. Linear Variable differential transducer, LVDTs were placed at the bottom face of lower flange of each girder at centra to measure the deflection.
2. The deflection at centre of each girder were taken by placing two loaded trucks of approximately 31 tones each back to back to create severe loading condition by placing more loads at centre. The measured deflection is given in table-1.
3. The Maximum deflection measured in different load positions is 3.32 mm in girder 1 of span 3. The Maximum deflection in span 1, 2, 3 and 4 are 2.83 mm, 3.30 mm, 3.32 mm and 3.02 mm. Maximum deflection in all girders are within permissible limit of L/1500 as prescribed in IRC SP:37 as the length of girder is 16.5 m.
4. It is observed that the max deflection in girders of span 1 and 4 is less than the maximum deflection of girders of span 2 and 3 and the increased deflection in girders of span 2 and 3 is up to 16%.
5. The reason behind the less deflection of girders of span 1 and 4 is that these girders are repaired and also strengthened with CFRP whereas girders of span 2 and 3 are only got repaired. It is also of note that girders of 1 and 4 were severely damaged if compared with girders of span 2 and 3. This indicates that the strengthening with CFRP done has increased the capacity of severely damaged girders of spans 1 and 4 considerably.
6. Full recovery was measured after removal of loads in all spans in two truck loaded conditions.
7. The load test with four truck loaded condition was done on span 1 and 4 only as these girders have been strengthened with CFRP system. Total Load of 113.6 tone was applied with 92.2 tons placed at the centre by placing trucks back to back. This loading arrange will produce more critical load than placing one lane 70R and two lanes class A loading.
8. The maximum deflection in girders of span 1 and 4 are 4.30 mm and 5.14 mm respectively. The maximum deflection is within permissible limit of L/1500 as prescribed in IRC SP:37 as the length of girder is 16.5m.
9. The Minimum recovery in girders of span 1 and 4 after removal of load is 95.1% and 91.8%, which is more than 75% as prescribed in IRC 51 for RCC structure.
10. The deflection was also measured in the girders in dynamic loading condition by passing two loaded truck over the bridge. The deflection measured are given in table-3. The maximum deflection observed in girders of span 1, 2,3 and 4 are 1.85 mm, 2.24 mm, 2.12 mm and 1.82 mm respectively. The deflection observed in girders of span 2 and 3 are higher side by 16 to 22 %. Less deflection in girders of span 1 and 4 were noticed as these girders are also strengthened by CFRP system.

Table 1. Deflection Readings for Static Load for Two Truck

Sr. No.	Position of Both Trucks	Girder No.	Deflection Observed in mm			
No.	**Trucks**	Girder No.	**Span 1**	**Span 2**	**Span 3**	**Span 4**
1	Centre Loading	Girder No. 1	1.49	2.40	2.31	1.80
		Girder No. 2	2.00	2.70	2.58	2.00
		Girder No. 3	1.70	2.15	2.16	1.77
2	Left Lane Loading	Girder No. 1	2.70	2.95	3.32	3.02
		Girder No. 2	1.87	2.30	2.29	2.08
		Girder No. 3	0.55	1.20	0.70	0.74
3	Right Lane Loading	Girder No. 1	0.69	1.25	0.90	0.86
		Girder No. 2	1.88	2.50	2.10	2.21
		Girder No. 3	2.83	3.30	3.00	2.93

**Full Recovery are observed after unloading the truck.*

Table 2. Deflection Readings for Static Load Test for Four Truck

Sr. No.	Position of Both Trucks	Girder No.	Deflection Observed in mm	Deflection Recovery in mm			% Recovery
				After 5 min	After 10 min	After 20 min	
1	Span 1	Girder No. 1	3.50	3.26	3.30	3.34	95.4
		Girder No. 2	4.26	4.00	4.04	4.05	95.1
		Girder No. 3	4.30	4.11	4.15	4.18	97.2
2	Span 4	Girder No. 1	4.80	4.57	4.58	4.64	96.7
		Girder No. 2	5.14	4.62	4.68	4.72	91.8
		Girder No. 3	4.70	4.23	4.28	4.35	92.6

Table 3. Deflection Readings for Dynamic Load Test for Two Truck

No.	**Trucks**	Girder No.	**Span 1**	**Span 2**	**Span 3**	**Span 4**
1	Two loaded trucks, each weighing 30 tons passed in 2 different lane	Girder No. 1	1.60	2.11	2.03	1.60
		Girder No. 2	1.85	2.24	2.12	1.82
		Girder No. 3	1.35	1.89	1.85	1.54

6. Conclusion

The distressed girders of all spans of the bridge were repaired by using Cement/Epoxy grouting and micro-concrete. Girders of span No. 1 and 4 were found more severely damaged and large deflection were also noticed in those girders. Girders of span 1 and 4 were also strengthened by using Carbon Fiber Reinforced polymer, CFRP system.Load testing were done by using 2 truck and 4 truck system placed back to back symmetrically at the middle of the span. Each truck has approximate weight of 31 tons as depicted in the fig 13. Load testing were performed to verify the strength of girders after repair and strengthening.The deflection in each girder were found within permissible limit of L/1500 as mentioned in IRC-37. The recovery is also much within the limit as specified in IRC-51.Though the condition of girders of span 1 and 4 had been more severely distressed as compared to girders of span 2 and 3, but the deflection in these girders were found less than 15% if compared with deflection of girders of span 2 and 3. That indicates that there is considerable increase in stiffness and capacity of girders of span 1 and 4. The reason is that these girders have also been strengthened by CFRP system.

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