# Stiffness Studies on GFRP Composite Bridge Deck Panels Under Fatigue Loading

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***Abstract***

*Recently bridge engineers are using fiber reinforced polymer (FRP) composites for the construction of new bridges and retrofitting and rehabilitation of existing bridges due to their light weight nature, good corrosion and fatigue resistance properties. This paper presents the stiffness studies on prototype glass fiber reinforced polymer (GFRP) composite bridge deck panels under fatigue loading. Two multicellular prototype GFRP composite bridge deck panels of size 3000 mm x 1000 mm x 300 mm were fabricated by conventional hand lay-up process and tested under fatigue load ranges of 10 kN to 83 kN and 83 kN to 400 kN at a frequency 1 Hz for 2 million fatigue cycles. The reduction in stiffness of the bridge deck panels after completion of 2 million fatigue cycles was found to be 7% and 14% under fatigue load ranges of 10 kN to 83 kN and 83 kN to 400 kN respectively.*

## I. INTRODUCTION

Maintenance of bridges is a growing concern worldwide. Deck slabs are one of the most severely affected components in reinforced concrete bridges. Several methods have been proposed for the mitigation of corrosion of steel in reinforced concrete (RC) deck slabs, but none has been successful in eliminating the corrosion.

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Existing methods of preventing this form of deterioration by replacing steel reinforcement with epoxy coated galvanized or stainless steel bars and treating the concrete surfaces with siloxanes and cathodic protection, are very costly and of limited use. Therefore to increase the durability of bridges in aggressive environments, a corrosion resistant material must be found out to replace the conventional RC decks. Bridges are frequently subjected to varying stresses due to the movement of vehicles and it is important to know the behaviour of the bridge components under such conditions. The application of FRP deck systems for the constru ction of new bridges and retrofitting of existing bridges requires a thorough knowledge about the fatigue behaviour of these deck systems under traffic loads.

## II. REVIEW OF LITERATURE

Dutta et al. (2003) conducted fatigue tests on three FRP composite bridge deck prototype panels and one FRP concrete hybrid bridge deck prototype panel under two extreme temperature conditions of -30$^0$C and 50$^0$C. The authors observed a progressive degradation in stiffness due to fatigue loading on all bridge deck prototype panels under two extreme temperatures. The authors concluded that there was no significant distress in any of the FRP composite bridge deck prototype panels during ten million fatigue load cycles. Kitane et al. (2004) conducted static and fatigue tests on a scaled model of a hybrid FRP concrete bridge superstructure. Three trapezoidal GFRP box sections were bonded together to make up a one-lane superstructure, and a layer of concrete was placed in the compression side of those sections. The authors observed no reduction in stiffness of the bridge model even after two million load cycles. The authors concluded that the fabricated bridge model met the stiffness requirement and showed significant reserve of strength under static loading. Kumar and Ganga Rao (1998) conducted fatigue tests on four deck-stringer systems reinforced with GFRP rebars and compared with the available test results of decks reinforced with steel bars. The authors concluded that the degradation rate of decks reinforced with GFRP rebars was almost similar with steel reinforced decks in the fatigue crack propagation zone. The reduction in stiffness of decks reinforced with GFRP rebars was linear even after 2 million cycles. Youn and Chang (1998) conducted static and fatigue tests on five 1/3$^{rd}$ scale FRP composite bridge deck panels to examine the effect of various loading positions on punching shear strength and fatigue strength of these deck panels. The authors concluded that both punching shear strength and fatigue strength decreased if the load could be applied nearer to the supports compared to the center of the panel.

## III. TEST SPECIMENS

The characterization of FRP composite materials was carried out at Composites Technology Centre, Indian Institute of Technology Madras, India. Based on the characterization resin as well as reinforcement that meet the requirements of bridge deck panels were selected. Thermoset resin such as vinylester resin and electrical chemical resistance (ECR) glass of woven roving mat (WRM) 610 gsm were used in the fabrication of prototype GFRP composite bridge deck panels by hand lay-up process. The accelerator, promoter and catalyst such as cobalt naphthanate, dimethyl amine and methyl ethyl ketone peroxide respectively, each of 1.5% by weight of resin were added to the vinylester resin. The cross section consists of a 3-cell rectangular section with additional stiffeners connecting the web to the top flange. The overall length, width and depth of multicellular bridge deck panels were 3000 mm, 1000 mm and 300 mm respectively. The thickness of the top flange, bottom flange and webs were kept as 30 mm. The thickness of additional stiffeners was kept as 20.5 mm. The fabricated prototype GFRP composite bridge deck panels are shown in the Fig. 1.

## IV. TEST SET-UP AND INSTRUMENTATION

The overall view of the test set-up is shown in Fig. 2. The loading frame consists of four heavy columns (A) and was connected to the strong test floor. In the shorter direction each pair of columns was connected by a secondary beam (B). The secondary beams were connected by a primary beam (C). The length, width and height of the loading frame were 6000 mm, 4000 mm and 5000 mm respectively. A maximum load of 2000 kN could be applied safely using two hydraulic jacks (D) each of capacity 1000 kN with the ram diameter of 226 mm and stroke of 250 mm that were attached to the primary beam. The platen diameter of the jacks was 400 mm. The span length (3000 mm) of the bridge deck panel was kept parallel to the primary beam (C) of the loading frame and was simply supported at the two ends along the shorter dimensions. The simply supported boundary conditions were simulated using the line supports. The dead load of future wearing surface was simulated by keeping the slotted weights on the top surface of the bridge deck panel. The details of test set-up are shown in Fig. 3.

The out-of-plane deflections at the top and bottom skins of the bridge deck panels were measured using dial gauges with an accuracy of 0.01 mm. The dial gauges were fixed at midspan and quarterspan from either side of the supports of panels. The position of dial gauges is shown in Fig. 4. Electrical resistance strain gauges having a gauge length of 10 mm were pasted on top and bottom skins of the bridge deck panels at midspan and quarterspans from either side of the supports. Delta rosettes were pasted on top and bottom skins of the decks at quarterspans from either side of the supports. All strain gauges were connected to a digital data logger and the data was recorded and stored in a computer at each incremental load.

## V. TEST DETAILS

Fatigue tests were conducted on the two prototype GFRP composite bridge deck panels FRPBD1 and FRPBD2 using the low frequency fatigue testing machine available in Structural Engineering Laboratory, Indian Institute of Technology Madras, India. The bridge deck panels FRPBD1 and FRPBD2 were tested under fatigue loading at a frequency of 1 Hz upto 2 million cycles with a load range of a load range of 10 kN (minimum load limit) to 83 kN (maximum load limit) and an enhanced fatigue load range of 83 kN (minimum load limit) to 400 kN (maximum load limit) respectively. The static tests were also conducted upto the factored load of 83 kN (wheel load + dynamic allowance + dead load including the weight of the future surface wearing course) after completion of 3, 6, 10, 13, 15, 18 and 20 lakh fatigue cycles. The deflections and strains were measured at every 10 kN load increment and upto the factored load of 83 kN.

## VI. TEST RESULTS

Load vs deflection graphs were plotted for the two GFRP composite bridge deck panels FRPBD1 and FRPBD2 after completion of 3, 6, 10, 13, 15, 18 and 20 lakh fatigue cycles as shown in Figs. 5 and 6. The stiffness of the bridge deck panels was calculated as the slope of the load vs deflection graphs. The percentage reduction in stiffness of the bridge deck panels due to different fatigue load ranges was calculated (Tables 1 and 2).

## VII. CONCLUSIONS

The following major conclusions drawn from the experimental study carried out

(1) The reduction in the stiffness of prototype GFRP composite bridge deck panel is observed to be linear upto 2 million cycles under the two different fatigue load ranges of 10 kN to 83 kN and 83 kN to 400 kN tested at a frequency of 1 Hz
(2) The reduction in stiffness of bridge deck panel after 2 million cycles of fatigue loading at a frequency of 1 Hz for a load range of 10 kN to 83 kN is found to be 7%.
(3) The reduction in stiffness of bridge deck panel after 2 million cycles of fatigue loading at a frequency of 1 Hz for a load range of 83 kN to 400 kN is found to be 14%.

## VIII. REFERENCES

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**Table 1 Reduction in Stiffness of GFRP Bridge Deck Panel FRPBD1 under Fatigue Loading**

| Sl.No. | Number of cycles ( x $10^5$) | Stiffness* (kN/mm) | Loss of stiffness (kN/mm) | Reduction in stiffness (%) |
|---|---|---|---|---|
| 1 | 0 | 33.88 | -- | -- |
| 2 | 3 | 33.74 | 0.14 | 0.41 |
| 3 | 6 | 33.34 | 0.54 | 1.59 |
| 4 | 10 | 32.84 | 1.04 | 3.07 |
| 5 | 13 | 32.61 | 1.27 | 3.75 |
| 6 | 15 | 32.12 | 1.76 | 5.19 |
| 7 | 18 | 31.70 | 2.18 | 6.43 |
| 8 | 20 | 31.44 | 2.44 | 7.20 |

*Load range is 10 kN to 83 kN

**Table 2 Reduction in Stiffness of GFRP Bridge Deck Panel FRPBD2 under Fatigue Loading**

| Sl.No. | Number of cycles ( x $10^5$) | Stiffness* (kN/mm) | Loss of stiffness (kN/mm) | Reduction in stiffness (%) |
|---|---|---|---|---|
| 1 | 0 | 33.00 | -- | -- |
| 2 | 3 | 32.39 | 0.61 | 1.85 |
| 3 | 6 | 31.95 | 1.05 | 3.18 |
| 4 | 10 | 31.14 | 1.86 | 5.64 |
| 5 | 13 | 30.53 | 2.47 | 7.48 |
| 6 | 15 | 29.98 | 3.02 | 9.15 |
| 7 | 18 | 29.14 | 3.86 | 11.70 |
| 8 | 20 | 28.23 | 4.77 | 14.45 |

* Load range is 83 kN to 400kN

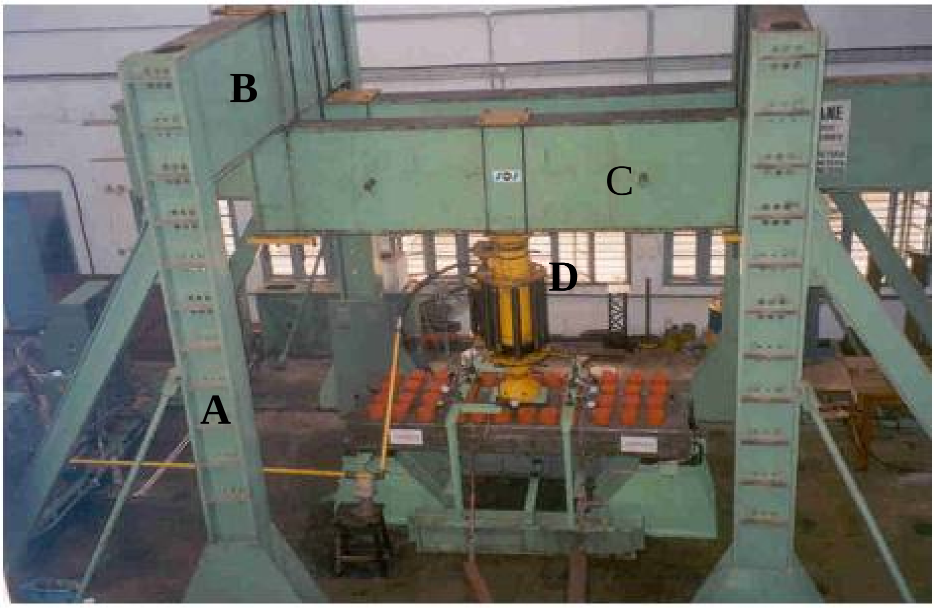



**Fig.2. Overall View of Test Set-up**

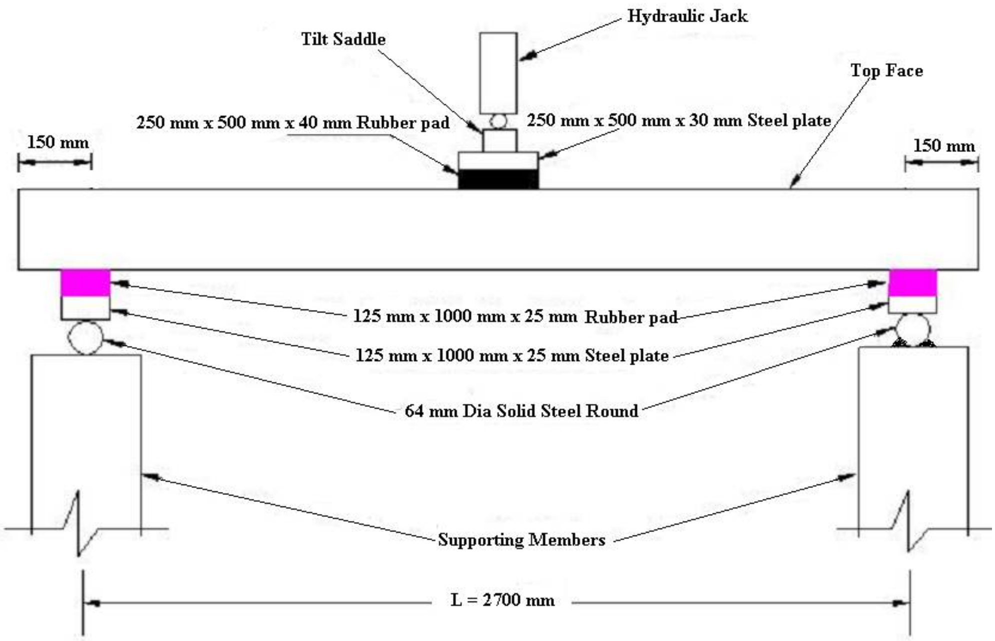
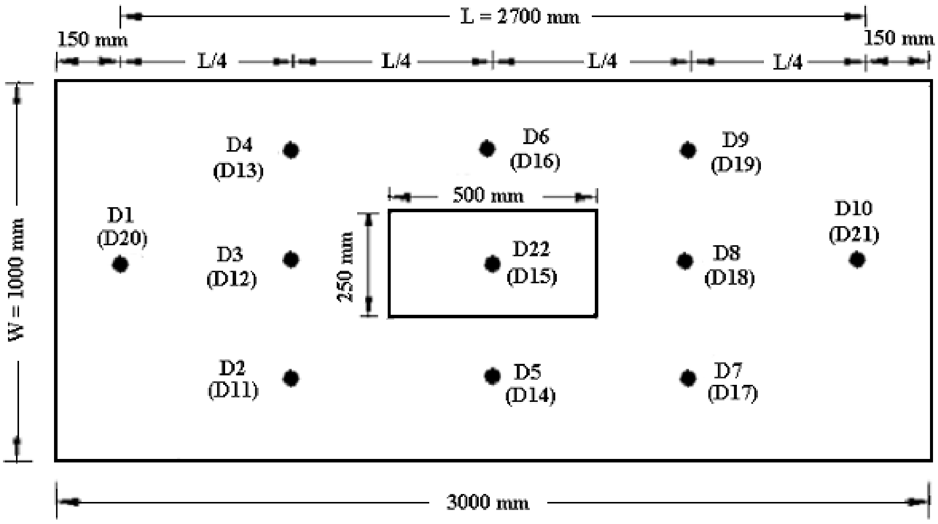



**Fig.3. Details of Test Set-up**




Note: Dial gauges at the bottom of the deck are shown within the parentheses

**Fig. 4. Position of Dial Gauges at the Top and Bottom Surfaces of Bridge Deck Panel**

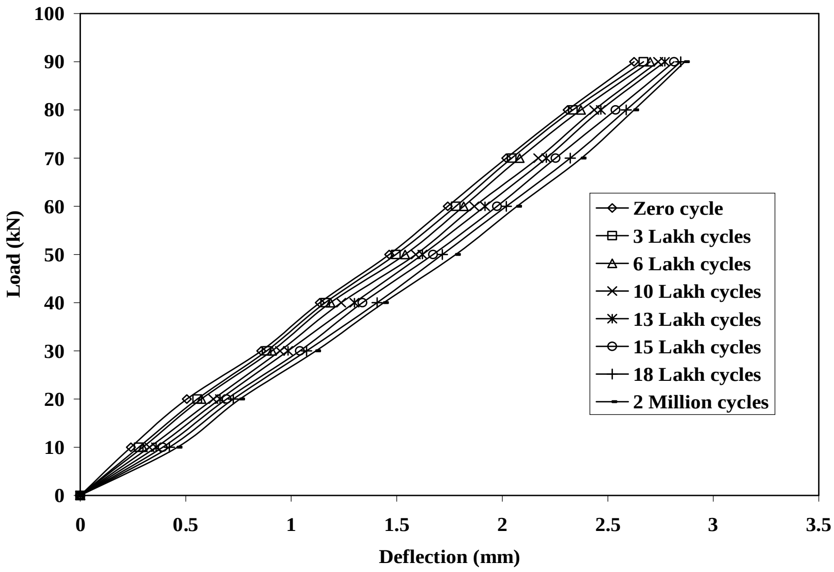



**Fig. 5. Load vs Deflection Curves upto Factored Load for Different Fatigue Cycles of FRPBD1**

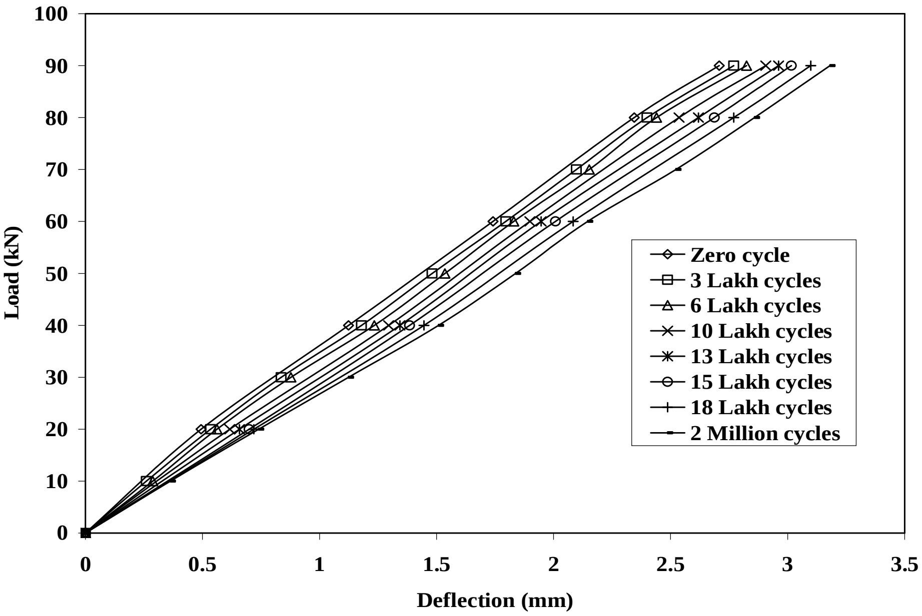



**Fig. 6. Load vs Deflection Curves upto Factored Load for Different Fatigue Cycles of FRPBD2**

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