CHAPTER 5

ANALYSIS AND STRENGTHENING OF RAIL BRIDGE GIRDER AT RATLAM: A CASE STUDY

5.1 General

In recent decades, the rapid deterioration of bridges has become a serious technical problem due to increased traffic flows, especially their axle load compared to when the bridge was designed. In India recently the speed of the train and its axle load is increased. A bridge that was designed earlier for lower load level or traffic volume now requires a restriction on its use. Rail bridges are more prone to damage because of more intense and concentrated loading and their conservative design methodology. Generally, the rail Bridge experience more wears and tear due to increased load on wagons, trains' intensity, aging, and environmental effect. Repair, replacement, rehabilitation is an essential part of the maintenance to keep the bridge in-service condition. Therefore, repair and retrofitting work should be carried out from time to time to avoid the catastrophic failure and replacement of parts or complete bridge.

In this chapter, The structural health of Ratlam-Godhra route bridge no 114 and bridge no 54 of the western railway of India studied extensively, which was deteriorated severely. The damage analysis and its repairing scheme for both bridges have been carried out and one additional span of 25.67 meter was also analysed to study the strength behavior of the retrofitted girder. The damaged girders were analyzed using ANSYS for Research Design and Standards Organisation (RDSO) rail loading. From the simulation results, the strengthening scheme was designed for both the girder. The bridge girder of a 19.67-meter span of bridge no 114 is retrofitted with the following scheme: three-layer of carbon fibre reinforced polymer (CFRP) in flexure zone and three layers of glass fiber reinforced polymer (GFRP) in shear zone using multiple combinations and 13.67-meter span of bridge no 54 is retrofitted with the following scheme: two layer of carbon fibre reinforced polymer (CFRP) in flexure zone and two layers of glass fibre reinforced polymer (GFRP) in shear zone. The real time test was carried out on the girder before and after the strengthening scheme by moving the WAGON 7 of RDSO rail throughout the bridges at a low and high speed ranging between 20 kmph to 100 kmph. After strengthening both the bridges are opened for traffic.

5.2 Background of bridge no 114

This four-span rail bridge on the Nakdi River route of Ratlam- Godhra, (M.P.) in India, was built in the year 1959-60 was reported with several cracks in the different parts of the bridge girder. Due to this deterioration of the bridge girder, the train's speed over the bridge was limited to 20 KMPH. The bridge was between Bordi-Anas station at location KM 556/23-25.

5.2.1 Details of bridge

The bridges have composite PSC I-girders supported on neoprene bearing (Figure 5.1) with the girder length of 19.67 meter. The schematic diagram is presented in figure 5.2. The details of the bridge are shown in Table 5.1

Figure 5. 1 Site view of bridge no 114

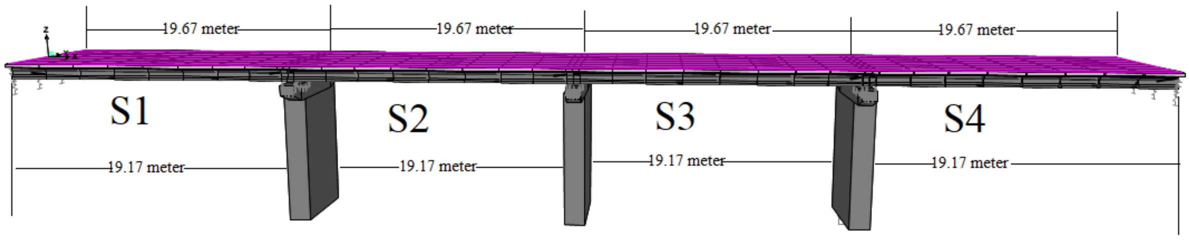
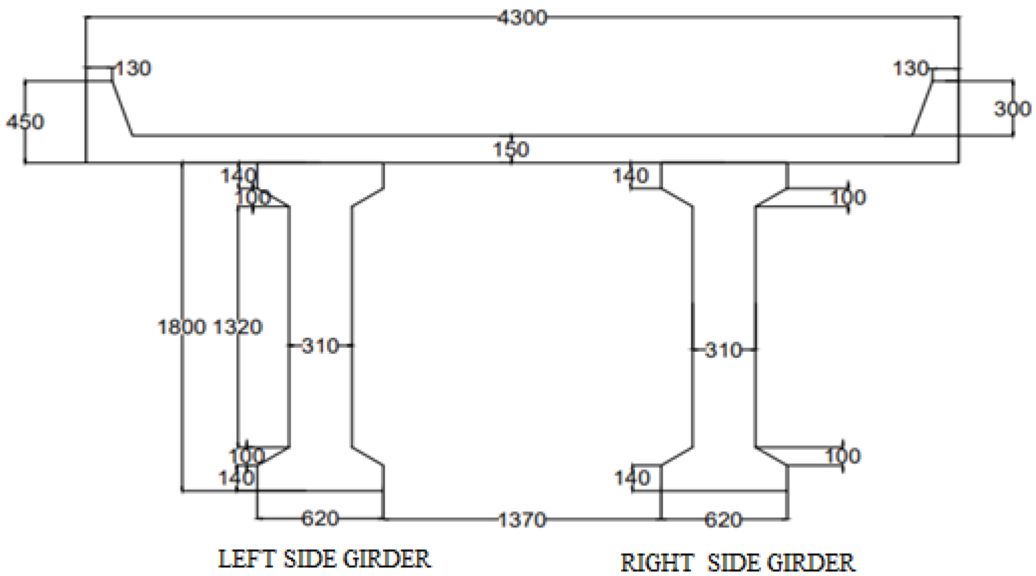


Figure 5. 2 Schematic diagram of bridge model

Table 5. 1 Details of girders and substructure of bridge

5.2.2 Cross section details

The carriage width of span is 4.3 meter and deck slab is rested on two longitudinal I-girder of span 13.67 meter. The detail cross section is shown in figure 5.3



(All Dimension are in mm)

Figure 5. 3: Typical cross section of the bridge

5.2.3 Inspection report of bridge no 114

A detailed inspection was conducted to find out the severity of deterioration of bridge including intensity of crack, damages in diaphragm corrosion in steel bars etc. the following finding is presented after an overview of bridge no 114

1. The PSC I girders show vertical cracks from the bottom of the girders. (Figure 5.4).
2. Severe deterioration of the diaphragm was observed.
3. Corroded reinforcement exposure is observed at the bottom slab. Figure 5.5
4. Spalling of concrete is observed in the diaphragm bottom
5. Cracks at the girder bottom at bearing locations are observed (Figure 5.6).
6. Severe deterioration at intermediate span locations is seen
7. Discoloration due to deterioration with time is seen in the overall structure
8. Termite attack is observed in the girders.

Figure 5. 4 Severe cracks observed in girder

Figure 5. 5 Deterioration in bottom deck slab

Figure 5. 6 Cracks and delamination at bearings

5.3 Numerical analysis of bridge girder

Numerical analysis of girders of three different span of 13.67 meter, 19.67 meter and 25.67 are carried out. There are two longitudinal I-beam at lateral spacing 1.99 m c/c along the span the bridge. It has been loaded with an RDSO and dead loads of the girder as stipulated in table 5.5. The bridge deck and girder have meshed with solid element, type SOLID 187. The retrofitted element of FRP has meshed with the SOLID 186 element. The element size automatically assigned 830.26mm, 1114.2mm and 1404.4mm for 13.67m, 19.67m and 25.67m length of the girder, respectively. Tetrahedron meshing having an element size 100 mm has been used to simulate the CFRP strips. The meshing details and node number are presented in Table 5.2.

Table 5. 2 Meshing details

Length of the girder (m)	Number of elements	Number of nodes
13.67	28,839	79,600
19.67	33,828	95,428
25.67	44,374	126,170

The loading pattern needs in the ANSYS to define the WAGON 7 rail locomotive according to the axle plan (Figure 5.7) of the Indian railway. The axle details of WAGON 7 is presented in Table 5.3. The bridge component i.e., deck slab, precast I-girder, is designed according to Table given below.

Table 5. 3 Major parameters of loading train (Source: RDSO)

S.N.	Parameter	Values
1	Weight of WAGON	123 t
2	Total No of Axle	6 nos
3	Axle Load	20.5 t
4	Max Design Speed	110 Km/h
6	Lateral Force/Axle	4 t
7	Dynamic Augment	≤ 50 %
8	Un sprung Mass/Axle	4.3 t

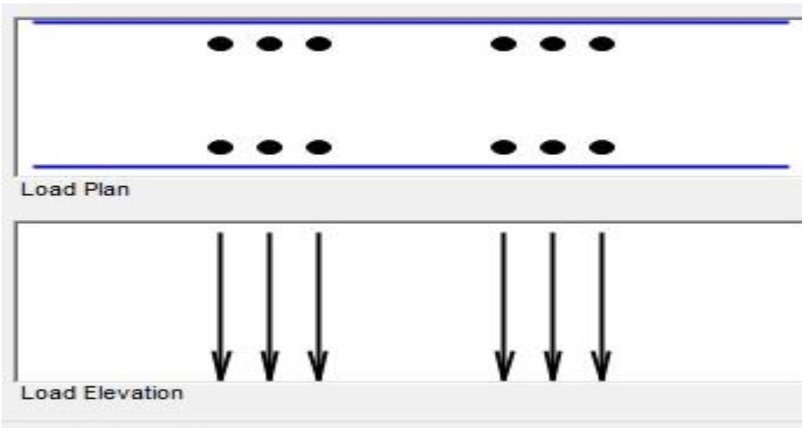


Figure 5. 7 Loading plan of Indian locomotive Wagon 7 whel axle

The modal of bridge deck slab along with both I-girder is shown in figure 5.8. The deformed shape of the deck slab and girder at time 1 sec is displayed in figure 5.9. The maximum deformation at 1 second was observed 4.11 mm at the middle of the girder.

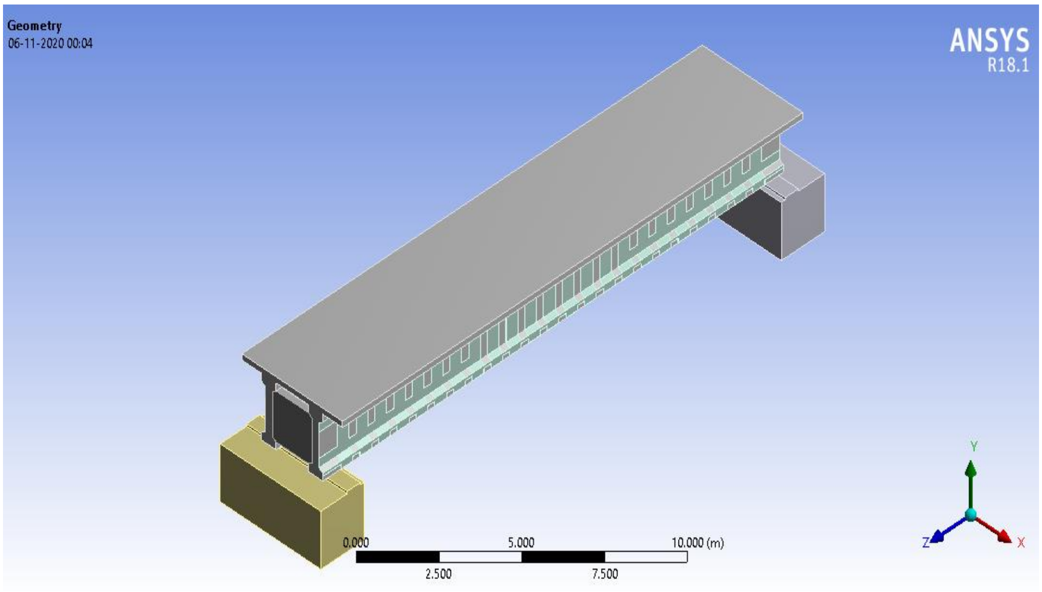


Figure 5. 8 Model of bridge deck slab with girders

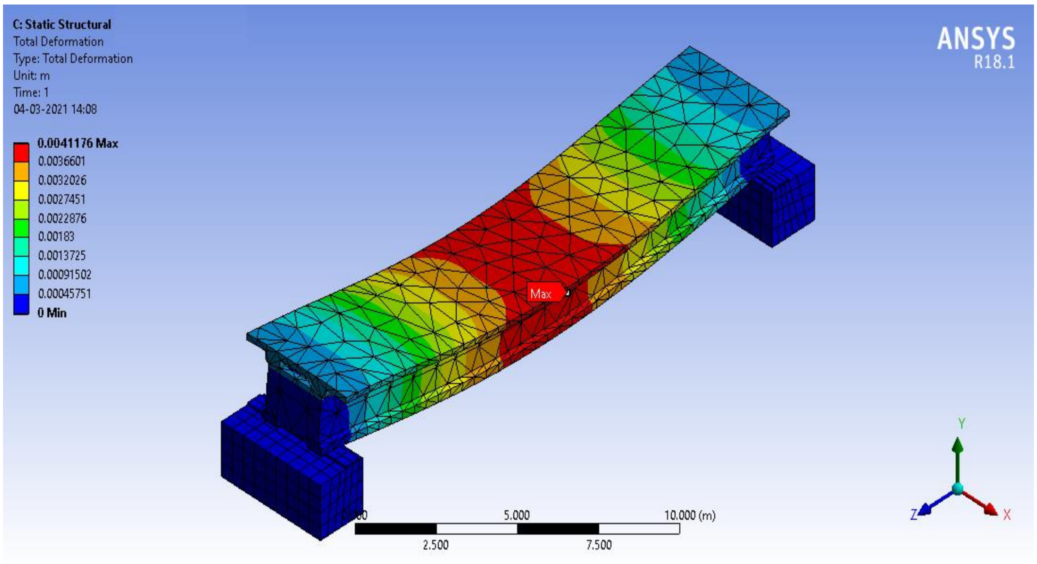


Figure 5. 9 Typical deformed shape of girder at frequency at time 1 second

5.3.1 Deformation of girder

The deformation due to live load has been displayed after finite element analysis of girder for different IRC loads. Few apparent changes has observed when the layers of composite fibre were increased. In Figure 5.10 it is clearly visible that for the longest span of bridge i.e. 25.67 m, the deformation was vastly reduced when the layer of composite fibres CFRP and GFRP were tripled. In the case 1 when the length of the girder was 13.67 meter and the single layer of composite fibre were glued then the deformation in the girder was 4.1749 mm when this layer increased by one layer then the deformation was found 3.5725 mm and in the case of triple layer it decreased and reached to 2.171 mm. In case 2 when the length of girder was 19.67 meter, the deformation in the single layer fibre 5.08 mm, in the double layered fibre, was 4.02 mm and in the triple layered fibre it came to 3.99mm.

In the case 3 when the length of the girder was 25.67 meter, then in the single layer composite fibre the deformation was 10.59 mm, as soon as the layer of fibres had doubled the deformation was decreased and reached 10.49 mm and in the following case when the layers of fibres have tripled the deformation was reduced to 5.10 mm.

The girder was again modelled without glass fibres (Figure 5.11) with the increasing number of layers of carbon fibres for all the three girder of 13.67mm, 19.67 mm and 25.67mm. In the case of 13.67 meter the deformation of the girder when there was no fibre, was found 4.517 mm. with the single layer of carbon fibre it was 4.17 mm, as doubled the layers for this girder the deformation came to 3.17 mm and in the three time CFRP wrapped girder the deformation was found 3.07 mm. for the second girder whose length was 19.67 meter the deformation was 5.21 mm in no fibre strengthening case. The deformation was reduced and reached to 4.58 mm when single layer CFRP was applied similarly, it further sink to 4.02 mm and 3.99 mm for two and three layer lamination of girder. The third girder with span length 25.67 meter was examined wrapped similarly by one, two and three layer of carbon fibre and the deformation was noticed 10.61 mm, 10.51 mm and 10.39 mm respectively.

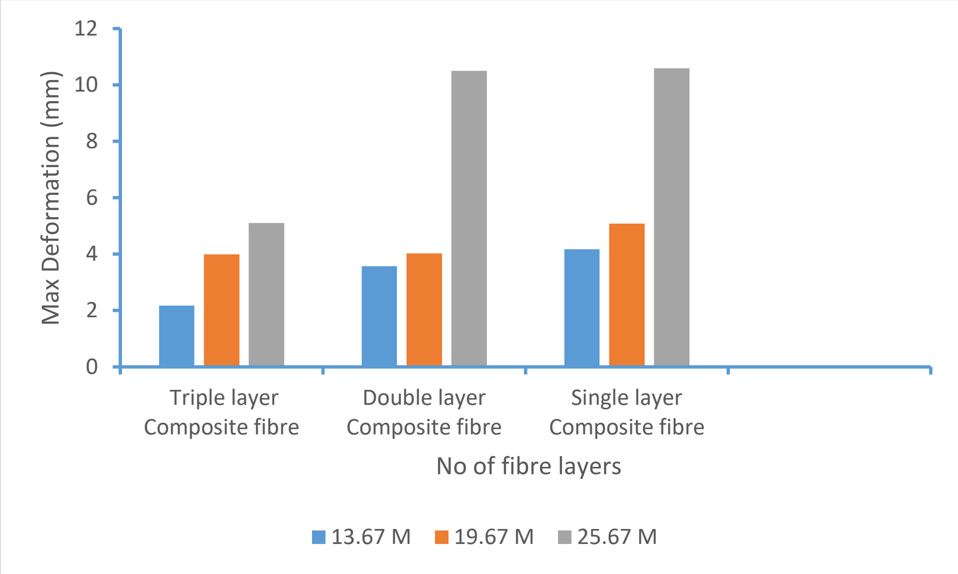


Figure 5. 10 Max deformation vs no of layer with varying length of girder

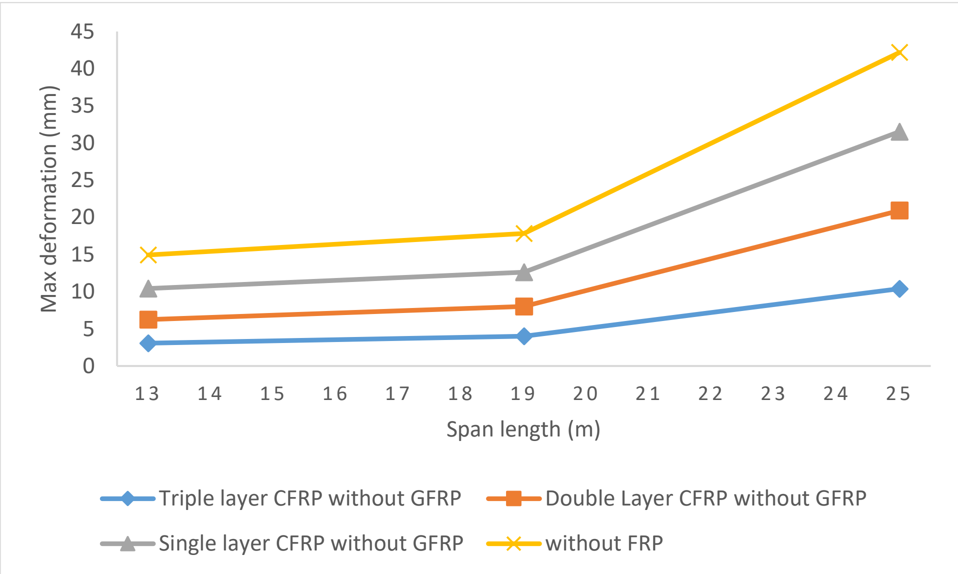


Figure 5. 11 Max deformation vs length of girder with varying fibre layer

5.3.2 Von Mises strain of girder

Figure 5.12 and Figure 5.13 confirmed that every laminated bridge girder experiences the yielding before going in failure mode as their Von Mises strain is greater than their simple deformation in each case. In Figure 5.13 the single, double and triple layer composite fibre stratum on all the three girder of sample. In the single layer and longest girder the strain was found 1.72 mm while it got reduced by 50 percent in the case of triple layer composite fibre on the same length of girder. The Von misses strain on the single layer laminated girder of 19.67 meter and 13.67 meter length is 0.55 mm and 0.26 mm. when the composite fibre layer tripled the strain found as 1.2 mm, 0.70 mm and 0.26 mm for descending length of all girder.

Figure 5.13 consist the von-mises strain of girders which was laminated only using the carbon fibre only. The single layered girder of 25.67 meter length showed von mises strain of 0.81 mm while other two girder of comparatively smaller length are showing 0.54 mm and 0.26 mm for 19.67 meter and 13.67 meter respectively. The similar trend was observed in the double and triple-layered girder.

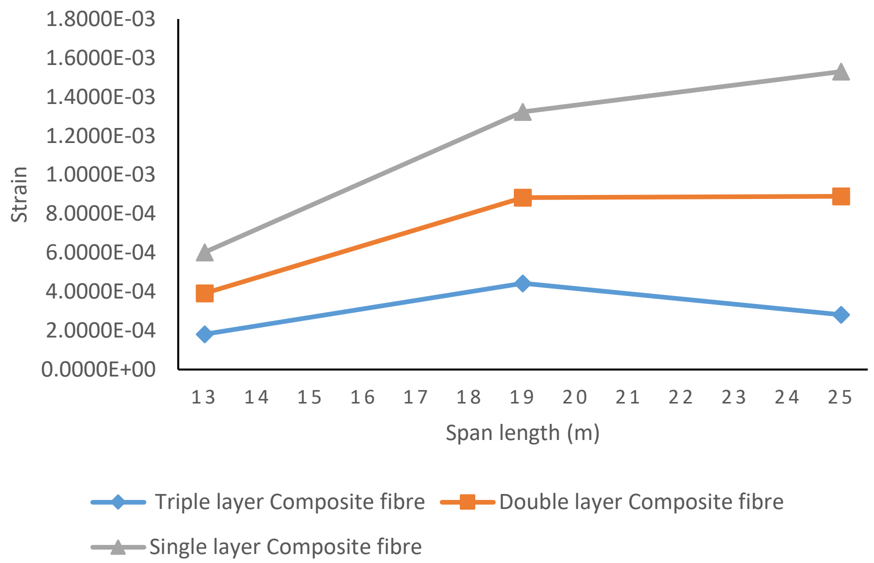


Figure 5. 12 Maximum von misses strain vs span length for composite girder

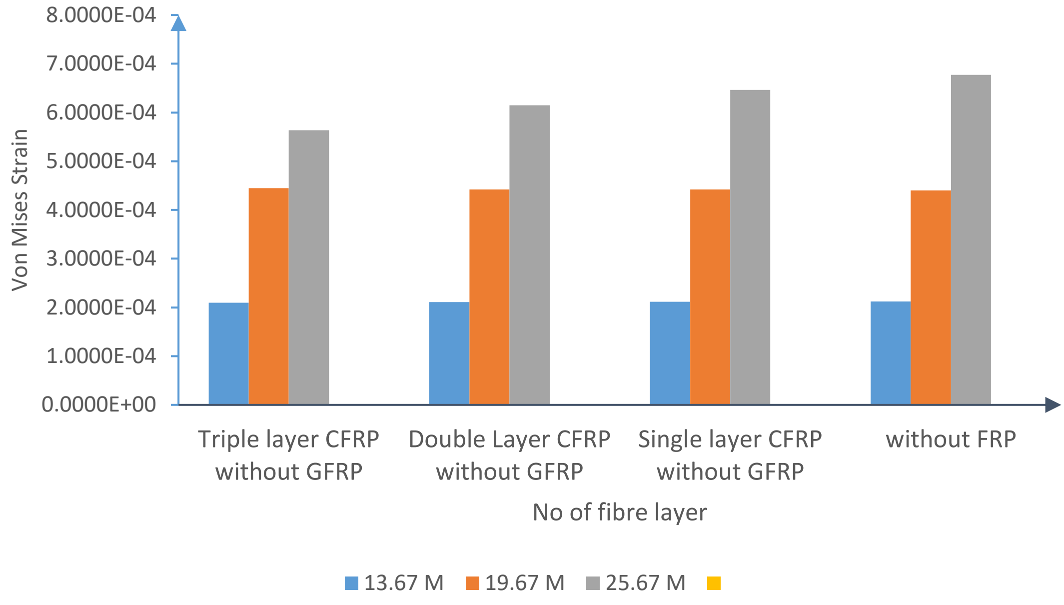


Figure 5. 13 Maximum von misses strain vs span length for carbon fibre

5.3.3 Maximum compressive stress

When all the five girders were retrofitted with both carbon and glass fibre the maximum compressive stress was found 7.25 MPa for 25.67 meter span in single layer fibre and reached this value to 3.54 MPa when the layers were tripled in the same beam. For the girder of 19.67 meter length, it was 4.47 MPa for the longest span and reduced to 4.3 MPa when increased the girder layer to three. For the 13.67 meter span and single layer lamination, the stress was 2.2 MPa and reduced to 2 MPa when it was wrapped by triple layer. The compressive stress in the double layer lamination is found as 7.2 for 25.67-meter span while 4.47 MPa and 2.24 MPa for 19.67 and 13.67-meter span. (Figure 5.14)

In the case of carbon laminated girder of length 25.67 meter, the compressive stress was found 7.2 MPa for single layer and reduced to 7 MPa for triple layer lamination. When the girder became slightly smaller of length 19.67 m, the compressive stress for a single layer was found to be 4.5 MPa and reduced to 4.4 MPa for three layer laminated girder. For the 13.67 meter long girder, the compressive stress was 2.2 MPa in single laminated cases and 2.20 MPa for triple layer lamination.(Figure 5.15)

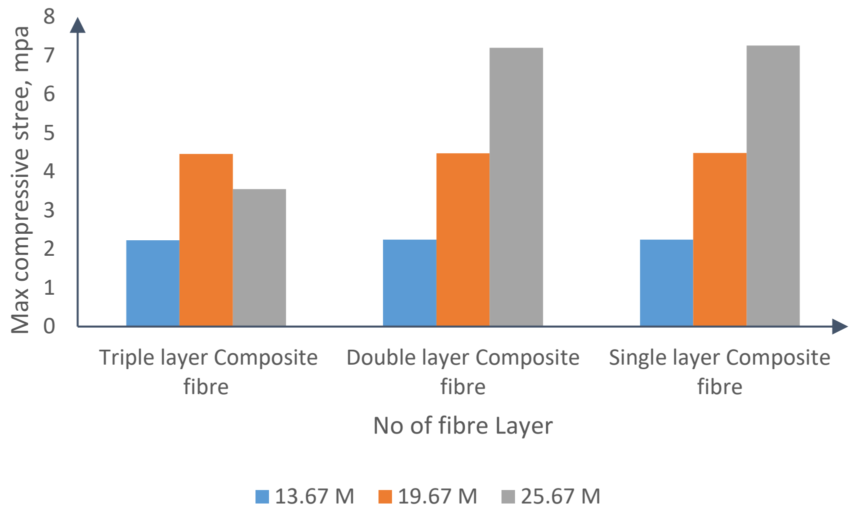


Figure 5. 14 Maximum compressive stress vs fibre layers

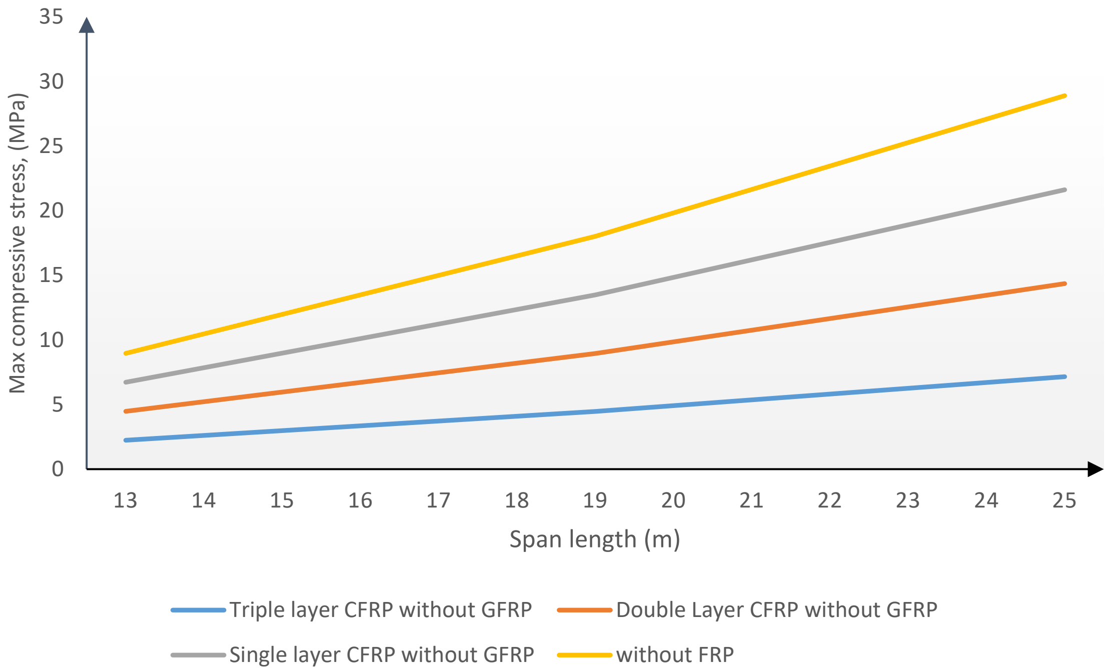


Figure 5. 15 Maximum compressive stress vs span length

5.3.4 Maximum tensile stress

It is well known that the concrete is weak in tension, especially the simple reinforced girder of all the structures. So it should ensure that if the load is traveling in the tension zone due to any reason, then the tension zone's strengthening is constitutive. Figure 5.16 assured that the effect of multiple layer FRP increased the strength of concrete considerably in the tension zone. In this figure the maximum tensile stress in singly, doubly and triple layer wrapped girder of three different length is being analysed. In the first case of the girder length 25.67 meter was singly wrapped have stress of 11.36 MPa, 6.8 Mpa for the 19.67 meter long girder and 3.22 MPa for 13.67 meter girder. As the strengthening of all girder were completed and tested again the maximum reduction was obsereved in the longest girder about 100 percent. In double-coated lamination, the stress in the longest girder of 25.67 meter length it is 11.20 MPa, in 19.67 meter long girder it is 6.71 MPa and in the shortest girder it is 3.21 MPa. In the three-layered girder case, the maximum stress has not occurred in the longest one as it has happened in fore cases. Here the maximum stressed girder was the second-largest i.e. 19.67 meter long girder.

Figure 5.17 proved that there will be no such increment in the tensile strength of concrete without glass fibers. The reduction in the tensile stress in all the girders was not as found in composite fibres.

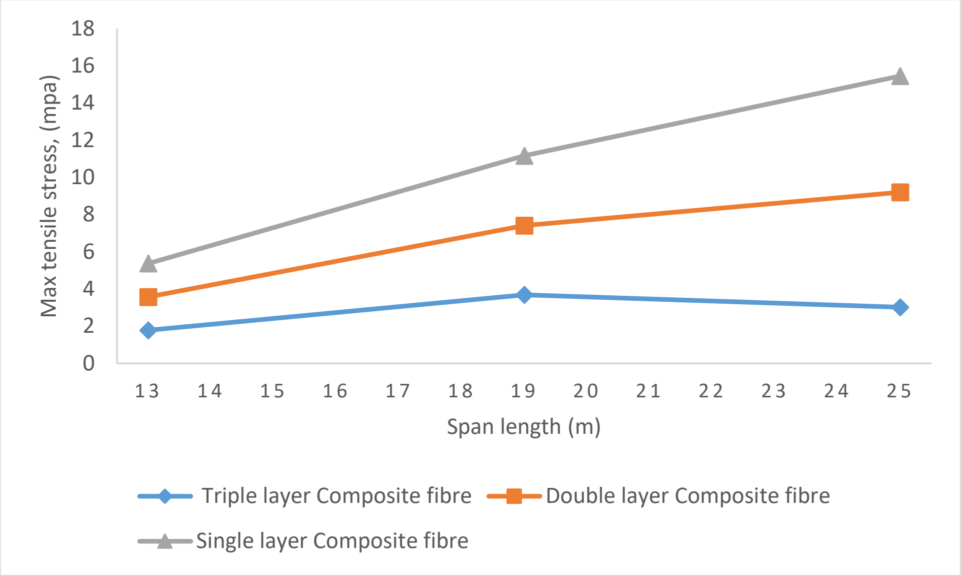


Figure 5. 16 Maximum tensile stress vs fibre layers for varying girder

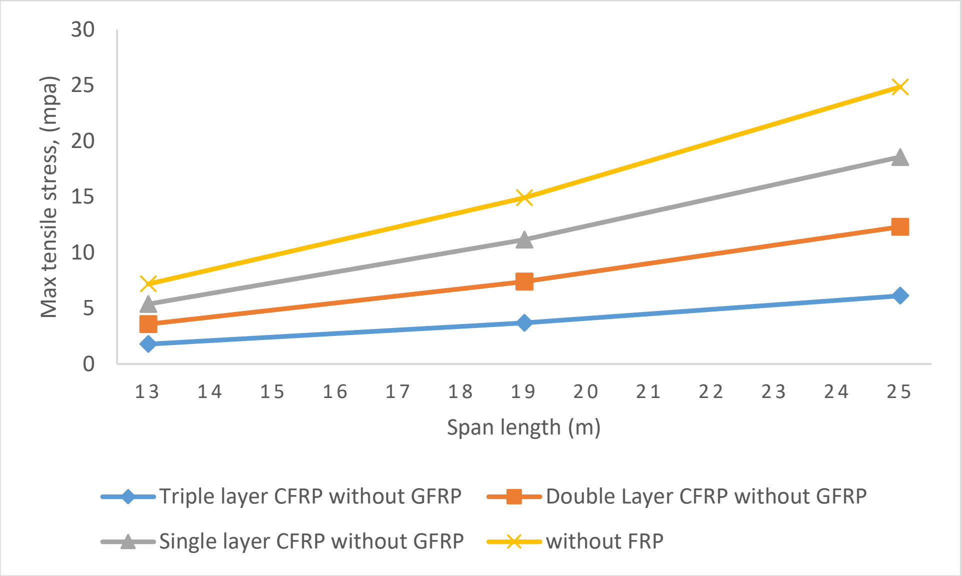


Figure 5. 17 Maximum tensile stress vs fibre layers for varying girder

5.3.5 Maximum Von-Misses stress

Figure 5.18 the von Mises stress of any structure describes its ability to yield before discomfiture. The Figure 5.12 consist the behavior of composite laminated girders. The stress in single-layered laminated girder the von Mises stress was found 15.67 MPa for the longest span which was 25.67m. Respectively for the double and triple layer it was 15.48 Mpa and

7.45 MPa. For shorter span length i.e. 19.67m and 13.67m the von Mises stress was reported 12.60 MPa and 4.83 MPa when the girder was double-coated by composite fibre and 7.45 MPa and 4.82 MPa for triple coated composite layer.

In the case where glass fibre was not attached to girder and only strengthened by one, two and three layers of carbon fibre is being discussed in Figure 5.19. In the case of triple layered wrapping of fibre the von mises stress on the girder length 25.67 m, 19.67 m and 13.67 m was 15.09 MPa, 12.80 MPa and 4.86 MPa, respectively. If the strength was done using double layered carbon fibre, then the stress was observed 15.30 MPa, 12.56 MPa and 4.87 MPa for the descending length of all three girders. When the layers of carbon downed to a single layer, the stress in the longest girder was 15.48 MPa while in the girders of 19.67 meter and 13.67 meter, the stress was 12.48 MPa 4.88 respectively.

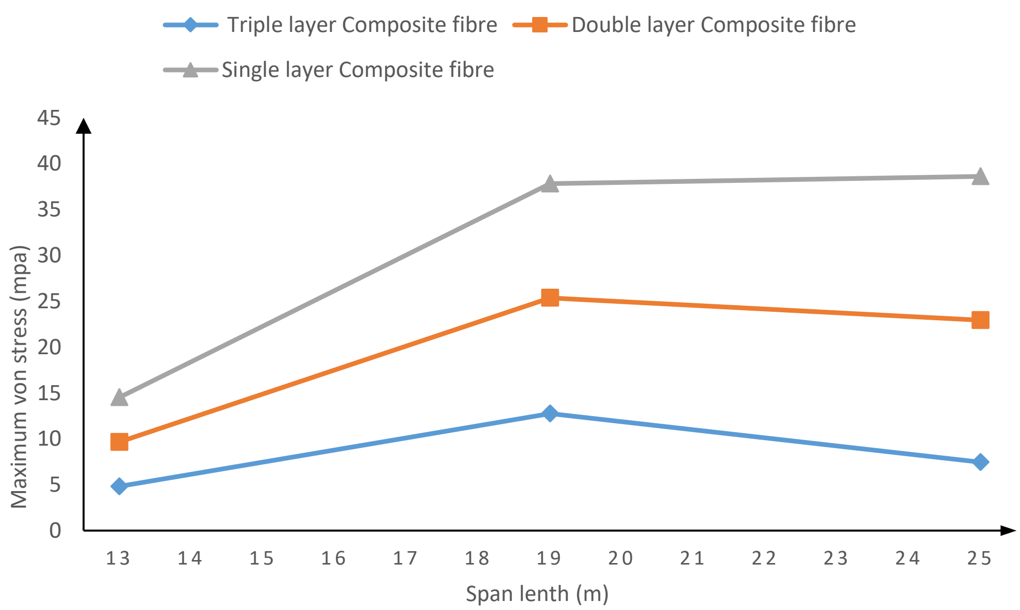


Figure 5. 18 Max Von Mises stress vs length of girder with varying fibre layer

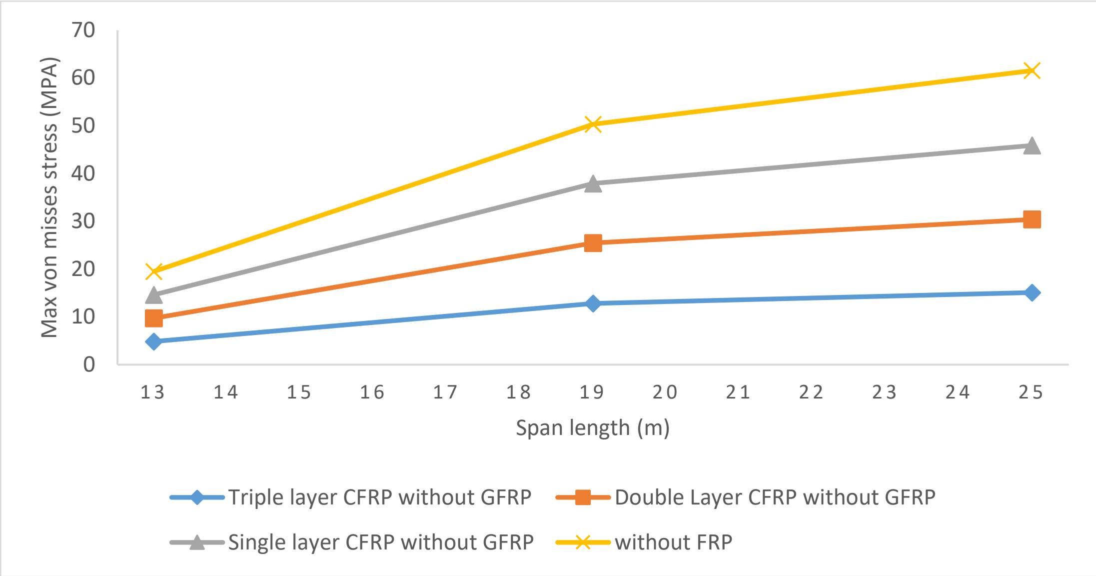


Figure 5. 19 Max Von Mises stress vs fibre layer with varying length of girder

5.3.6 Strain energy

Figure 5.20 explains the effect of an enormous variation of fibre on the different size of girder. The single-layer composite fibre produces the 930.23 Joule strain energy for 13.67 meter girder. After doubling the composite layer strain energy comes to 926.37 Joule and in the case of triple layer fibre the strain energy was found 924.01 Joule. In the 19.67m and 25.67 meter long spans the strain energy reported 4840.1 joule and 16956 joule when doubling the both carbon and glass fibre wrapping. Figure 5.21 explains the case where only carbon fibre used for retrofitting the girder. In this analysis, the strain energy in unstrengthened beam was found 17438 Joule for 25.67 m girder and decreasing gingerly when the layer of fibres was single, doubled and tripled. In the case of single-layer carbon wrapping, the strain energy in 25.67 meter girder was found 17312 joule and in the other two girders it was 4952.3 joule and 932.35 joule for 19.67 meter and 13.67 meter, respectively. If we see the difference in the length of girder, then the difference in the strain energies is more than three times each other. A similar pattern was noticed in the double and tripled layer laminated beam of all three sizes.

Similarly, in the shorter span, the reduction in strain energy was not as much as seen in the composite retrofitted girder. In the 19.67 meters un-retrofitted girder the strain energy was found 5017.1 Joule and decreasing very minutely when the number of layers were increased to double and triple. A similar pattern was continued in the 13.67m long girder.

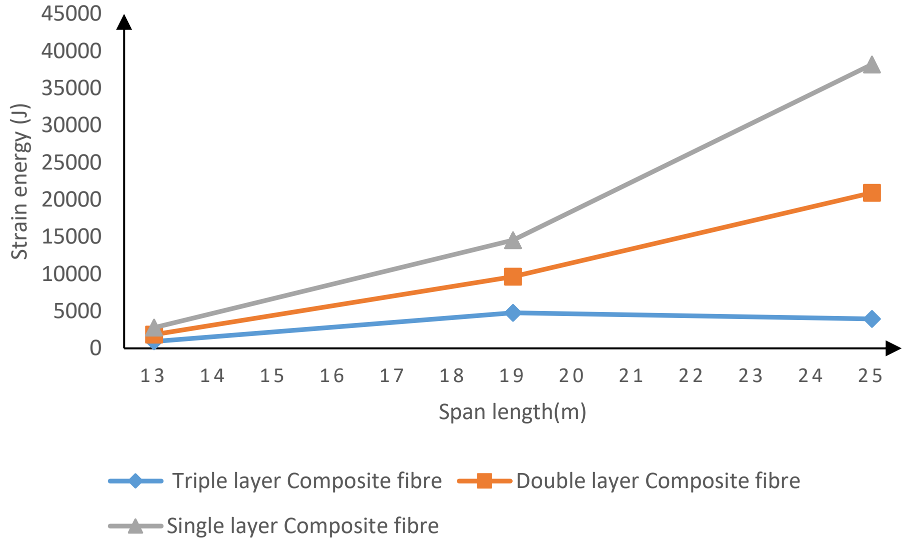


Figure 5. 20 Strain energy vs length of girder with a varying fibre layer

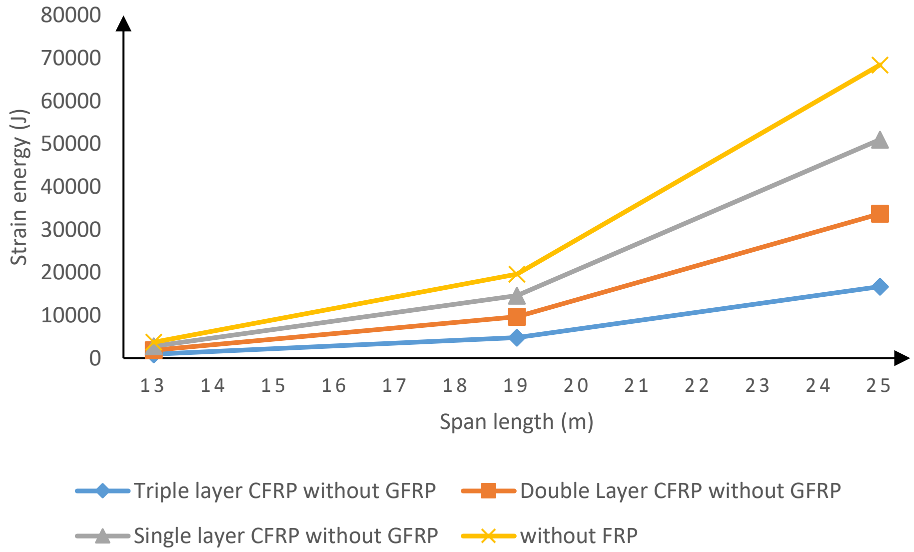


Figure 5. 21 length of girder vs strain Energy with varying fibre layer

5.3.7 Frequency of girder for different mode shape

The natural frequency of Ratlam bridge no 114 and 54, for which the span length was 13.67 m and 19.67 respectively, have been analyzed for the first five-mode shape and compared here. One additional length of 25.67 m has also been analyzed to compare the results.

a. Modal Frequency of girder in Mode shape 1

To find out the natural frequency of girder five-mode shape, we have analyzed use and for each mode, the cases of composite fibres and without glass fibre have been discussed. In Figure 5.22 for mode 1 the frequency of single layer composite fibre of largest girder i.e. 25.67 meter was found 7.01 Hz and of second girder it is found 10.749 and for smallest girder it was found 20.06 Hz.

To find out the vibration (mode shape, natural frequency), the modal analysis of any structure is very useful. It can represent any structure's motion under dynamic loading because of lateral force originated by electrostatic impellers. In Figure 5.22 and Figure 5.23 the frequency of different lengths of girder was examined in three cases without any fibre, with composite fibre and with carbon fibre. The result are compared with each span length and also with the different layers of fibres. Figure 5. 23 Consists the frequency of girder of different length and wrapped with carbon fibre only. The frequency of un-laminated largest girder was found 6.98 Hz while for 19.67m and 13.67m girders it was 10.7 Hz and 20.04 Hz, respectively. With the triple layer of carbon fibre in the longest girder of span 25.67m the frequency was found 7.0 Hz and for 19.67m and 13.67 meter girders the frequency was reported as 10.73 Hz and 20.04 Hz.

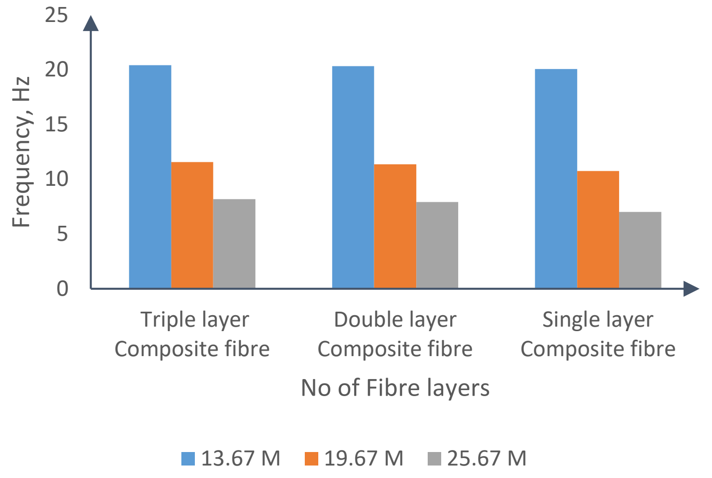


Figure 5. 22 Frequency vs no of fibre layers mode shape 1

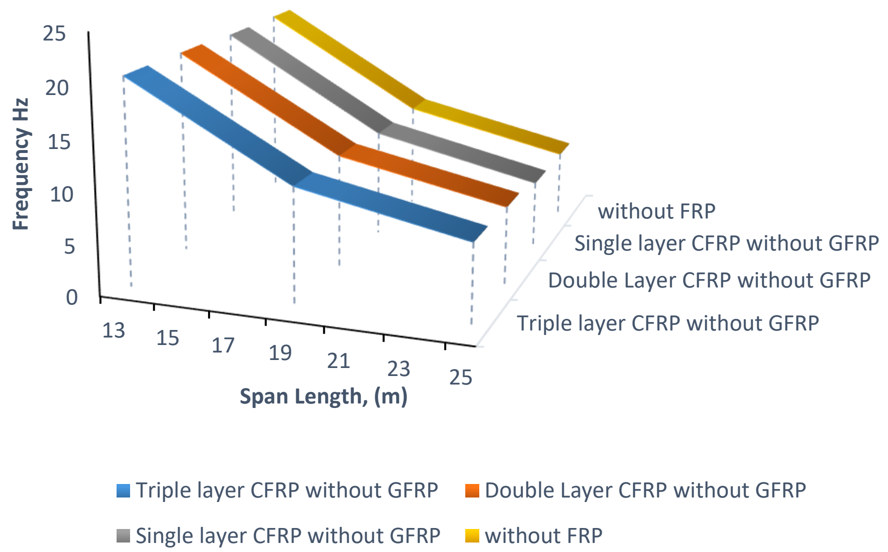


Figure 5. 23 Frequency vs span length in mode shape 1

b. Modal Frequency of girder in mode shape 2

Figure 5. 24 describes the vibrations of the girder in mode 2. for single-layer composite laminated girder of length 25.67m the frequency was found 10.83 Hz, In girder length 19.67m and 13.67 meter it was seen as 17.59 Hz and 34.11 Hz. A similar pattern was observed in double and triple layer of composite fibre laminated girder. When the girder was laminated only using carbon fibre the frequency in mode has been displayed in figure 5.25. In this figure

the frequency of triple layer carbon fibre laminated girder of length 25.67 meter was found 10.94 HZ. While other girders of length 19.67 meter and 13.67 meter was noted 17.79 Hz and 34.17 Hz. the frequency in the doubly laminated girder of 25.67 Meter, 19.67 meter and 13.67 meter was relieved as 10.88 Hz, 17.72 Hz and 34.15 Hz. when the strengthening of girder reduces to the single-layer carbon fibre than the frequency in mode 2 was 10.83 Hz in 25.67 meter long girder, 17.60 Hz in 19.67-meter long girder and 34.11 Hz in shortest sample girder. In the case where all girders are un-laminated, the frequency was found as 10.81 Hz for 25.67m length, 17.52 Hz for 19.67 meter and 34.11 Hz for 13.67 meter girder.

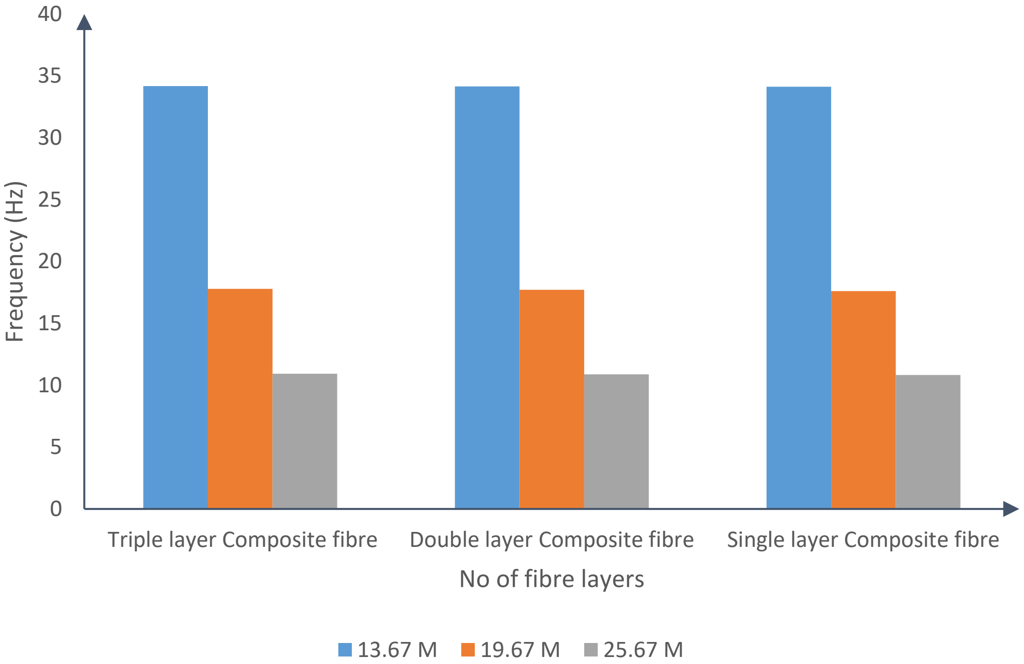


Figure 5. 24 Frequency vs span length in mode shape 2

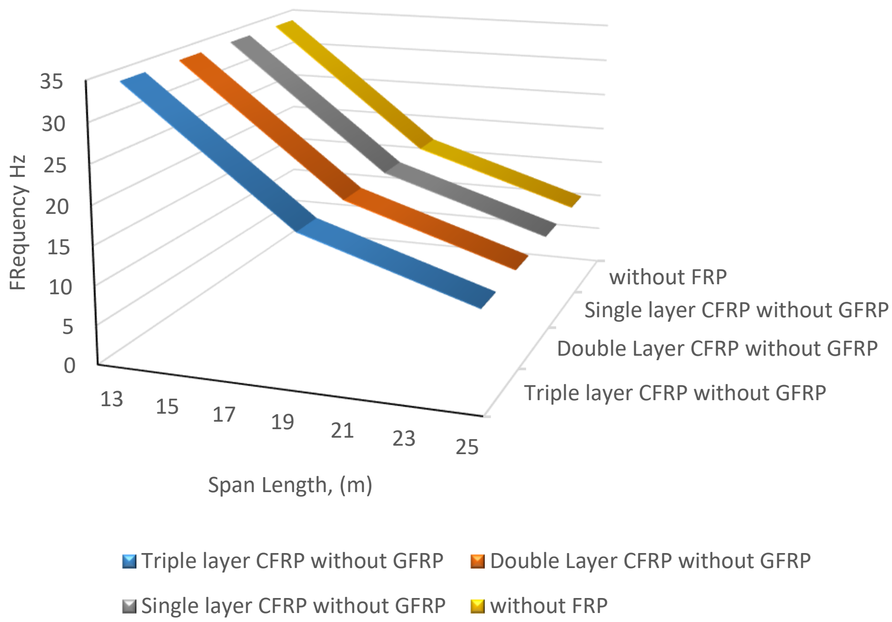


Figure 5. 25 Frequency vs span length in mode shape 2

c. Modal frequency of girder in mode shape 3

Figures 5.27 and 5.28 describe the frequency of all the three different length girder for mode shape 3 which was retrofitted in two different types of fibre combination i.e. first with composite fibre of carbon and glass, and second only strengthen by Carbon fibres. In Figure 5.27 it can be seen that the Single layer Composite fibre when applied in longest span then the

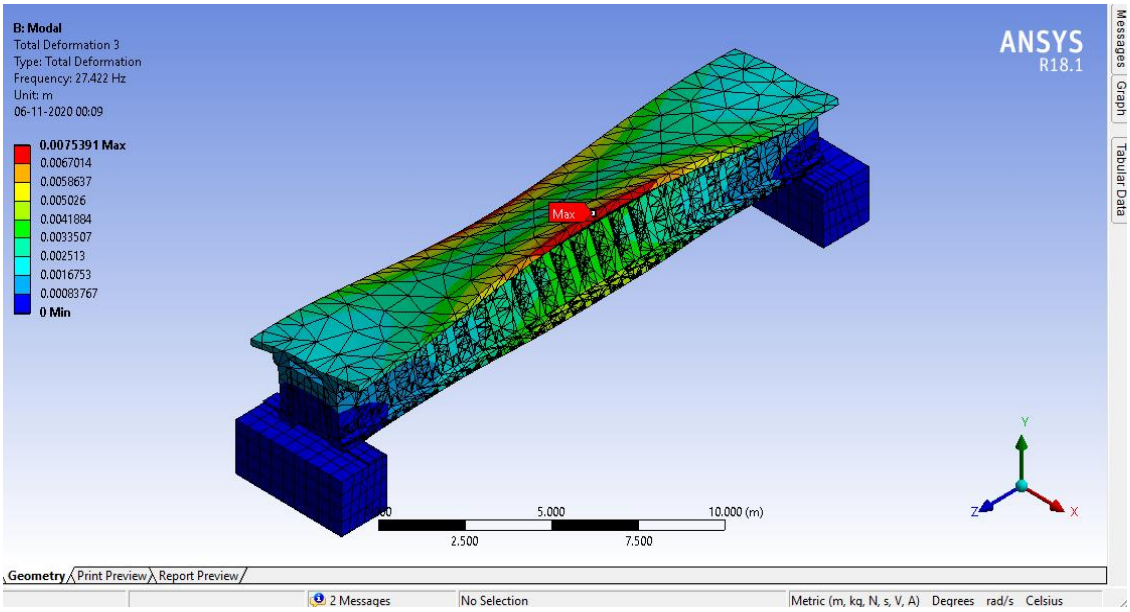


Figure 5. 26 Deformed imaged of girder in mode shape 3

Figure 5.27 and 5.28, describe the frequency of all three different length girders for mode shape three, which was retrofitted in two different types of fibre combination i.e. first with the composite fibre of carbon and glass, and second only strengthen by Carbon fibres. In Figure 5.27 it can be seen that the Single-layer Composite fibre when applied in the longest span then the frequency obtained comes to 10.82 Hz and when it was applied to 19.67 meter and 13.67 meter long girder the frequency was reported 17.60 Hz and 34.12 Hz. It can also be concluded that the frequency difference in the shortest and longest sample girder was just more than double. The frequency for double and triple-layer composite fibre of span 25.67 meter was 14.95 Hz and 15.04 Hz and for 19.67 meter and 13.67 meter span it was confirmed to 17.71 Hz, 17.78 Hz and 34.14 Hz, 34.16 Hz respectively.

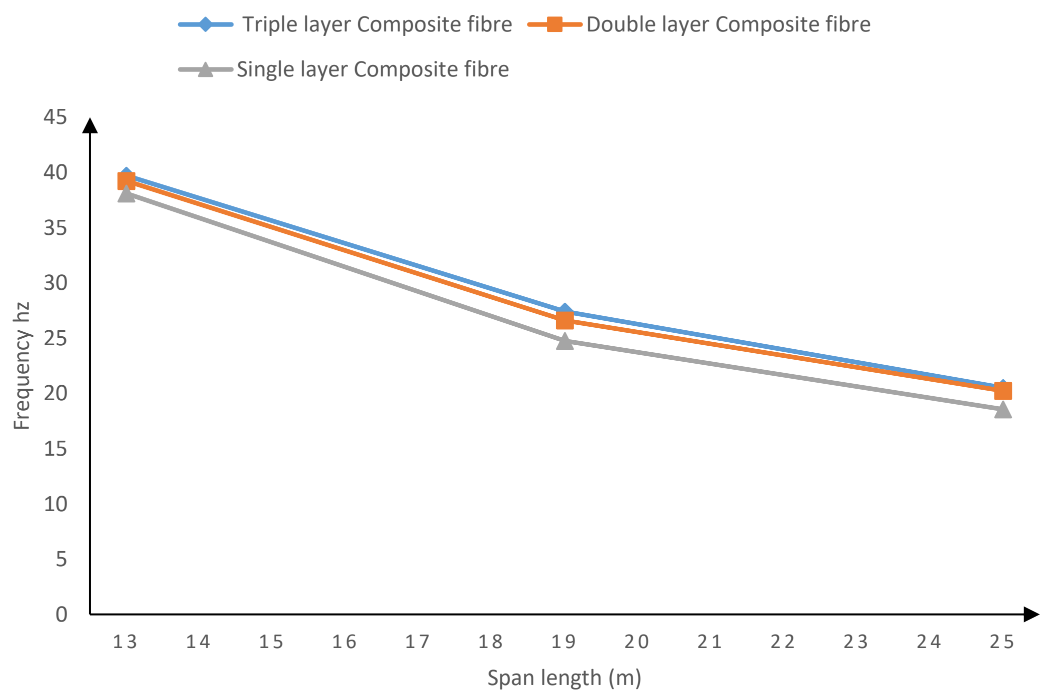


Figure 5. 27 Frequency vs span length in mode shape 2

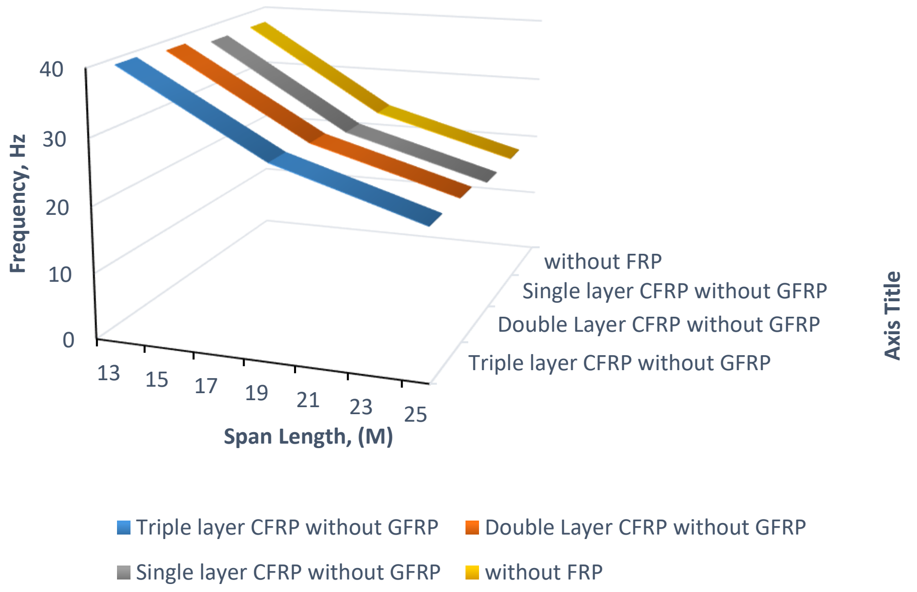


Figure 5. 28 Frequency vs span length mode shape 3

d. **Modal frequency of girder in mode shape 4**

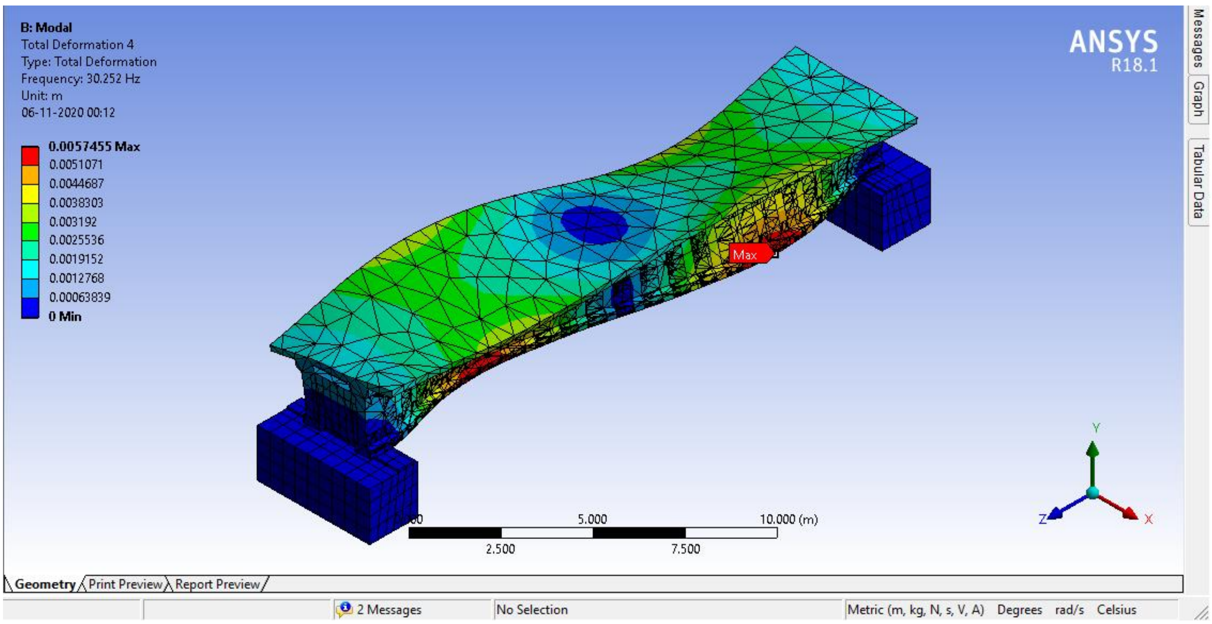


Figure 5. 29 Deformed imaged of girder in mode shape 4

Analysis of modal frequency depict about the dynamic properties of tested structure. The primary objective of this analysis was to find out the mode shape and frequency of girders. Figure 5.30 and Figure 5.31 Contains frequency in mode 4 with and without glass fibre while carbon fibre was always in flexure. In Figure 5.22 the single layer Composite fibre wrapped girder showed more than 2.5 times frequency in the shortest girder than the longest girder of case. This trend was continued in double and triple-layered girder too. In Figure 5.23 the frequency of single layered carbon strengthened girder of span length 25.67 meter was noted as 19.61 Hz while girder of length 19.67 meter and 13.67 meter was found a 29.71 Hz and 50.52 Hz, respectively. When the Carbon fibre layered was increased in all the girder the frequency obtained in 25.67 meter, 19.67 meter and 13.67m girder was 20.84 Hz, 30.06 Hz, and 50.62 Hz, respectively. Similarly, the frequency in all the three-carbon swaddled girders in descending order was found at 21.82 Hz, 30.224 Hz and 50.642 Hz.

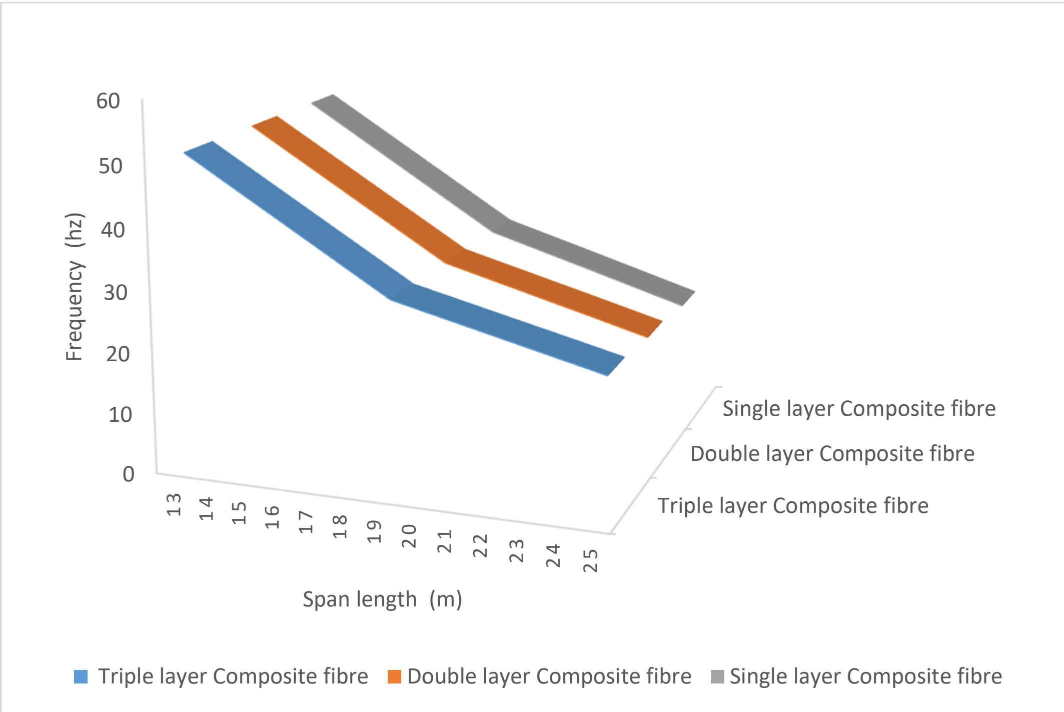


Figure 5. 30 Frequency vs span length in mode shape 4

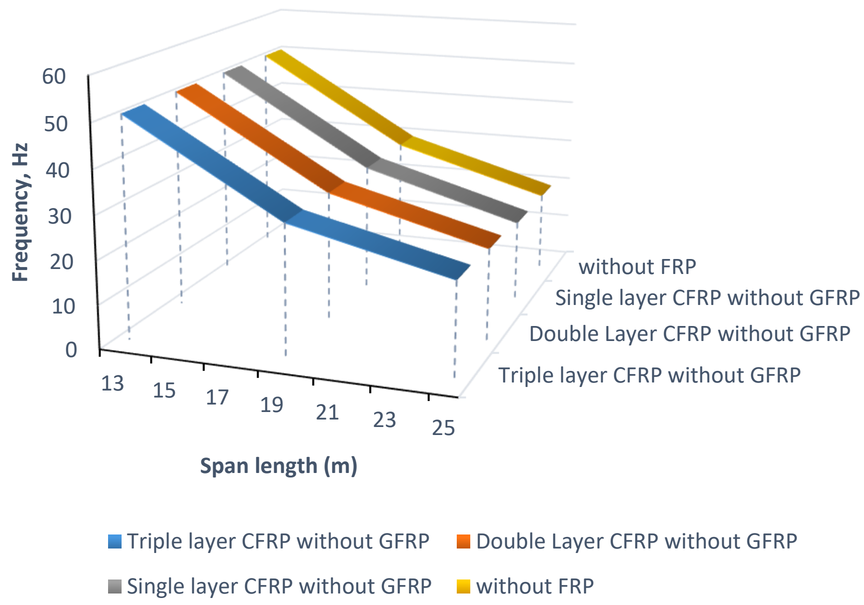


Figure 5. 31 Frequency vs span length in mode shape 4

e. Modal frequency of girder in mode shape 5

Figure 5.24 and Figure 5.25 represents the frequency of laminated girder in mode shape 5. In Figure 5.24 the single-layer composite fibre on the girder of length 25.67 meter showed the frequency of 23.91 Hz and the girder of 19.67m and 13.67m showed the 34.69 Hz and 54.51 Hz respectively. The double-layered composite fibre of the longest girder showed a frequency of 23.91 Hz and the other two girder in descending order showed 34.69 and 54.54 Hz respectively. Similar stance was observed in triple Layered girders of all the three spans. In Figure 5.25 the mode shape 5 and frequency for three different spay and three type of Carbon fibre arrangement were compared. In the first combination the single layer carbon fibre on the girder of three different span i.e. 25.67 meter 19.67 meter and 13.67 meter was applied and frequency was measured for mode shape 5. The frequency for the largest and second-largest girder was 23.91 Hz and 34.70 Hz. The frequencies in the smallest girder after lamination of single layer was found the highest and it was 54.51 Hz. For the double layer, the 25.67 meter girder frequency was noted 23.99 Hz and the girder with 19.67 meter span and 13.67 meter span reported their frequency 34.82 Hz and 54.54 Hz, respectively. Similar Easel was noticed for next added layer of FRP. For three layer FRP retrofitted girder the frequency of 25.67 meter girder was 24.07 Hz, for 19.67 meter it was 34.911 Hz and for 13.76 meter long girder's frequency was 54.56 Hz.

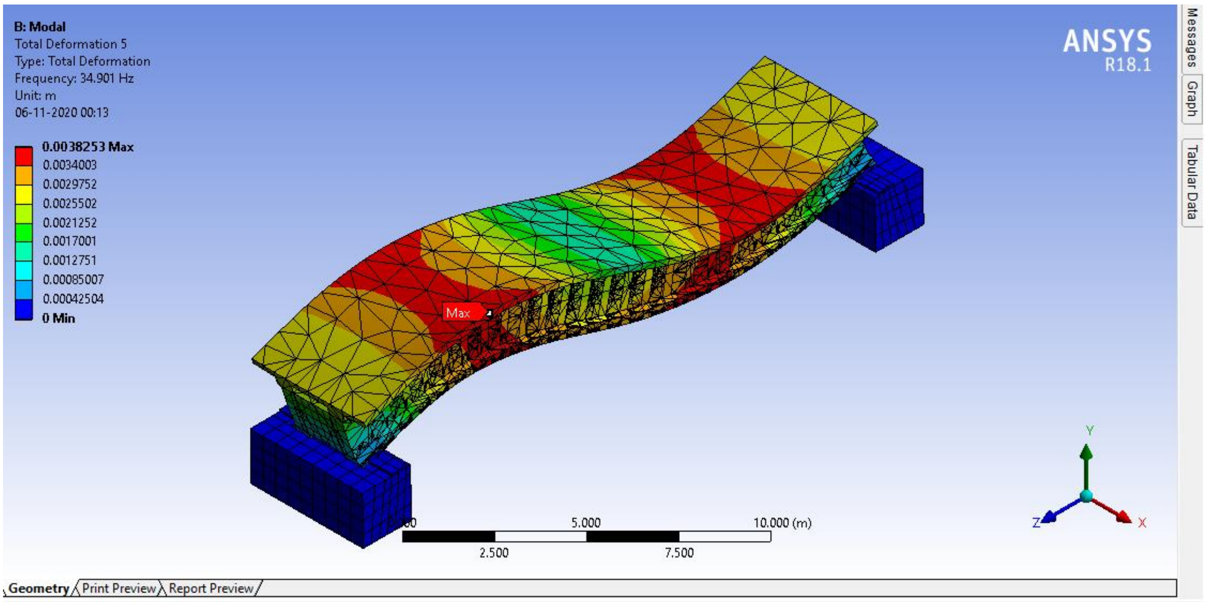


Figure 5. 32 Deformed imaged of girder in mode shape 5

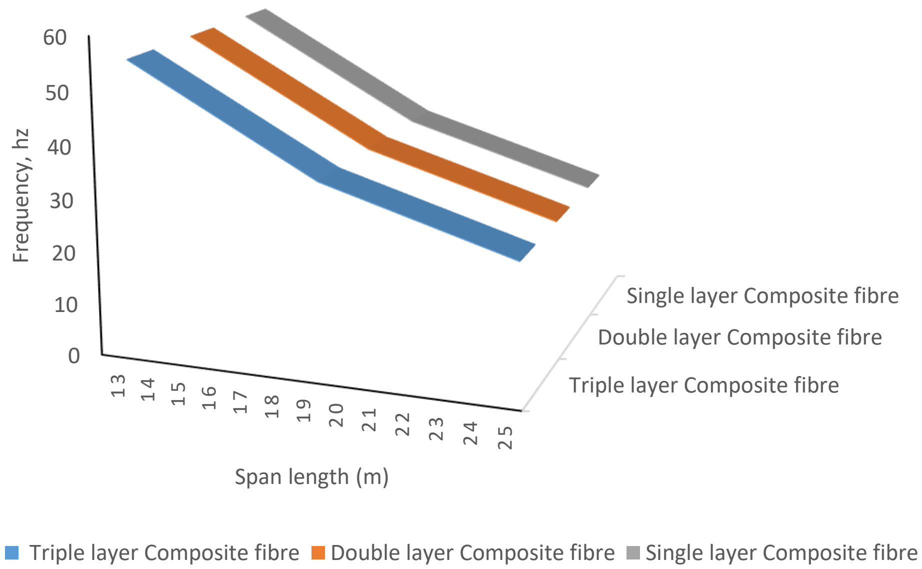


Figure 5. 33 Frequency vs span length in mode shape 5

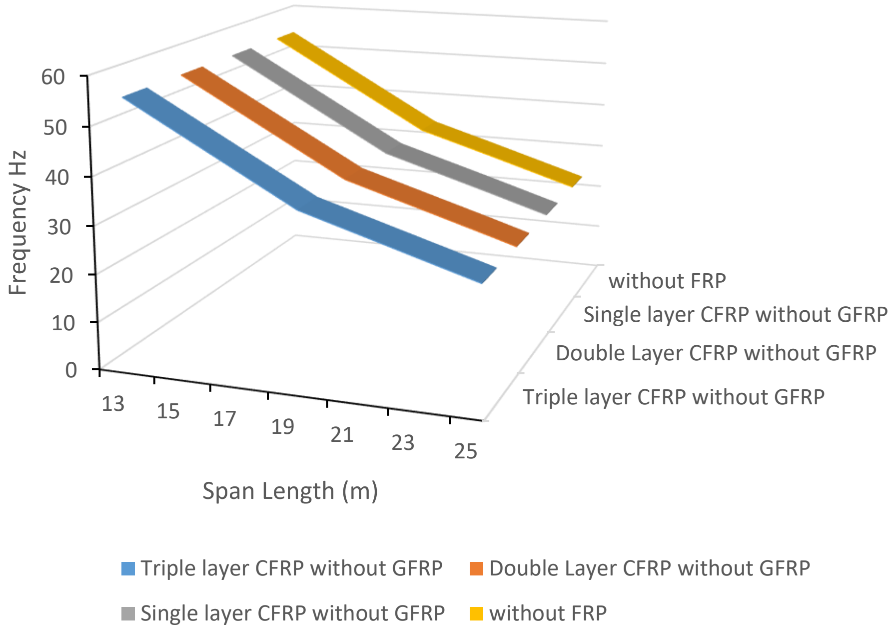


Figure 5. 34 Frequency vs span length in mode shape 5

5.4 Strengthening scheme of girder

In the above simulation, the three different sizes of girder is analyzed for the different lamination condition of fibre. From the result, it can be concluded that shear strengthening is essential for girder to perform better. The ANSYS result shows that glass fibre in shear zone has spectacular effect in reducing the deformation and increasing natural frequency. The effect of increasing of layer was observed better in the girder of span length more than 15 meter I-girder whereas in the I-girder smaller than 15 meter has diminutive increases in properties.

It is recommended that for girder of length 13.67 meter, double layer glass fibre in the shear zone and two wraps of carbon fibre in flexure. And for the girder 19.67 meter and 25.67 meter the three layer carbon lamination should be used in flexure and three layer glass for high-speed trains.

5.4.1 **Strengthening of bridge no 114**

As per the result of finite element analysis, it is suggested to strengthen the bridge according to the size of its girder. The effective length of girder of bridge no 114 is 19.67 meter. So, according to the recommendation, the flexure zone of the girder will be laminated by three layer of carbon fibre reinforced polymer and shear strengthening will done using glass fibre reinforced polymer as shown in Figure 5.35. The anchors of carbon fibre will be installed at a distance of 250 mm. the width of glass fibre is 500 mm as shown in Figure 5.35 and the site image of fibre wrapping in Figure 5.36. The application of fibres at site is represented in figure 5.37.

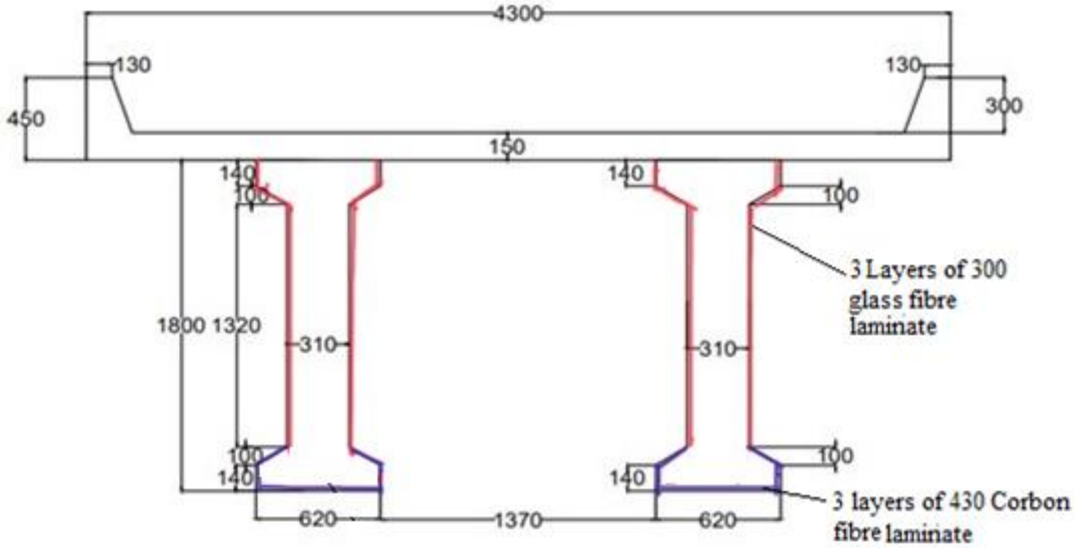


Figure 5. 35 Section view of strengthening plan

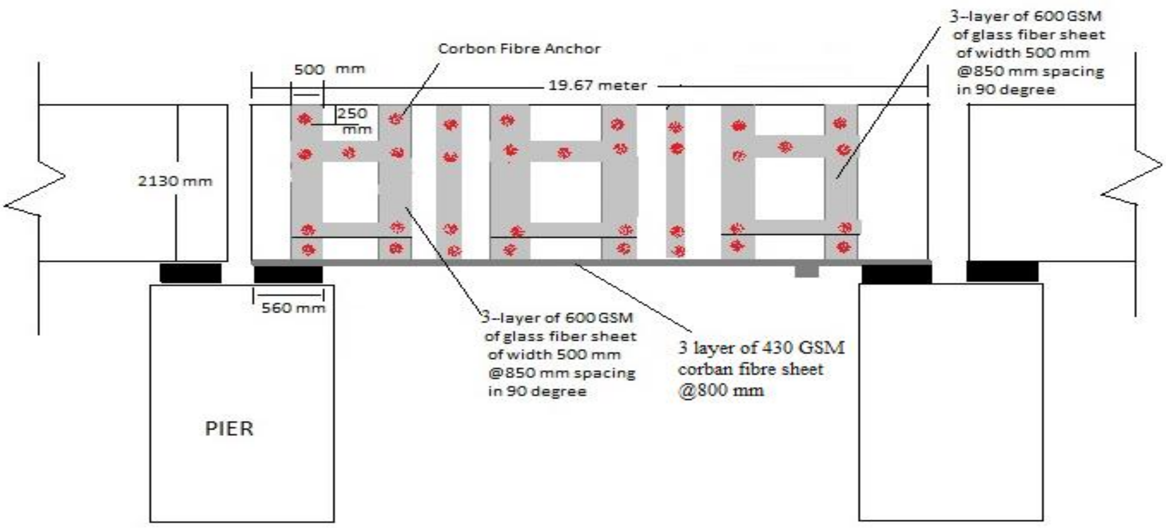


Figure 5. 36 Side view of strengthening plan of girder

Figure 5. 37 strengthening using fibre at site of bridge no 114

5.5 Field testing of bridge

Before and after the strengthening of girder as per prescribed fibre layers, the bridges were tested using WAGON 7 locomotive to observe the deflection and natural frequency in the girders with the help of linear potentiometer and accelerometer, as shown in Figure 5.38 then after bridge was strengthened as per the above-prescribed scheme.

Figure 5. 38 Load applied on the bridge using wagon 7

5.5.1 Testing procedure

The measurement of the deflection and natural frequency of the RCC Girders of simply supported over masonry piers was done using a linear potentiometer and accelerometer respectively at mid-span for one cracked span, and one uncracked PSC I Girders in the span of the bridge No 114 and bridge no 54.

5.5.2 Testing apparatus of the bridge girder

Pre and Post strengthening test was carried out using a linear potentiometer. To assess the natural frequency of the beam before and after strengthening the accelerometer was used. An independent support system using steel cribs was created to place sensors.

5.5.2.1 Measurement of deflection

The maximum deflection in the PSC I girder occurs at the mid-span. An independent platform of steel cribs was provided at the site for the Linear Potentiometer placement after cleaning the surface. The platform to support the linear potentiometer is made to be even, and the same is checked with the spirit level. The linear potentiometer is clamped on its stand which is fixed and secured with the platform. The contact with the bottom chord of the girder is established with the head of the plunger such that the initial reading is recorded with the corresponding change in the voltage. The TIPO PM 25 5K MR Potentiometer was used (Figure 5.39)

Figure 5. 39. TIPO PM 25 5K MR

The data collection and analysis are done with the help of DGC cDAQ 9178 software for deflection. The electric signals through the cable go to the NI 9205 module which is attached to NI compact DAQ 9178 chassis & this hardware is integrated into the cDAQ 9178 software.

5.5.2.2 Natural Frequency measurement using Accelerometer

The measurement of the Natural frequency of the RCC Girders simply supported over masonry piers was done at mid-span for one cracked span and one uncracked PSC I Girders in the two Spans. Pre-stressed concrete (PSC) bridge girders No 54 have undergone distress with age through loss of pre-stressing force and through the development of structural cracks in the concrete. It is expected that such 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. Accelerometers are mounted onto the girders for recording the frequency. The motion (or dynamic force) of the vibrating body is converted into an electrical signal by the vibration transducer or pickup.

Figure 5. 40 B& K accelerometer

The accelerometer is attached to the metal base plate using the magnetic property. Figure 5.40 shows the accelerometer B&K Model No. 4396 used for recording the vibration. The technical specifications are given below.

5.5.2.2.1 Data collection and analysis

The data collection and analysis are done with the help of LAB VIEW 2011 software of National Instruments. The signals through the cable go to the NI 9234 module, which is attached to NI cDAQ 9178 chassis, and this hardware is integrated into the Lab View 2011 software.

5.5.2.2.2 Data acquisition of the natural frequency

The vibrations in the girder are measured by the accelerometer in an acceleration vs time-domain graph using National Instruments DGC cDAQ 9178 & National Instruments module 9025 along with accelerometer B&K Model No.4396. The locomotive WAG 7 was moved over the girder. The corresponding vibrations in the girder were recorded in the software. This data is converted into an acceleration vs. frequency domain graph using Fast Fourier Transform (FFT) algorithm. DGC cDAQ Software is incorporated for the processing of signals and the FFT of the acquired data. The software algorithm is available in the form of a block which has the formulation for carrying out the FFT of the acquired. The data is analyzed in various segments and is cropped to get the modal participation of the desired frequency.

The linear potentiometer and accelerometer is fixed in such a way that it is independent of the girder vibrations and other movements (figure 5.41)

Figure 5. 41 Arrangement of deflection sensor and accelerometer

5.6 Pre-strengthening test of girder

As mentioned, the bridge is deteriorated very brutally and needs urgent attention. Before applying any repairing method, it needs to be tested for its residual strength and workability remained. A locomotive of Indian railway WAGON 7 (with given parameter in table 3) moved on the entire span of the bridge (Figure 5.38) at the rate of 20 km/hr and 100 km/hr, respectively, for maximum deflection and natural frequency. An independent arrangement of platform made for placing sensors like potentiometer and accelerometer on the bottom side of the girder to evaluate deflection and natural frequency. The accurate residual strength assessment of the bridge can only be calculated by field testing of the bridge.

5.6.1 Maximum deflection under static loading before strengthening

In the Maximum deflection of the girder is shown in figure 5.42. Under static loading conditions the Initial amplitude in Figure 5.40 is equal to 23.84 mm and final amplitude is equal to 20.26 mm, so the deflection will be 3.58 mm.

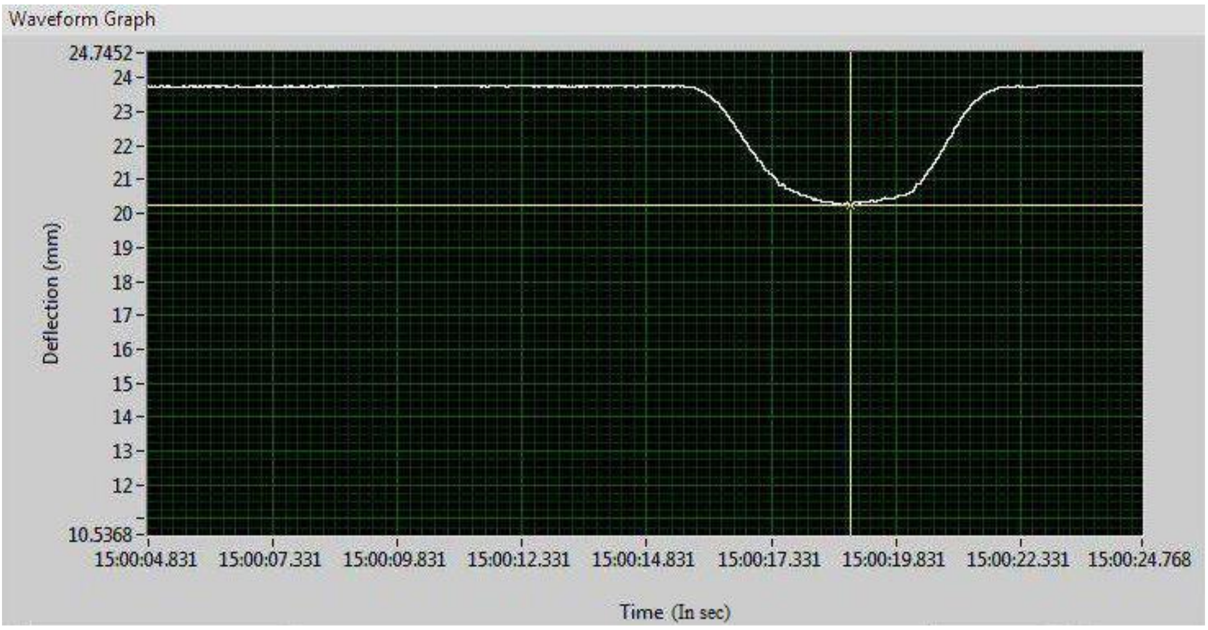


Figure 5. 42 Displacement vs Time under dynamic loading static load

5.6.2 **Maximum deflection under dynamic loading before strengthening**

Dynamic load test the train started with the speed of 20 KMPH and accelerated to the 100 KMPH. The deflection and natural frequency have been recorded in between the speed at several interval, The Figure 5.43 recorded the maximum deflection of girder. The initial amplitude is recorded as 16.553 mm final amplitude =11.992 mm so total deflection can be calculated as Initial amplitude - Final amplitude which will be as 16.553-11.992=4.5 mm

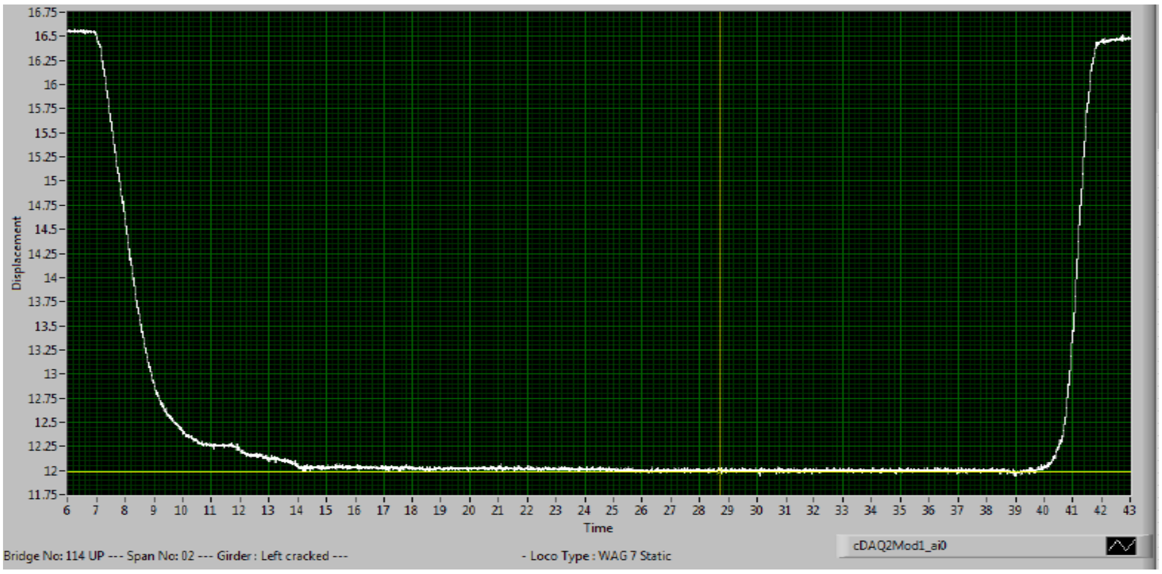


Figure 5. 43 Displacement vs time under dynamic loading dynamic load

5.6.3 Maximum natural frequency under dynamic loading in bridge girder before strengthening

When the WAGON 7 moved across the bridge to record the natural frequency of girders. The graph of the maximum natural frequency of bridge no 114 before strengthening is shown in figure 5.44, the maximum natural frequency before strengthening is recorded as = 9.79 Hz

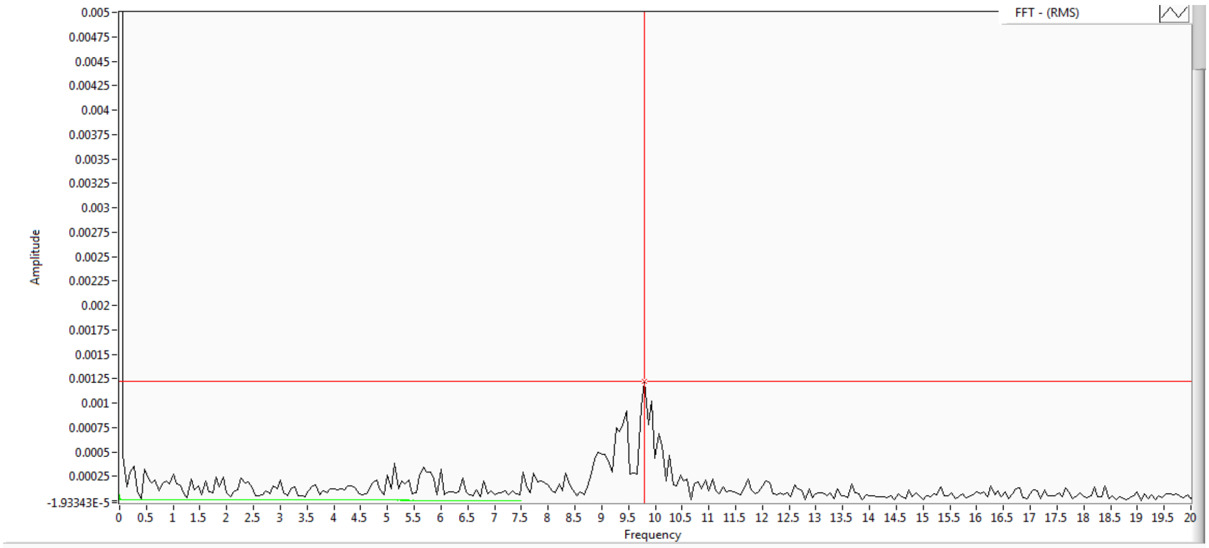


Figure 5. 44 Amplitude Vs frequency under dynamic loading

The pre strengthening data obtained at different speed of locomotive WAGON 7 are listed here in table 5.4

Table 5. 4 Pre-strengthening test results of Bridge no. 114

Girder Type	Types of Loading	Deflection (mm)	Natural Frequency (Hz)
LSG	Dynamic Load at 100 KMPH	4.5	8.09
LSG	Dynamic Load at 75 KMPH	3.65	8.26
LSG	Dynamic Load at 20 KMPH	3.64	8.45
LSG	Static	3.58	NA
RSG	Dynamic Load at 100 KMPH	3.52	8.90
RSG	Dynamic Load at 75 KMPH	3.4	9.68
RSG	Dynamic Load at 20 KMPH	3.45	9.79
RSG	Static	3.41	NA

(LSG- Left side girder, RSG- Right side girder)

5.7 Post strengthening deflection and natural frequency of the bridge

After strengthening the bridge by repairing and laminating the girder, again using WAG 7, the static and dynamic load was applied on bridge no 114.

5.7.1 Maximum deflection under static loading in bridge no 114 after strengthening

After strengthening the girder, the Maximum deflection is decreased compared to pre-strengthening results (Figure 5.45). Under static load, the Initial Amplitude is equal to 22.23 mm, and the final amplitude is equal to 19.36 mm, so the deflection of the girder is equal to 22.23-19.3608 = 2.87 mm

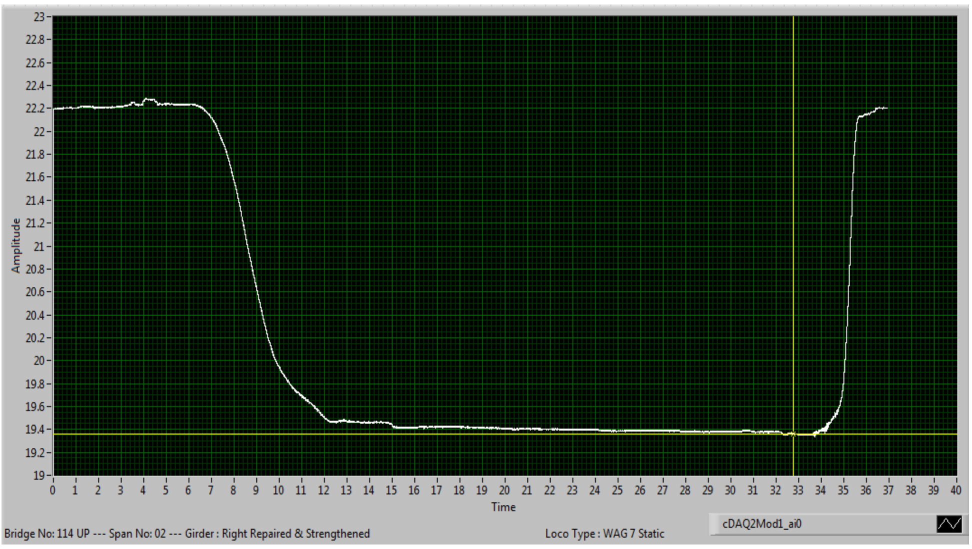


Figure 5. 45 Amplitude vs time for static load after strengthening

5.7.2 Maximum deflection under dynamic loading after strengthening

On applying dynamic load through wagon 7 on girders of bridge no 114 after strengthening, the maximum deflection is shown in figure 5.46**.** The initial amplitude is equal to 19.97 mm and final amplitude is equal to 16.48 mm, so the final maximum deflection comes to 3.39 mm

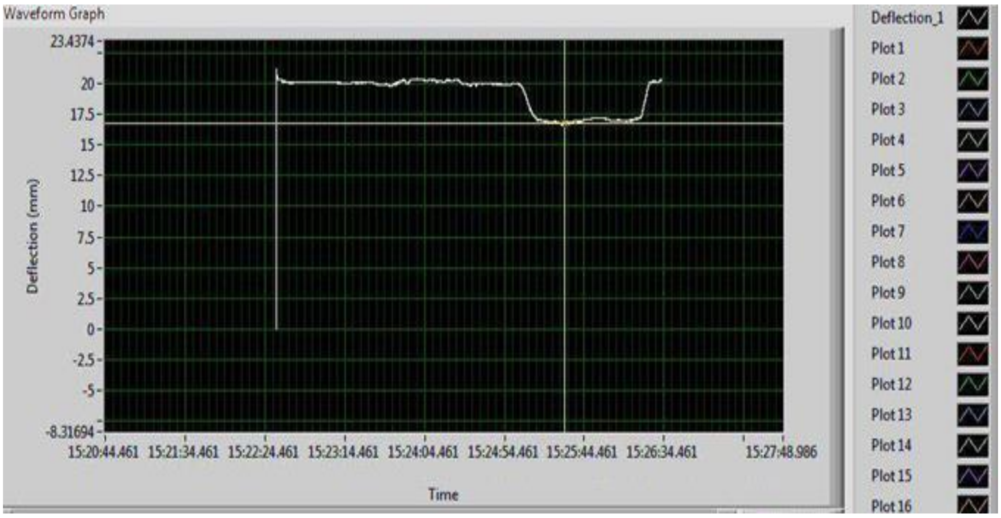


Figure 5. 46 Displacement vs time under dynamic loading

5.7.3 Maximum natural frequency in bridge girder after strengthening

The maximum natural frequency of bridge girder no 114 post strengthening on applying dynamic load is shown in Figure 5.47. The maximum natural frequency of girder is 9.8 Hz.

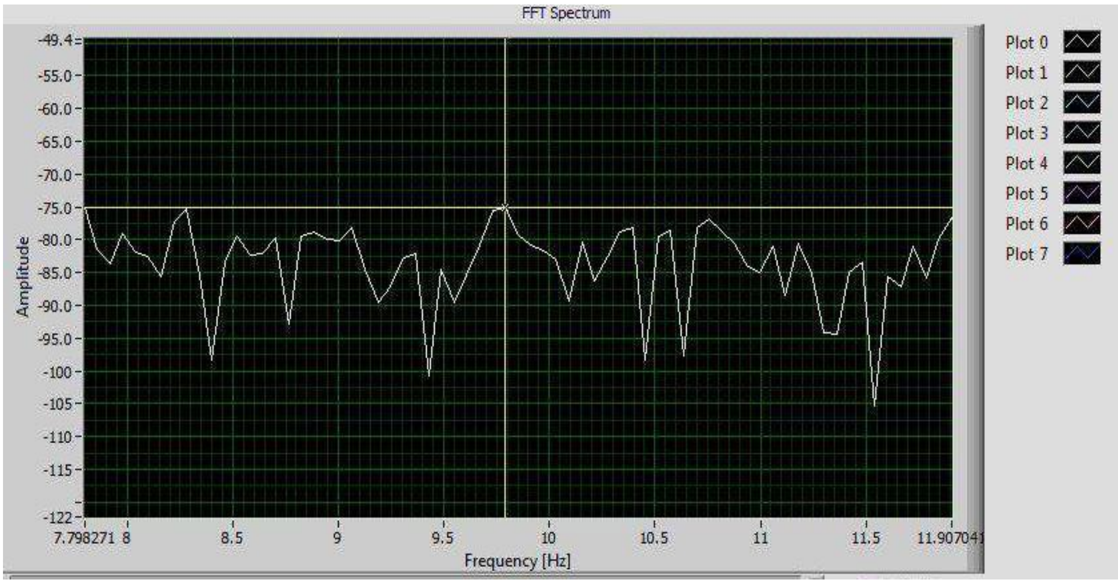


Figure 5. 47 Amplitude Vs frequency variation of girder of 114

5.7.4 Post strengthening result for bridge no 114

After strengthening, the bridge girder was tested for all the three recommended layers of wrapping under static and various dynamic loading conditions to understand the deflection and natural frequency. Natural frequency and deflection data were recorded for all three layers of fibre and listed in table 5.5.

Table 5. 5 Post strengthening result of bridge no 114

Girder Position	No of fibre layers	Type of Loading	Deflection (mm)	Natural Frequency (Hz)
LSG	One Layer fibre	Dynamic @ 100 KMPH	3.39	8.66
LSG	One Layer fibre	Dynamic @75 KMPH	3.35	8.68
LSG	One Layer fibre	Dynamic @ 20 KMPH	3.35	8.69
LSG	One Layer fibre	Static	3.30	NA
RSG	One Layer fibre	Dynamic @ 100 KMPH	3.30	9.05
RSG	One Layer fibre	Dynamic @75 KMPH	3.28	9.79
RSG	One Layer fibre	Dynamic @ 20 KMPH	3.28	9.82
RSG	One Layer fibre	Static	3.24	NA
LSG	Two Layer fibre	Dynamic @ 100 KMPH	3.13	9.02
LSG	Two Layer fibre	Dynamic @75 KMPH	3.09	8.69
LSG	Two Layer fibre	Dynamic @ 20 KMPH	3.08	8.71
LSG	Two Layer fibre	Static	3.08	NA
RSG	Two Layer fibre	Dynamic @ 100 KMPH	3.06	9.28
RSG	Two Layer fibre	Dynamic @75 KMPH	3.01	9.70
RSG	Two Layer fibre	Dynamic @ 20 KMPH	2.91	9.88
RSG	Two Layer fibre	Static	2.89	NA
LSG	Three Layer of fibre	Dynamic @ 100 KMPH	2.87	9.52
LSG	Three Layer of fibre	Dynamic @75 KMPH	2.82	9.64
LSG	Three Layer of fibre	Dynamic @ 20 KMPH	2.80	9.71
LSG	Three Layer of fibre	Static	2.789	NA
RSG	Three Layer of fibre	Dynamic @ 100 KMPH	2.76	9.84
RSG	Three Layer of fibre	Dynamic @75 KMPH	2.74	9.89
RSG	Three Layer of fibre	Dynamic @ 20 KMPH	2.74	9.91

RSG	Three Layer of fibre	Static	2.67	NA

5.8 Result and discussion

In table 5.5 the deflection and natural frequency are listed for different dynamic loading speed and static loading for the various fibre layer wrapping. From table 5.5 it is concluded that the natural frequency with every layer of wrapping of girder increases as compared to unstrengthen girder. The left side girder (LSG) of bridge no 114 has more cracks compared to the right side of the girder. When the static loading applied using WAGON 7 after the single layer fibre lamination of left side girder the deflection is reduced by 8.31 % and in double layer wrapping this decrement in deflection was recorded as 16.16 percentage and in the three layer wrapping of carbon and glass fibre the deflection reduced by 28.36 % in proportion of unstrengthen deflection of LSG. Similarly, for the static load test on the right side of girder (RSG) the deflection reduction in one, two and three-layer was recorded as 5.16%, 17.81 %, and 27.56 %, respectively. The dynamic load test of the girder was recorded on three-speed 20 KMPH, 75 KMPH and 100 KMPH for all the three combinations of fibre layer. The reduction in the deflection was greatly reduced in the 100 KMPH speed of WAGON 7. So it can be concluded that the three layer fibre wrapping in long girders will be highly effective. The reduction in deflection in the dynamic test @100 KMPH in LSG is 34.24 %, 45.40 and 58.54 % in single, double and triple layer of fibre wrapping. At the same time, the deflection reduction in the dynamic test @100 KMPH in the RSG is 6.60%, 14.96% and 27.38% when single, double and triple layering of fibre were applied. This trend was not continued with this intensity in the dynamic loading of 20 KMPH. In this case the reduction in deflection in left side girder is recorded as 8.44%, 17.90% and 21.90%, respectively for ascending order of fibre wrapping. In the right side girder, the dynamic load test reduces deflection by 5.17%, 18.30 % and 25.71 % for one, two, and three layers of fibre wrapping, as shown in Figure 5.48.

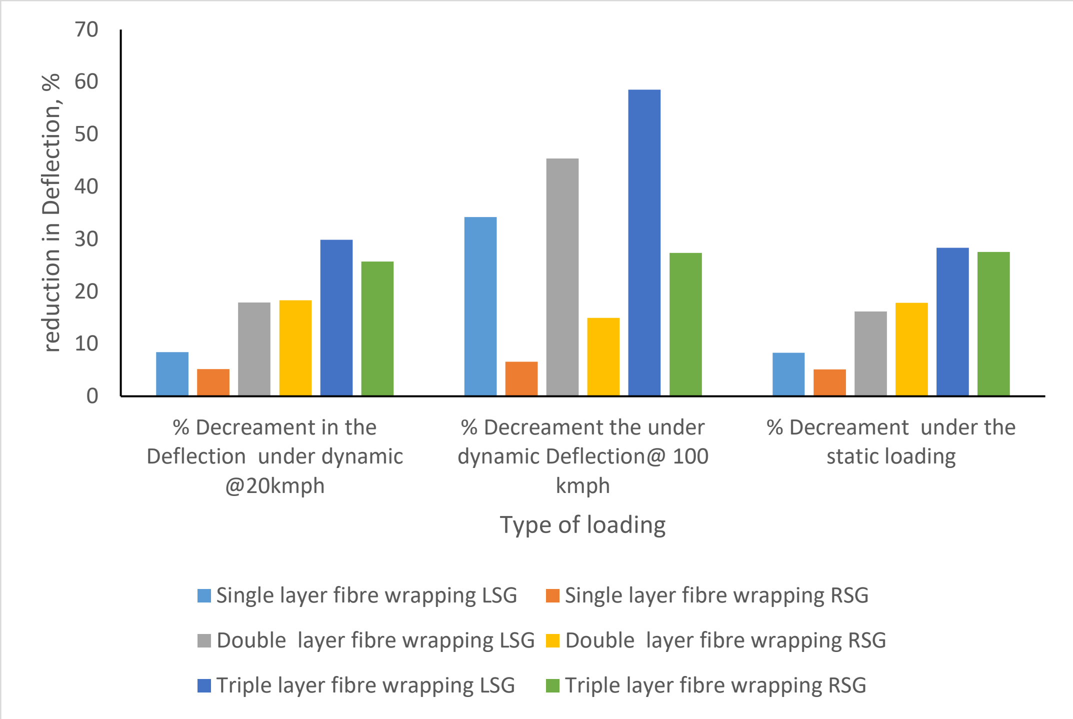


Figure 5. 48 Reduction in deflection in different loading

Figure 5.49 represents the increment in the natural frequency after the fibre applied on the girder of bridge no 114. The left side girder gives a lower natural frequency than the right side girder as it contained more crack. When the WAGON moves at very low speed of 20 KMPH the frequency increment in the bridge girder was recorded as 2.83, 2.98 and 12.98 percent of unstrengthen girder. In the case of single double and triple layer wrapped at left side girder respectively. In the same speed of the wagon the RSG shows negligible increment. The increment in frequency in RSG is recorded as 0.25%, 0.82%, and 1.15 % in ascending order of fibre wrapping around the girder. The increment in the natural frequency at the speed of 100 KMPH in the LSG is 7.07, 11.51 and 17.60 percent when girder was laminated by one, two and three-layer of fibre wrapping. Similarly, the right side girder of bridge shows the increment as 1.69, 4.5, and 10.56 percent of unstrengthened beam at the wagon speed of 100 KMPH.

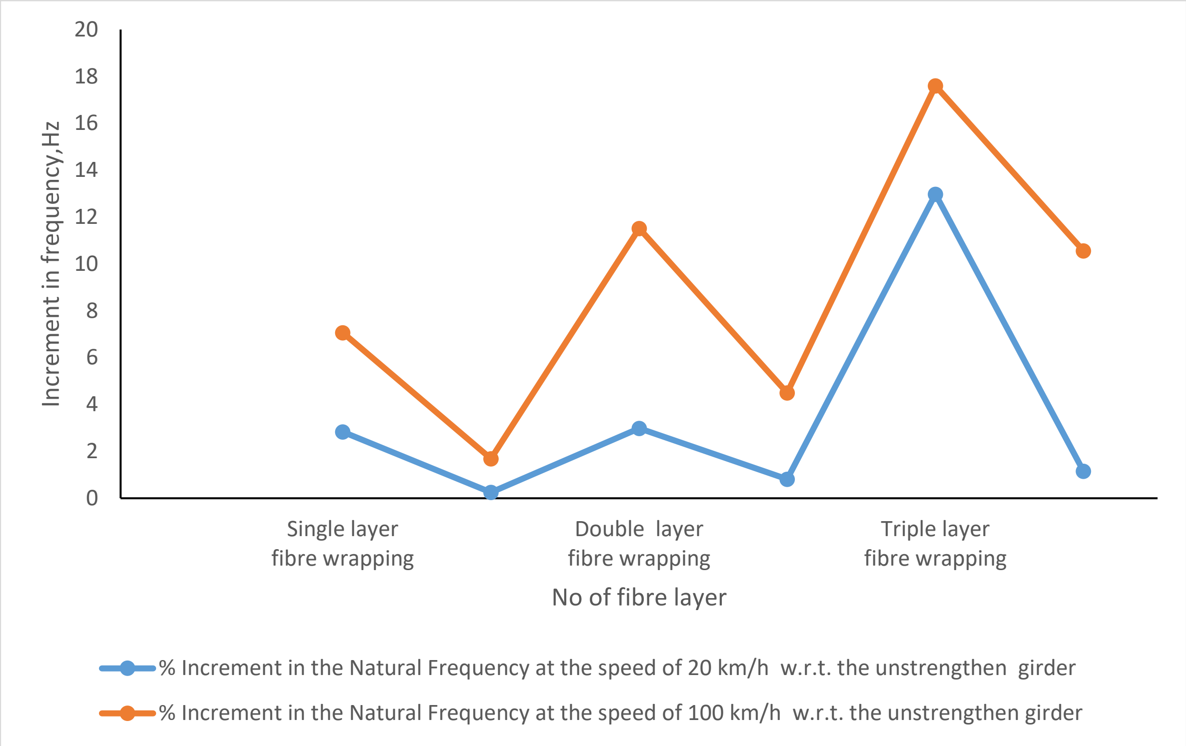


Figure 5. 49 Change in natural frequency at different fibre layer

5.9 Analysis and strengthening of Ratlam-Godhra railway bridge no 54

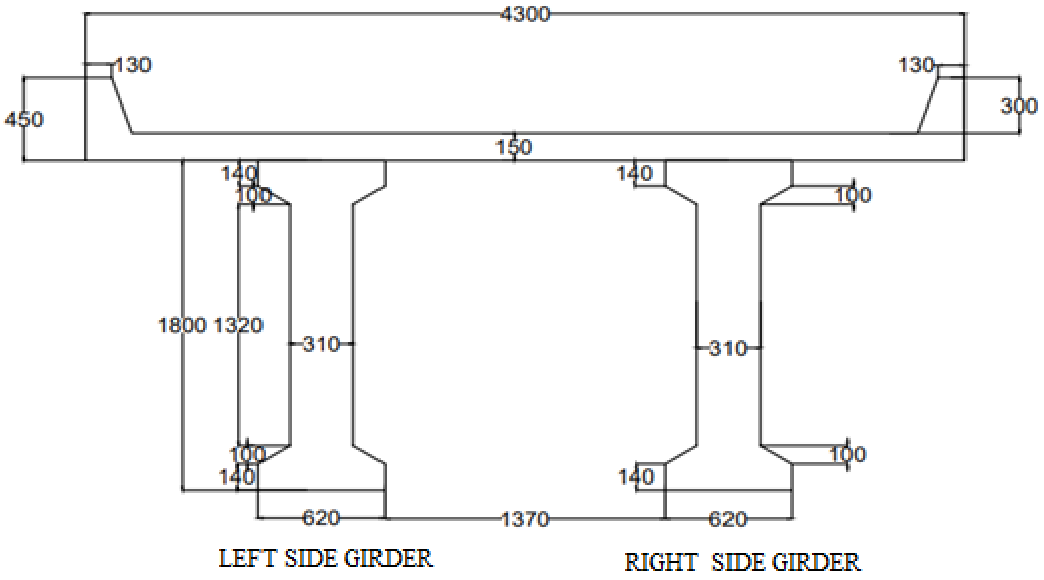
The rail bridge no 54 of western railway is situated at the Hadap River at Ratlam-Godhra route M.P. India. The bridge was built in the year 1959-60 was reported with several cracks in the different parts of the beam. After a detailed inspection and analysis of girder a strengthening plan was recommended and real time load testing was carried out after strengthening the girder.

A finite element analysis of girder was carried out to find out the appropriate fibre plates. Recommended fibre plates were glued in the shear and tension zone of the beam. Using Indian locomotive WAGON 7, the deflection and natural frequencies were measured after one layer, two layers, and three layers of composite fibre strengthening in static and dynamic loading conditions. Comparison of pre and post retrofitting strength in terms of deflection and natural frequency has been discussed. The results ticked a significant improvement in deflection and natural frequency after repairing, and thus the speed of regular running trains resumed up to 100 km/hr, which was restricted up to 20 km/hr before strengthening of girder.

5.9.1 Background of bridge no 54

The Ratlam-Godhra bridge no 54 is located at chainage Km 510/9-15 between station Limkhedha and Mangal Mahudi. (Figure 5.50) The span of the bridge is 13.67 and 19.67 meter long. Each girder consists of 4 diaphragms (2 intermediate and 2 at the end). The weight of a girder is approximately 70 T. the substructure is stone masonry in cement mortar and gravity type. All the section details of the can be seen in Figure 5.51.

Figure 5. 50 View of bridge no 54 at site



(All dimension are in mm)

Figure 5. 51 Cross-section details of bridge no 54

5.9.2 Damage detection in the girder of bridge 54

A detailed inspection was conducted to find out the severity of the deterioration of the bridge, including intensity of crack, damages in diaphragm corrosion in steel bars, etc. the following finding is presented after an overview of bridge no 54

1. The PSC I-girders show vertical cracks from the bottom of the girder in Span. (Figure 5.52)
2. The more no cracks on the right side of the girder were observed than on the left side of the girder.
3. Discoloration due to deterioration with time is seen in the overall structure
4. Severe deterioration of the diaphragm observed
5. Severe spalling and corroded reinforcement exposure is observed at the bottom slab. This may be attributed to the carbonation that taken place in the structure.
6. Spalling of concrete is observed in the diaphragm bottom (Figure 5.53)

7. Cracks at the girder bottom at bearing locations are observed.
8. Severe deterioration at intermediate span locations is seen.
9. Termite attack is observed in the girders.

Figure 5. 52 Severe cracks in girder

Figure 5. 53 Spalling in diaphragm and girder

5.10 Modeling of Ratlam bridge No 54

Modeling of three different sizes of the girder was carried out in section 5.3 of this chapter. All three lengths were 13.67,19.67 and 25.67. The 13.67 meter and 19.67 meter girder is of bridge no 54, the 19.67-meter girder belongs to bridge no 114, while the span of 25.67 meters was analyzed additionally to correlate the trend of all the parametric analysis.

So the modeling and analysis result is being taken from the above study.

5.10.1 Strengthening Scheme of Ratlam bridge No 54

From the analysis done in section 3.6 of chapter 3 and section 5.3 of this chapter no 5, it is concluded that if the girder size is larger than 15 meters then the three-layer carbon and fibre wrapping will be needed. At the same time, if the girder size is equal to or smaller than 15 meter then the double layer carbon wrapping in flexure and double layer of glass fibre polymer should be sufficient. So as per the recommendation, the bridge girder is retrofitted accordingly with 2 layer of glass fibre is in the shear zone and two-layer of carbon fibre in the tension zone. As shown in figure 5.54 figure 5.55 and the site image is in figure 5.56.

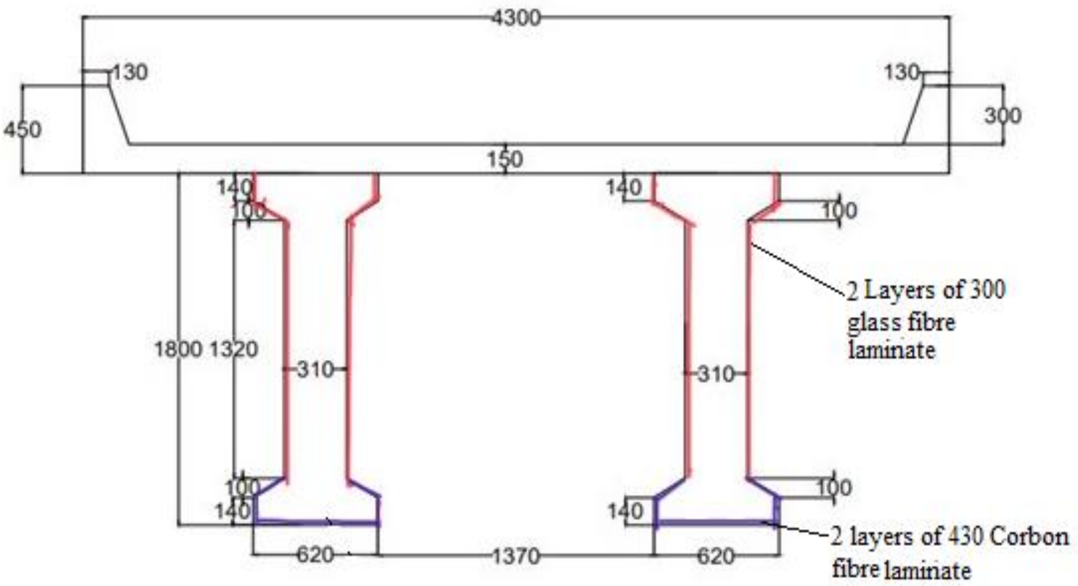


Figure 5. 54 Section view of strengthening plan

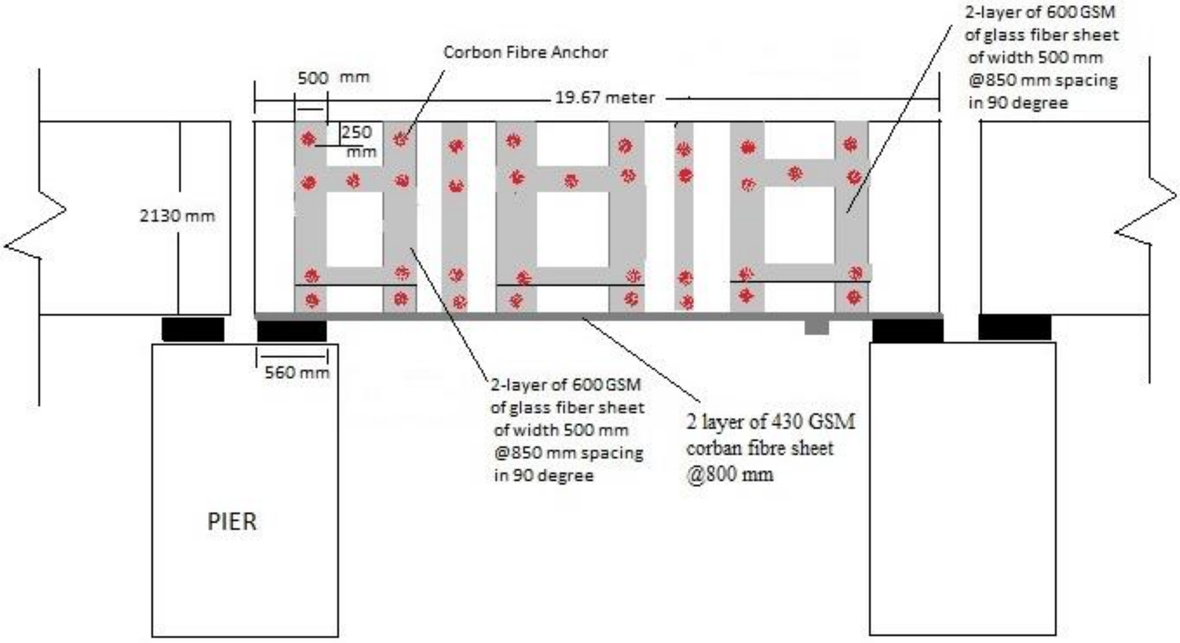


Figure 5. 55 Side view of strengthening plan of girder

Figure 5. 56 Lamination of bridge no 54 at site

5.10.2 Testing of Ratlam bridge no 54

After strengthening, the WAGON – 7 rail engine of Indian Railways was made to run over the bridge to record the deflections and frequencies in the static and dynamic loading conditions at different speeds (Figure 5.57). The details of WAGON 7 are listed in table 2 below:

Figure 5. 57 Load applied on the bridge using wagon 7 and sensors at site

5.11 Pre and post strengthening results of bridge no 54

Pre and post-analysis of deflection and natural frequency in Span no 2 and 4 of Bridge 54 of the Indian railway have been recorded after laminating the complete span. To put weight on the girder a Rail locomotive of WAG-7 type have used. Every span has two beams which are named LSG and RSG, for all data recording purposes.

5.11.1 Pre-strengthening test results

Before strengthening, the deflection and natural frequencies were collected by applying the load on every span separately. Some of the graphical figure among them with the highest value on the respective girder were represented here.

The Initial amplitude shown in the figure is equal to 20.67 mm The final amplitude is equal to 17.22 mm, so the maximum deflection will be 20.67-11.992=3.45 mm which can be seen in figure 5.58.

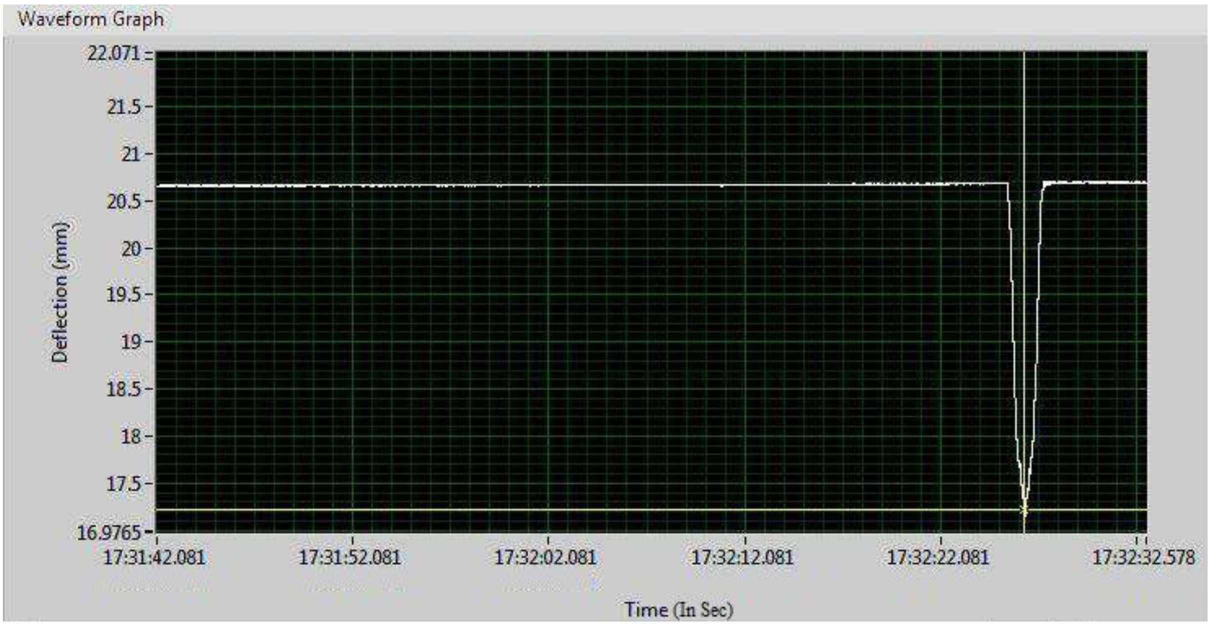


Figure 5. 58 Displacement vs time under static loading

The initial amplitude is recorded 19.97 mm and final amplitude to 16.32 mm so the final maximum deflection is equal to 3.65 mm under dynamic loading applied by wag-7 (figure 5.59).

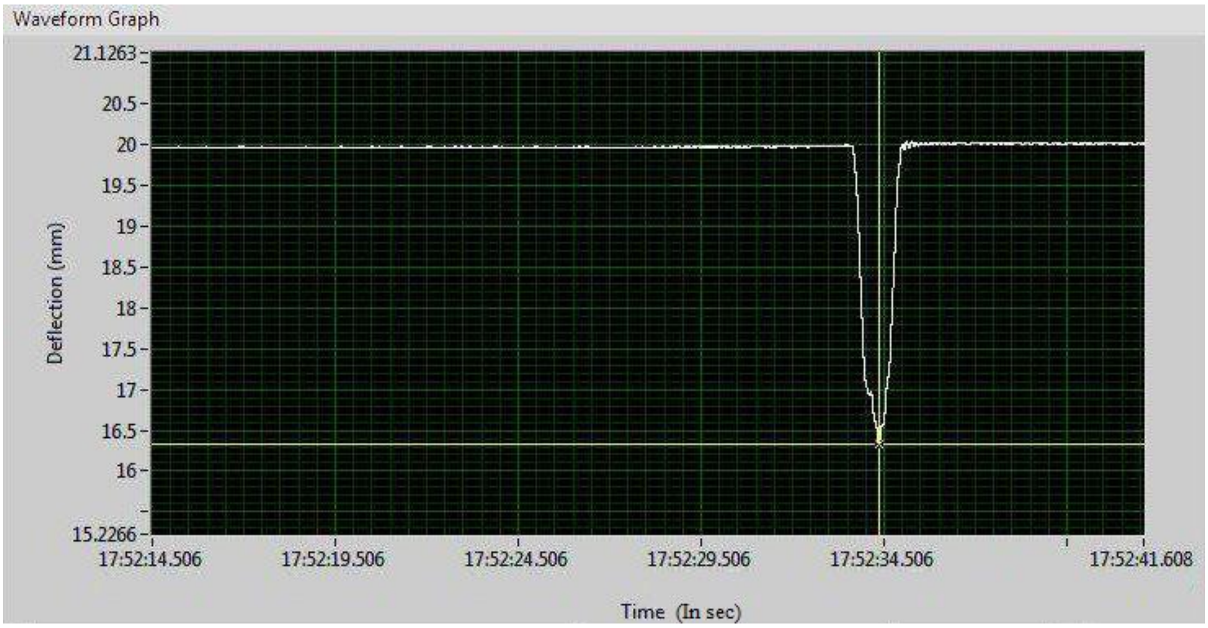


Figure 5. 59 Displacement vs time under dynamic loading

The maximum natural frequency is recorded 9.68 hz in unstrengthen condition under dynamic load as shown in figure 5.60.

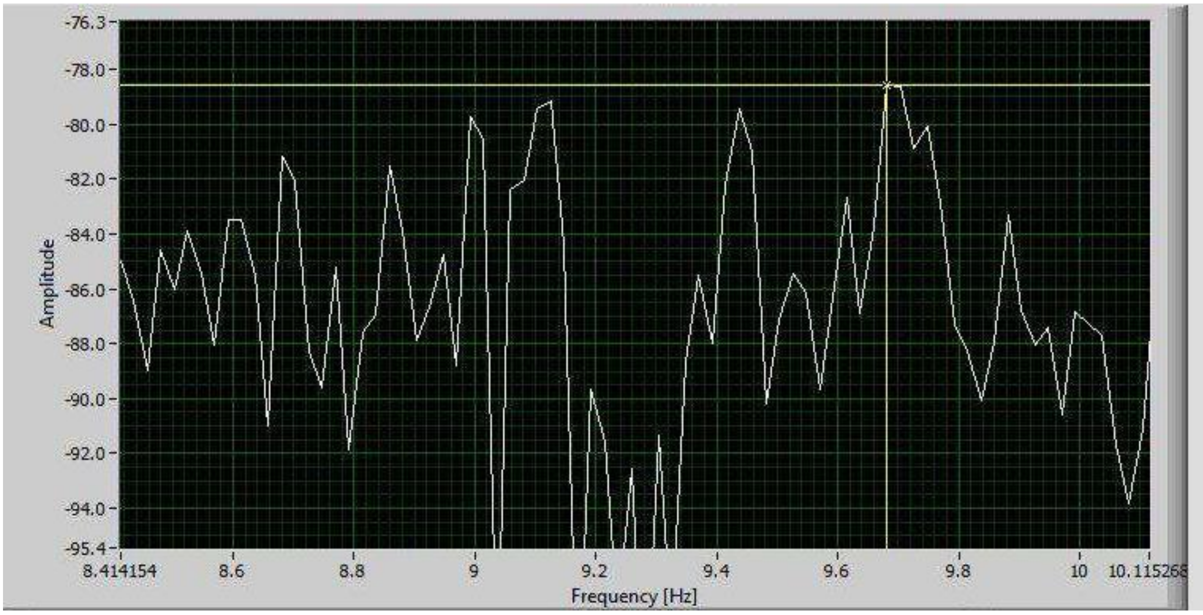


Figure 5. 60 Amplitude vs. frequency under dynamic load

Pre-strengthening test results obtained on the various spans of Bridge 54 for natural frequencies have been listed in Table 5.6.

Table 5. 6 Pre-strengthening test results of deflection and natural frequency

Girder Type	Types of Loading	Deflection (mm)	Natural Frequency (Hz)
LSG	Dynamic Load at 100 KMPH	3.65	7.3
LSG	Dynamic Load at 75 KMPH	3.59	7.6587
LSG	Dynamic Load at 20 KMPH	3.52	8.28
LSG	Static	3.45	NA
RSG	Dynamic Load at 100 KMPH	3.41	8.42
RSG	Dynamic Load at 75 KMPH	3.36	9.34
RSG	Dynamic Load at 20 KMPH	3.36	9.6819
RSG	Static	3.36	NA

5.12 Post-strengthening test results

The post strengthens data were collected for one and two layer of fibre for both deflection and natural frequency. The maximum Deflection is represented here. In Figure 5.61 the time vs deflection graph of deflection 3.07 mm (figure 5.61) under dynamic loading and deflection 3.15mm with static loading is presented in Figure 5.62.

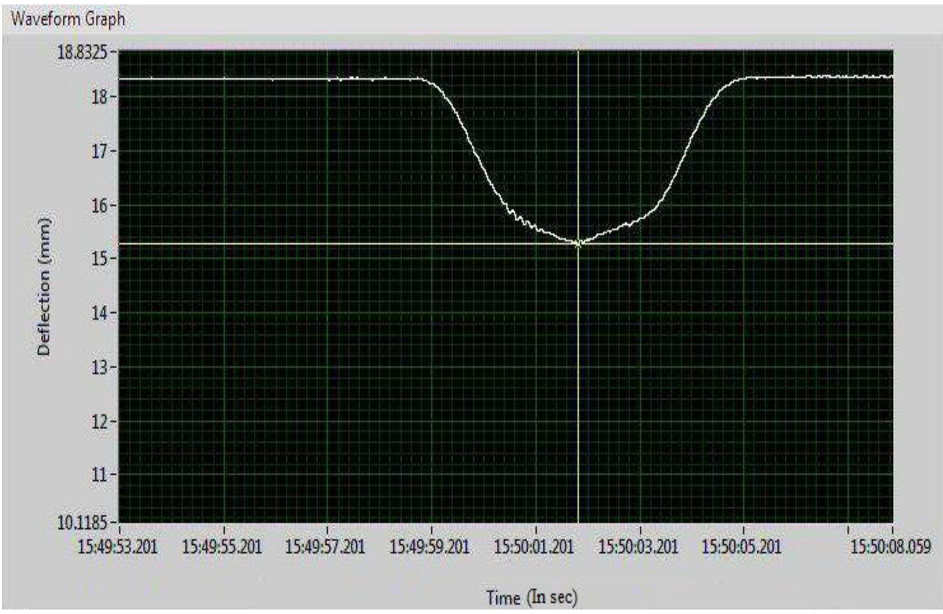


Figure 5. 61 Displacement vs time under dynamic loading

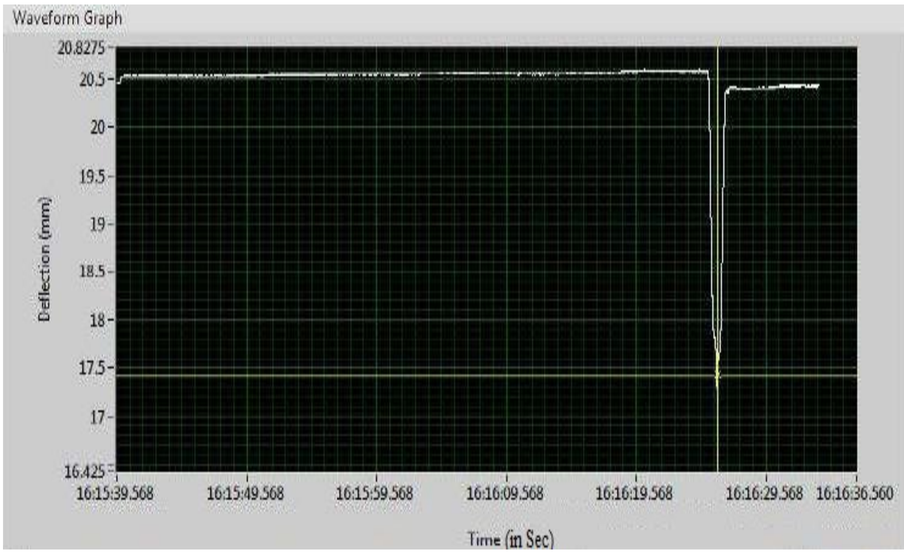


Figure 5. 62 Displacement vs time under static loading

5.12.1 Post-strengthening test results for natural frequency of bridge no 54

The maximum natural frequency after strengthening of bridge no 54 is shown here in Figure 5.63. The maximum natural frequency recorded is 8.78 Hz

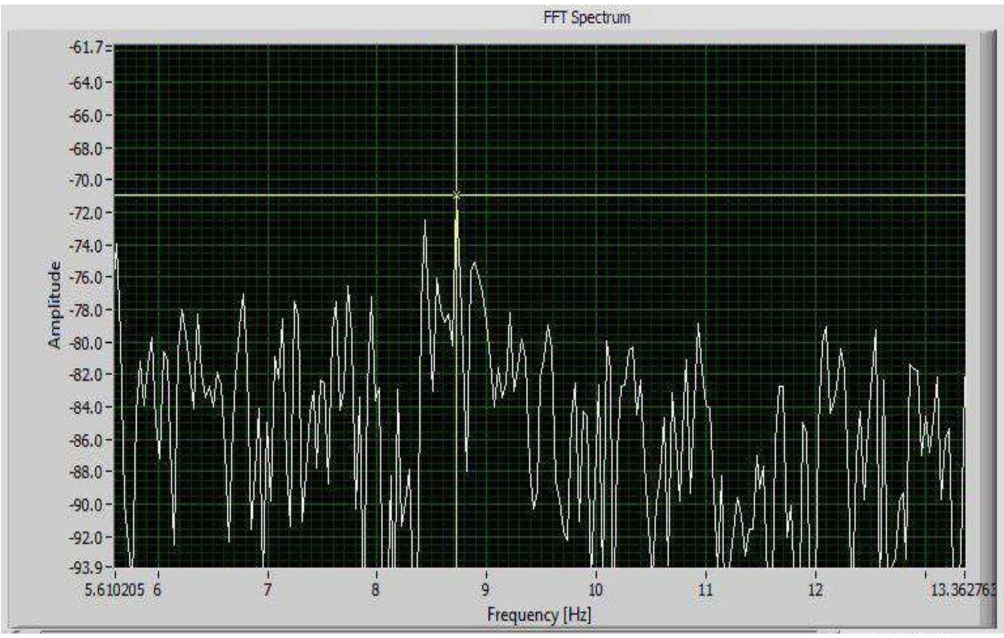


Figure 5. 63 Displacement vs time under dynamic loading

The Post strengthen deflection and Natural frequency obtained Using B & K Accelerometer have been listed here in Table 5.7.

Table 5. 7 Post strengthening test results

Girder Position	No of fibre layer	Type of Loading	Deflection (mm)	Natural Frequency (Hz)
LSG	One Layer fibre	Dynamic @ 100 KMPH	3.15	7.79
LSG	One Layer fibre	Dynamic @75 KMPH	3.099	8.04
LSG	One Layer fibre	Dynamic @ 20 KMPH	3.08	8.422
LSG	One Layer fibre	Static	3.07	NA
RSG	One Layer fibre	Dynamic @ 100 KMPH	3.065	8.65

RSG	One Layer fibre	Dynamic @75 KMPH	3.06	9.56
RSG	One Layer fibre	Dynamic @ 20 KMPH	2.97	9.7
RSG	One Layer fibre	Static	2.925	NA
LSG	Two Layer fibre	Dynamic @ 100 KMPH	2.523	8.78
LSG	Two Layer fibre	Dynamic @75 KMPH	2.42	8.99
LSG	Two Layer fibre	Dynamic @ 20 KMPH	2.35	8.71796
LSG	Two Layer fibre	Static	2.2	NA
RSG	Two Layer fibre	Dynamic @ 100 KMPH	2.1	9.3585
RSG	Two Layer fibre	Dynamic @75 KMPH	2.3	9.6
RSG	Two Layer fibre	Dynamic @ 20 KMPH	2.25	9.881
RSG	Two Layer fibre	Static	2.2	NA

5.12.2 Result and discussion

In table 5.7 the deflection and natural frequency are listed for different speed of dynamic loading and static loading for the different fibre layer wrapping. From table 5.7 it is concluded that the natural frequency with every layer of wrapping of girder increases as compared to unstrengthen girder. The left side girder (LSG) of bridge no 54 has more cracks in compared to the right side of the girder. When the static loading was applied using WAGON 7 after the single layer fibre lamination of the left side girder, the deflection was reduced by 12.37 %. In double layer wrapping, this decrement in deflection was recorded as 56.81 percentage. Similarly, for the static load test on the right side of the girder (RSG) the deflection reduction in one and two was recorded as 14.87% and 52.72 %, respectively. The dynamic load test of the girder was recorded on three speed 20 KMPH, 75 KMPH and 100 KMPH for single and double combination of fibre layer. The reduction in the deflection was greatly reduced in the 100 KMPH speed of WAGON 7. So it can be concluded that the two layer fibre wrapping in short girders will be sufficient. The reduction in deflection in the dynamic test @100 KMPH in LSG is 15.87 % and 44.66 % in a single and double layer of fiber wrapping.

In contrast, the deflection reduction in the dynamic test @100 KMPH in the RSG is 11.25% and 62.38% when single and double fiber layers were applied. This trend was not continued with this intensity in the dynamic loading of 20 KMPH. In this case the reduction in deflection in the left side girder is recorded as 14.28%, and 49.78%, respectively for ascending order of fibre wrapping. In the right side girder, the dynamic load test reduces deflection by 13.13%, and 49.33 % for one and two layers of fibre wrapping, as shown in Figure 5.64.

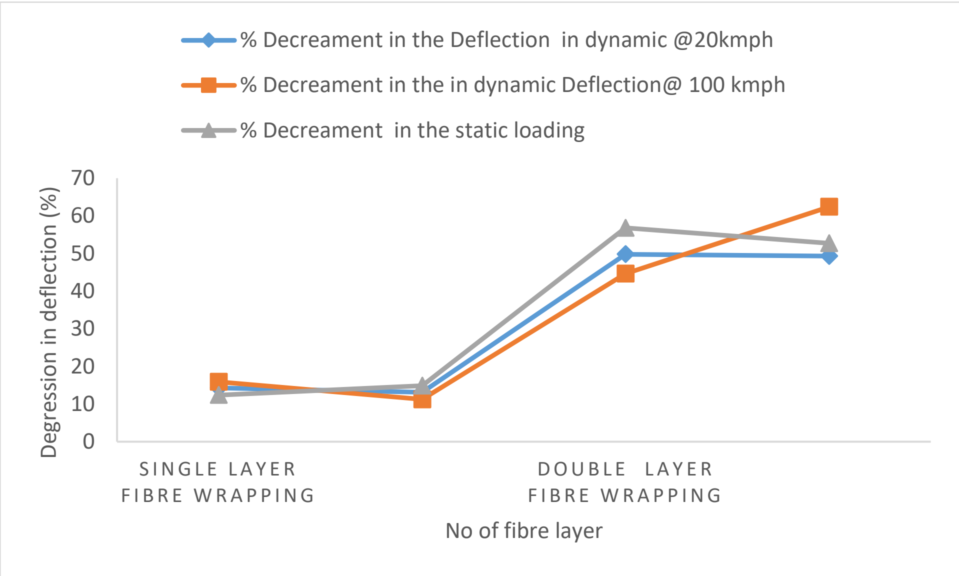


Figure 5. 64 Degression in deflection at different fibre layer

The Figure 5.65 represents the increment in the natural frequency after the fibre applied on the girder of bridge no 54. The right side girder gives the better natural frequency than left side girder as left girder was reported more deteriorated. When the WAGON moves at very low speed of 20 KMPH the frequency increment in the bridge girder was recorded as 1.71%, and 5.28% in left girder than of its unstrengthen frequency in the case of single and double layer wrapped at left side girder, respectively. In the same speed of wagon, the RSG shows negligible increment. The increment in frequency in RSG is recorded as 0.18%, and 2.05 % in ascending order of fibre wrapping around the girder. The increment in the natural frequency at the speed of 100 KMPH in the LSG is 6.71 and 20.27 when the girder was laminated by one and two-layer of fibre wrapping. Similarly, the right side girder of the bridge shows the increment as 2.73 and 11.14, percent of unstrengthened beam at the wagon speed of 100 KMPH.

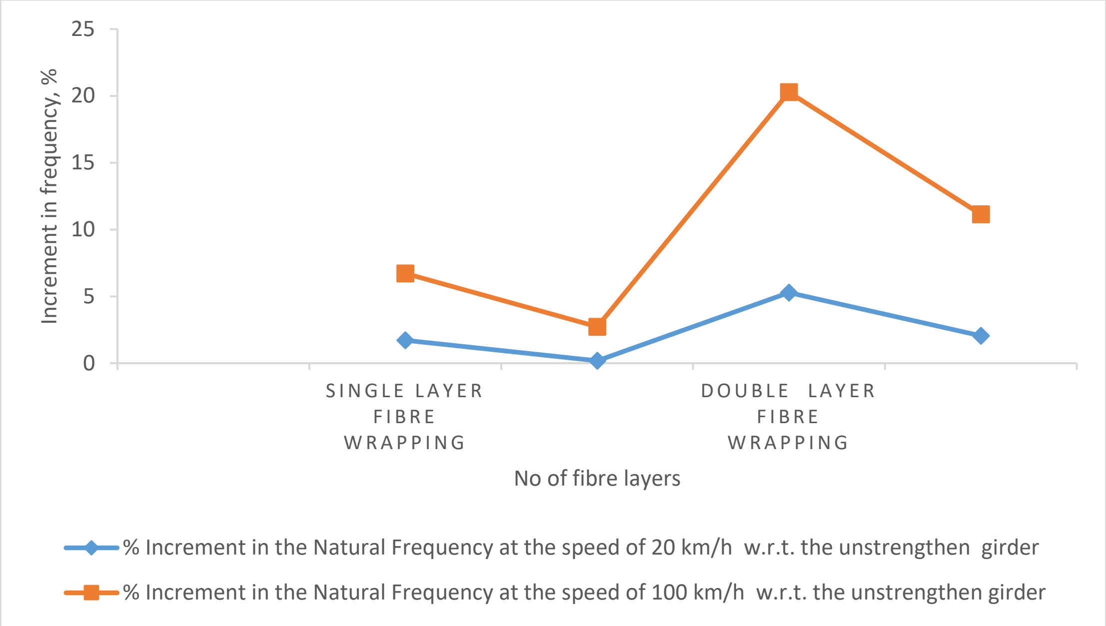


Figure 5. 65 Increment in frequency at different fibre layer

5.13 Summary

The overall vulnerability assessment of the bridge through analytical and practical means using several instruments on the site has been done, and repairing of the bridge performed accordingly. After the strengthening, the allowed speed of trains was changed up to 100 km/hr from 20 km/hr, saving an average 5 minutes for every traveler during the passing of this bridge**.** By means of this Strengthening of girder the durability and life span of bridge increases with adequate safety and workability.

The post strengthening test result of the static and dynamic behavior of the bridge has been studied extensively, which reveals that the suitability and better serviceability of carbon and glass fiber to the reinforced concrete for the long durability. Based on the above test on, the following conclusion can be drawn:

1. Two different bridges of western railway named bridge no 114 and bridge no 54 in between Ratlam and Godhra have been analyzed numerically, and in the field, testing using RDSO specified wagon load of rail locomotive WAGON 7.
2. The girder length of bridge no 114 is 19.67 and bridge no 54 is 13.67 meter and one hypothetic length 25.67 is been simulated using WAGON 7 IN ANSYS for static and modal loading.
3. The maximum deflection was found in a single layer composite fibre 25.67 meter long rail bridge which is reduced to half i.e. reach at 5.10 mm from 10.57mm. While without GFRP in shear this reduction was not observed.
4. The maximum tensile stress in the case of single-layer composite fibre was 6.25 mm which was reduced to 3.02 mm when the composite layer of fibre was tripled. Which indicates that with the help of fibers tension got reduced to the maximum extent.
5. The natural frequency was increased by 15 percent in mode shape 1 for the longest length of girder and 10 percent of bridge no 114 and 4 percent for bridge no 114 in ANSYS simulation, which is almost the same as our testing results.
6. Maximum von misses strain is reduced by 15 percent in bridge no 54 while approx 100 percent in the 25.67 m long girder. i.e. the effect of yielding after lamination was maximum in the longest girder.
7. After strengthening, the reductions in static deflection recorded on the left side of the girder of bridge no 114 as 22.78 % as compared to the when it was recorded before strengthening of girder and in the right side of the girder of bridge no 114 was 22.61 % as compared to the when it was recorded before strengthening of girder.
8. After strengthening, the reductions in dynamic deflection recorded in the left side of the girder of bridge no 114 as 39.50 % as compared to the when it was recorded before

strengthening of girder and in the right side of the girder of bridge no 114 was 23.16 % as compared to the when it was recorded before strengthening of the girder.

9. After Wrapping with the suggested method, reductions in static deflection recorded on the left side of the girder of bridge no 54 as 36.23 % as compared to the when it was recorded before strengthening of girder and on the right side of the girder of bridge no 114 was 41.66 % as compared to the when it was recorded before strengthening of girder.
10. After strengthening, the reductions in dynamic deflection recorded in the left side of the girder of bridge no 54 as 35.61 % as compared to the when it was recorded before strengthening of girder and in the right side of the girder of bridge no 114 was 34.01 % as compared to the when it was recorded before strengthening of girder
11. After strengthening, the average percentage of the natural frequency of the cracked span increased by 14.28 % in comparison to when it was recorded before strengthening. The natural frequency strengthens girder of bridge no 54 is more than the cracked girder's natural frequency, indicating that an after strengthening girder has enhanced stiffness compared to the cracked girder.
12. Before strengthening, the speed restriction was 20 km/h, and Now after strengthening, the maximum allowable speed of the train is 100 km/h on bridge no 54. Due to increment in the above two, the Speed restriction removed, resulted in a saving of 5 min during the passing of this bridge.