Retrofitting and Rehabilitation of Bridge with FRP: Case Study

Dr. Gopal Rai

Dhirendra Group of Company (DGC) www.dgc24.com, gr@dgc24.com

Abstract

This paper aims at the topic of strengthening of existing old deteriorated bridges with the help of case study of retrofitting of half century old Indian railway bridge. The structure has monitored before and after strengthening. The two response parameter has considered for the monitoring i.e. deflection and frequency, because deterioration and cracks affect the stiffness of structure and hence these responses. The result shows significant change in response.

Keywords: Retrofitting, Frequency, Stiffness, PSC I girder, FRP.

Introduction

Deterioration of ageing bridges has been well noted worldwide. Retrofit of deteriorated infrastructure has become a major challenge for governments in developed and under developing countries in the last decades. In response, there has been an escalating world-wide tendency to select Fiber Reinforced Polymer (FRP) composite retrofit systems as an alternative to traditional bridge rehabilitation schemes. Accordingly, several design codes were developed to standardize the bridge strengthening process using FRP systems. This paper covers the effectiveness of external FRP strengthening of bridge elements such as I-girders with help of case study.

Description of case study

Western Railway has proposed rehabilitation of PSC I girders on Bridge of Godhra-Ratlam section of Ratlam Division of Western Railway, India. The Bridge has been observed to require immediate strengthening. The bridges were constructed during 1958-60 and as such no detailed design & drawings are available. The bridges have composite PSC I girders supported on neoprene bearing. The main reason for retrofitting of the PSC I girders on the bridges was due to development of cracks on the girders. As the cracks are propagating with time strengthening of these girders are required immediately to arrest further deterioration.

Preliminary Structural Assessment

The overall evaluation included a thorough field inspection, measurement of different load response parameter such as deflection and frequency for static and dynamic load and a structural capacity analysis. Existing construction and operational documents for the bridges were reviewed, including the design drawings, project specifications, as-built information, and past repair documentation. Assuming that the PSC girder beams behave as simple reinforced girder beam with no prestress. As the existing reinforcement details are not known, an analysis is done on the girder to find the reinforcement required for the section. Based on this reinforcement and section details the capacity is found out.

Table 1. Dimension Details of Bridge of PSC I Girder.

Sr. No.	Details	
1	Type of superstructure	PSC-I girders
2	Span	1 x 18.29 m
3	Clear span	18.15 m
4	Effective span	19.17 m
5	Overall length of girder	19.67 m
6	Overall length of deck slab	20.20 m
7	Diaphragm details	6 (4 Intermediate and 2 End) size-1880x1450x275 mm
8	Name of river	Nakdi river
9	Year of casting and launching of Bridge	1958-60
10	Total weight of girder (per span)	145 T (Girders +Deck slab+Diaphragms)
11	Ballast cushion	300 mm
12	Details of track	60 Kg, Sleeper-PSC
13	Bank height in approaches	10.5 m
14	Dimensional details of girder cross section	Overall depth-2130 mm Width of Top and bottom bulb- 620,Thickness of web-310 mm, Depth of web-1435 mm
15	Thickness and width of deck slab	Thickness-150 mm,width-4300 mm
16	Substructure type and material type	Stone masonry in cement mortar, gravity type substructure

1) Visual Inspection

The PSC I girders had been severe cracks. Discoloration due to deterioration with time had seen in the overall structure. Spalling/ delamination of concrete had been observed in diaphragm bottom. Cracks at the girder bottom at bearing locations had been observed. Termite attack had observed in the girders. Surface deterioration had been observed throughout the structure. Severe spalling and corroded reinforcement exposure had been observed at the bottom slab. This may be attributed to the carbonation taken place in the structure. It is expected that such a distress will be reflected through a change of stiffness of the girder. As the stiffness of the girder changes, the natural frequency will also change. Hence, it may be possible to monitor the health of a bridge girder in a non-destructive in-situ manner by measurements of the natural frequency at regular intervals. It has decided to monitored natural frequency and deflection of the bridge before and after strengthening.

(a)

(b)

Fig 1. Deterioration of structural members of Ratlam Railway Bridge. (a)Cover delamination and corroded reinforcement exposure observed in deck slab bottom (b) Severe cracks seen in girder

Fig 2. Structural health monitoring of Ratlam railway bridge with help of sensor

2) Pre-strengthening Monitoring for deflection and frequency

The bridge girder has monitored with the help of LVDT and accelerometer. The frequency has measured for dynamic forces and deflection has measured for static as well as dynamic forces. The un-cracked and undamaged girder has also monitored for reference.

(a) Before Strengthening

(b) After Strengthening

Fig 3. Actual load has applied to bridge for monitoring

FRP Strengthening of PSC I Girder of Railway Bridge

The strengthening design for the PSC I girders was proposed with the help of Prestressed carbon laminates and carbon fiber wrapping. It has assumed that there is no prestress in the PSC girder beams and that it is acting as RCC girder beam.

Flexural Strengthening

In order to increase the flexural capacity and stiffness, reduce the distribution and width of the flexural cracks and improve the performance of the RC members under the service load conditions, the FRP material can be epoxy-bonded to the areas under tension while the fibers are oriented parallel to the principal stress direction. This type of strengthening can increase the ultimate flexural strength of the strengthened members from 10% to 160% (2). For the railway bridge 3 numbers of prestressed laminate has provided at bottom of I girder and 2 number of non-prestressed laminate has provided at side face of bottom flange of I girder (as shown in figure) to increase the stiffness and the flexural capacity of the girder. The numbers of prestressed and un-prestressed laminate has calculated through retrofitting design calculation.

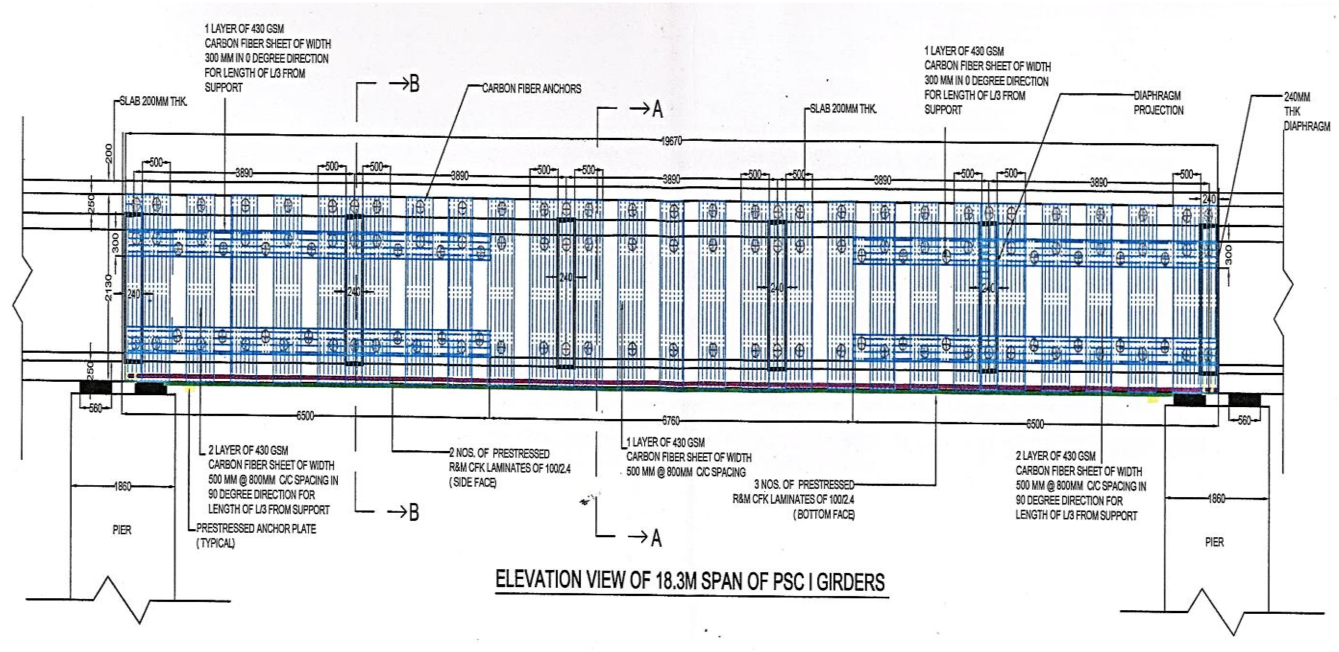


Fig 4. Elevation View of 18.3m Span of Ratlam Railway Bridge PSC I Girders

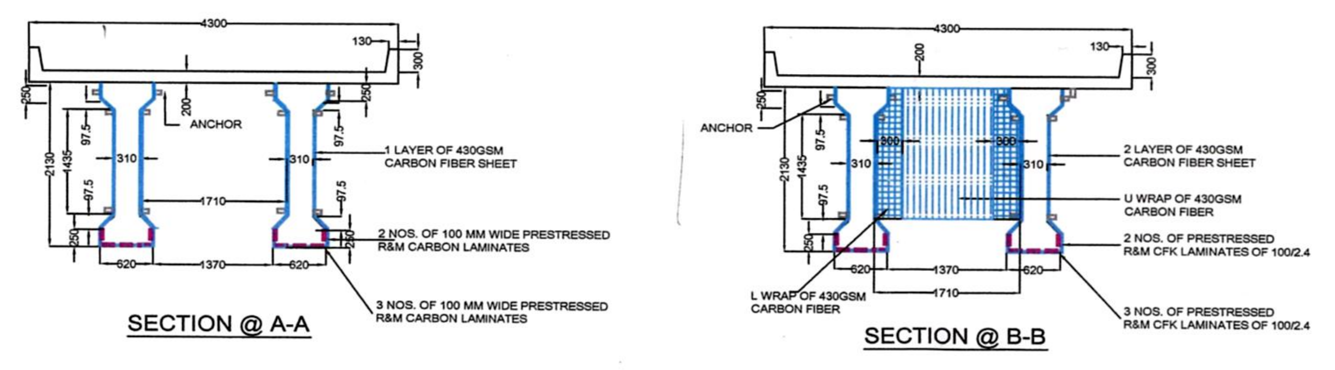
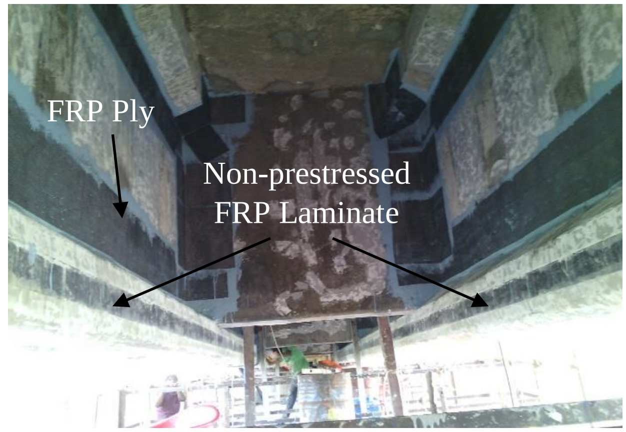


Fig 5. Sectional elevation of Ratlam railway bridge PSC I girders

Shear Strengthening

The shear strength of an RC beam is attributable to aggregate interlock, compressive zone concrete, dowel action, and transverse steel reinforcement, and can be increased significantly by bonding the FRP composites externally to the RC member, having the fibers crossing the shear cracks and parallel to principal tension stresses. Thereby, the beam will fail in flexure and the brittle shear failure can be avoided. To this end, the FRP composite is bonded to the beam covering either only the two sides of the beam (side bonding), or the two sides together with the tension face (U-jacketing). It is noteworthy that, covering the whole cross-section (closed wrapping) is possible only in bridge columns (and not the girder), because of girder's being integral with the slab. For the railway bridge girder FRP ply has applied as U wrap (as shown in figure) as it is most efficient.



(a) **(b)**

Fig 6. FRP Retrofitting of Ratlam railway bridge girder**. (a)** U- Wrap FRP applied to PSC I girder. **(b)** FRP ply and non-prestressed laminate applied to inner side face of PSC I girder

Parametric investigation and experimental result

The frequency of any structural member is depend on the stiffness and the mass of member.

$$\omega = \sqrt{\frac{k}{m}}$$

$$2\pi n = \sqrt{\frac{k}{m}}$$

$$n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$n \propto k \; \ldots\ldots\ldots\ldots \qquad \textit{for constant mass}$$

Where,

ω = Circular frequency

k = Stiffness of the member

m = Mass of the member

n = natural frequency

The natural frequency will be directly proportional to stiffness of structural member if its mass keeps constant. In the retrofitting of railway bridge the stiffness of the girder increases with increase in negligible mass, which is one of the important feature of FRP retrofitting.

Similarly, the deflection in any structural member depends on the load acting on it and the stiffness of the member. The deflection in the girder of railway bridge can be reduce by increasing its stiffness.

$$\delta = \frac{P}{k}$$

$$\delta \propto \frac{1}{k} \quad \dots\dots\dots\dots \qquad for\ constant\ P$$

The deflection and the frequency of the bridge girder has measured before and after strengthening. The change in the response of one of the bridge girder for its retrofitting is as follows.

Table 2. Comparison of pre-strengthening results with post-strengthening results for natural frequency.

Sr. No	Girder	Loading Condition	Natural Frequency in Un-Cracked Girder	Natural Frequency in Cracked Girder	Natural Frequency in Post Strengthened Girder at 20kmph	% Increase in the Natural Frequency as compared to the un-cracked girder at 20kmph
1	Span 2	Dynamic	9.574	8.6435	9.2885 Hz	97.02 %

Table 3. Comparison of pre-strengthening results with post-strengthening results for Deflection

Sr. No.	Girder	Loading Condition	Deflection in Un-Cracked Girder (mm)	Deflection in Cracked Girder (mm)	Deflection in Post Strengthened Girder (mm)	% Reduction to the excessive deflection compared to Un-cracked girder
1	Span 2	Static	2.728	3.9656	3.08	71.48 %
2	Span 2	Dynamic	2.644	3.9055	3.01	70.49%
Average % Reduction to the excessive deflection of cracked Span No.2 girder as compared to the sample un-cracked Span No.1 girder						70.99%

Observations

- The deflection in the un-cracked girder is less than the deflection observed in the cracked girder indicating that stiffness of un-cracked girder is more than cracked girder.
- Natural Frequency of un-cracked girder is more than the natural frequency of cracked girder indicating that un-cracked girder has enhanced stiffness compared to cracked girder.
- After strengthening there is an average 70.99 percentage reductions in excessive deflection in the cracked girder of span 2 as compared to the un-cracked girder of span No.1. Also, the reduction in excessive deflection is within 25% of the un-cracked girder.
- The natural frequency of the cracked girder is within 25% of the natural frequency of un-cracked girder.
- After strengthening the average percentage of the natural frequency of the cracked span girders is increased to 97.02 percentage of the un-cracked girder of span No.1.The natural frequency of cracked girder has been improved and brought closer to that of un-cracked girder.
- With the strengthening measures the stiffness of the cracked girder has been improved as indicated by the reduction in deflection and improvement in the natural frequency.

Conclusion

Retrofitting of the bridge with prestressed and non prestressed laminate has increased the flexural strength of the girder and reduced its deflection.

The cracked girder got stiffened after retrofitting and hence its natural frequency has increased.

References

1. DGC Engineering Pvt. Ltd. (2017), *"Report On Strengthening & Instrumentation of PSC I Girder (114, 132, R5,129, 54) at Ratlam, Godhra Junction."*
2. Dr. Khaled Galal (2016), **"***FRP Retrofitting of Bridges*." The Second International Conference on Infrastructure Management, Assessment and Rehabilitation Techniques.
3. Abolghasem Nezamian and Sujeeva Setunge (2007), *"Case Study of Application of FRP Composites in Strengthening the Reinforced Concrete Headstock of a Bridge Structure."* Journal of Composites for Construction.