CHAPTER 4

ANALYSIS AND STRENGTHENING OF VEHICLE BRIDGE GIRDER AT PUSA : A CASE STUDY

4.1 General

Among all the world bridges, the percentage of simple reinforced concrete (R.C.) girders is more common. Generally, the Simple Reinforced concrete bridges need modification and improvement in their performance during their service life because of changes in the environmental conditions, changes in their usage, aging, deterioration.

In this Chapter, the damage analysis and its strengthening scheme has been discussed for a RC bridge girder at Pusa Muzzafarpur, Bihar. The bridge reported severe damage. The visual inspection was carried out to observe the deterioration in the superstructure of the bridge. It was observed that the crack in the bottom and side of girder observed and the corrosion in the reinforcement bar is been observed and spalling of cover is detected. The Pusa bridge girder of span 16.5 meter and two additional girder of 22.5 meter and 28.5 meter was analysed using ANSYS to find the strength behavior of cracked girder. The girder was also analysed with the one, two and three layer of composite fibre polymer respectively for IRC loading. According to the strength behavior of the girder a strengthening plan is designed. After strengthening accordingly, the real time testing was performed to determine the strength in service condition. The bridge girder's plasticity has been calculated in terms of deflection recovered when the load was removed.

4.2 Background of Pusa Bridge

This bridge connects Pusa and Muzaffarpur in Bihar, India. two-Lane bridge at Pusa Muzaffarpur road is a simply supported R.C. bridge and has three concrete girders with a reinforced concrete deck slab. It is situated at Pusa mile stone 26 K.M. Dist- Muzaffarpur, Bihar. The bridge's substructure consists of simple R.C. piers, abutment, and the type of foundation is a pile foundation. (Figure 4.1 and Figure 4.2). The length of the girder is 16.5 meter and the bridge has the pile type foundation and 3 numbers of R.C. girders with R.C. deck Slab. The total length of the bridge is about 70 m, and the bridge belongs to seismic zone IV. With the time the intensity of traffic increased on the bridge and load increased on the girder. The environmental effect and age of the bridge also a key factor in the deterioration of the bridge. An inspection was performed on this Pusa bridge to estimate the profundity of the dilapidation.

Figure 4. 1 View of Pusa-Muzaffarpur bridge

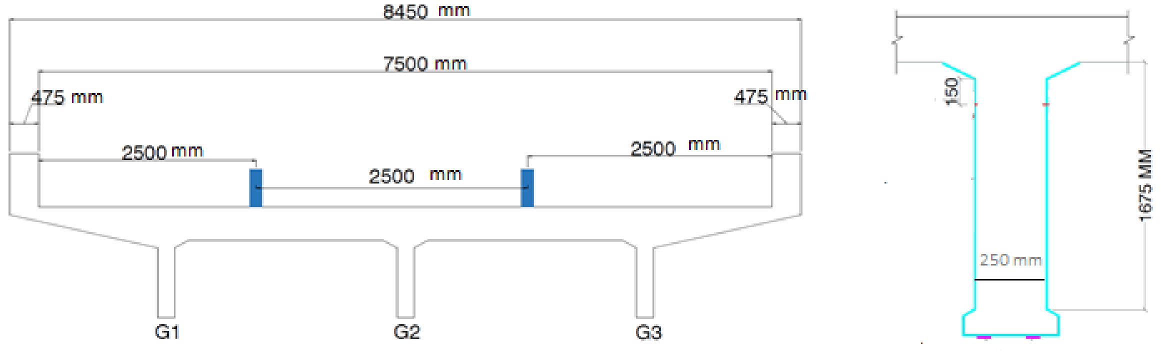

Figure 4. 2 Cross section of Pusa bridge and its girder

4.3 Damage analysis of Pusa bridge

There was excessive deflection noticed in span no.1 and 4 which resulted to reduced flexural strength of girders as these were found severely distressed. It is clear from the visuals on site that the cover is about to get separated in a larger length. This indicates that the cover's delamination has already been started or has tendency to start in the future. It must happen because there are voids between reinforcing bars, which can be noticed where the cover has already been separated,

1. The superstructure was found in a very distressed condition. There were various wide cracks found at multiple locations in span No. 1 and 4. These cracks were very severe, wide and active and very detrimental for the bridge's structural strength and safety. (Figure 4.3)
2. The concrete cover was found delaminated at multiple locations as shown in Figure 4.4. The reinforcements were poorly exposed due to delamination of concrete cover. It was found that there was no concrete present between reinforcing bars. The section was almost hollow at several locations at the bottom due to the presence of voids between reinforcing bars. This must-have resulted as adequate compaction of concrete between crowded reinforcing bars might not have ensured at the time of construction.

3. The reinforcing bars were found exposed at several locations as shown in Figure 4.5. The reinforcement was also found corroded.
4. The overall condition of concrete was terrible. The flexural cracks were extensive and present in the girder's full depth, indicating that the girder has wholly lost its flexural strength. 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.
5. Reinforced Concrete longitudinal girders' overall conditions are appalling; they are in severely distressed condition having numerous wide cracks originating from the bottom and going up to the top of girders.
6. The neoprene bearing has been used in the bearing which seems depressed very brutally due to unsymmetrical load distribution by girder. (Figure 4.6)

Figure 4. 3 Wide flexural cracks in the full depth of RC girder

Figure 4. 4 deterioration in bridge girder

Figure 4. 5 Exposed reinforcement of girder with shear and flexure cracks

Figure 4. 6 Stifling of bearing

4.4 Modeling of bridge girder and deck slab

For meshing, SOLID 187 element has been used for the girder, supports and diaphragm of girder and SOLID 186 element has been used for the all type of FRP on 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 and the final result for deflection under static and modal loading is represented in figure 4.9 and figure 4.10, respectively.

4.4.1 Loading details on the 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 two lane road and has been loaded in both the lanes symmetrically with six axles of 7.8t, 11.5t, 11.5t, 11.55t, 11.55t 7.9 t on one lane. The contact area of tires 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 (Figure 4.7 and Figure 4.8). The self-weight of the girder has also been considered by applying standard earth gravity in the ANSYS environment. The pavement weight 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.

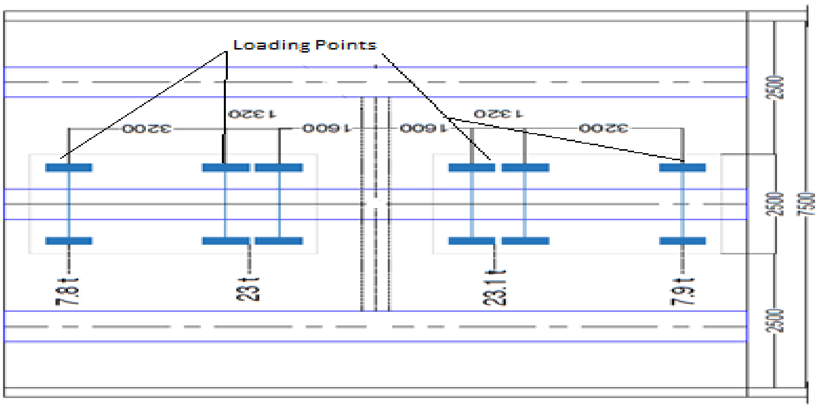

Figure 4. 7 Loading scheme of the deck slab

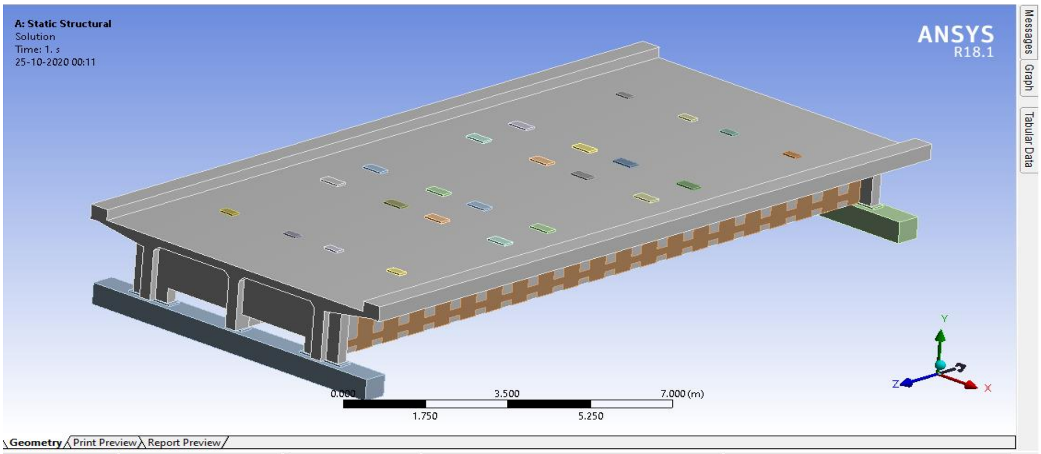

Figure 4. 8 FEM model of loading of bridge’s deck slab

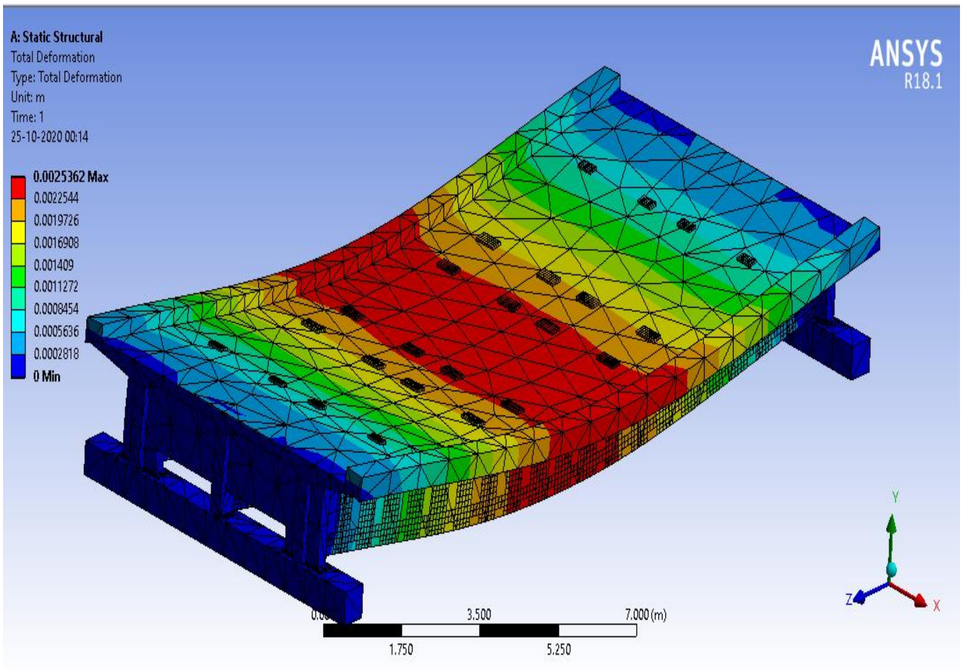

Figure 4. 9 Typical deformed girder under static load

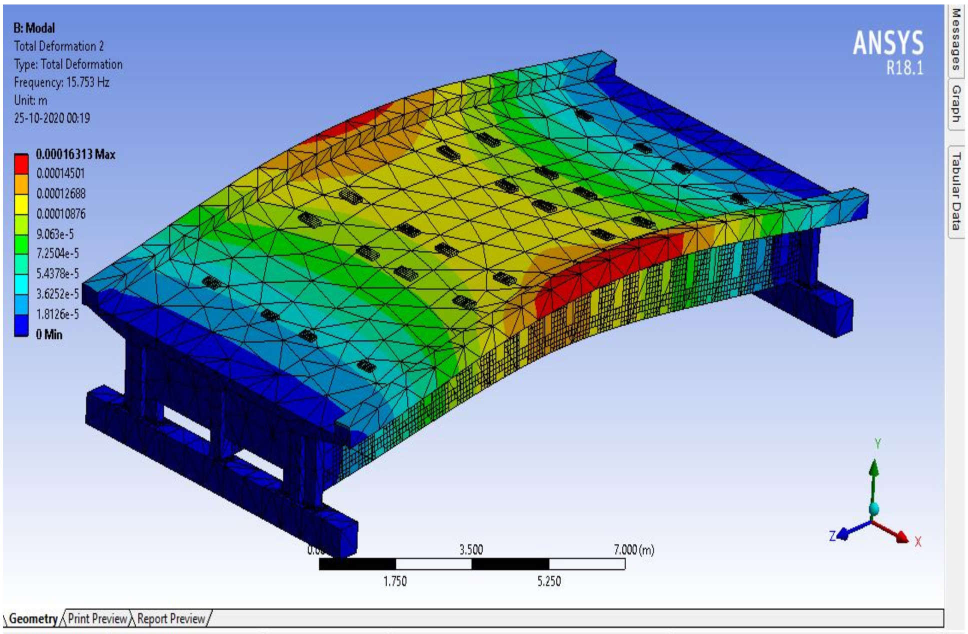

Figure 4. 10 Typical deformed girder under modal loading

4.4.2 Maximum deformation in the girder of Pusa bridge

Figure 4.11 described the contribution of GFRP and CFRP when they swathe more than a layer on a girder of varying length. The bridge girder of size 28.5 meter showed at least double recovery in the term of deflection when the layer of the composite was tripled while the relatively smaller girders have shown minor augmentation and figure 4.12 shows that without GFRP, the reduction in deformation in all the girders irrespective of size, the reduction in deformation was not improved significantly.

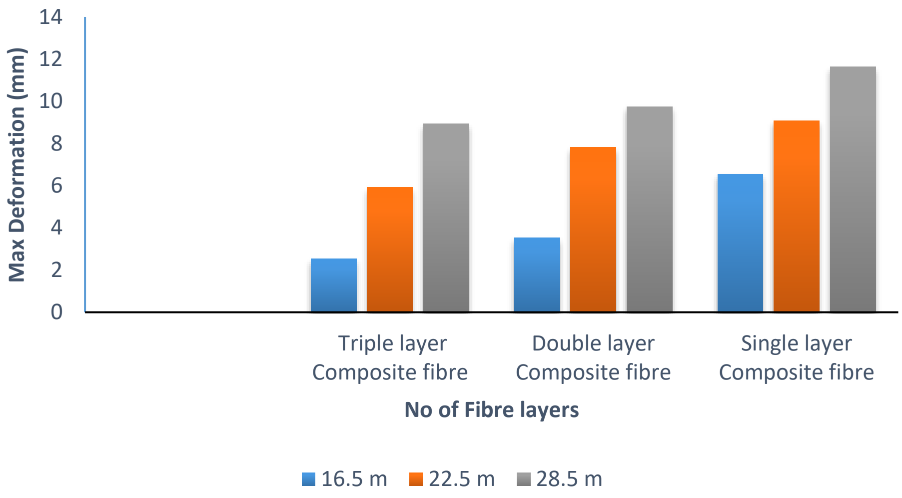

Figure 4. 11 Max deformation vs fibre layer for varying length of girder

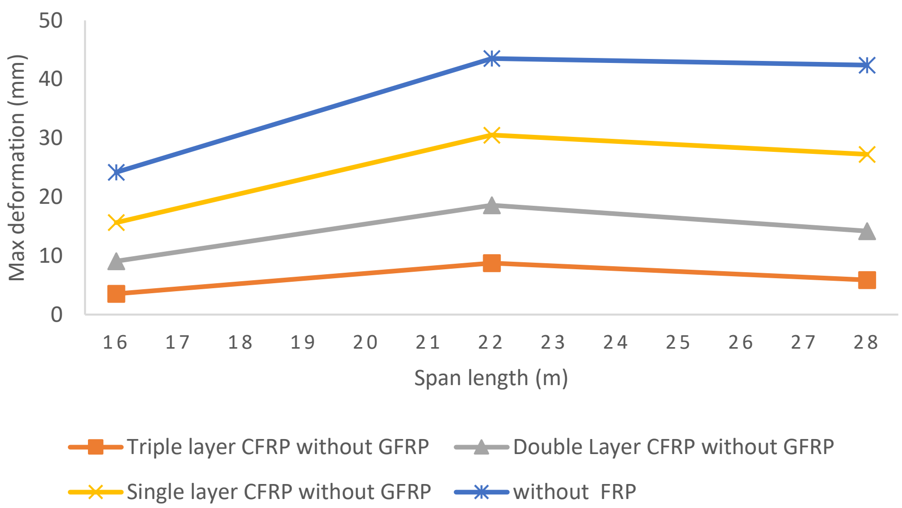

Figure 4. 12 Max deformation vs span length different fibre layer

The deformation due to live load has been displayed after finite element analysis of girder for different IRC loads. Few apparent changes have observed when the layers of composite fibre were increased. In figure 4.11 it is clearly visible that for the longest span of bridge i.e. 28.5 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 16.5 meter and the single layer of composite fibre were glued then the deformation in the girder was noticed 6.55 mm while this layer increased by one more layer then the deformation was found 3.54 mm and in the case of triple layer it decreased and reached to 2.53 mm. In the case 2 when the length of girder was 22.5 meter, the deformation in the single layer fibre 9.08 mm, in the double layered fibre it was 7.8 mm and in the triple layered fibre it came 8.75mm this time .

In the case 3 when the length of the girder was 28.5 meter, then in the single layer composite fibre the deformation was 11.63 mm, as soon as the layer of fibres were doubled the deformation was decreased and reached upto 9.74 mm and in the next case when the layers of fibres were tripled the deformation was reduced upto 8.92 mm.

The girder was again modeled without glass fibres (Figure 4.12) with the increasing number of layer of carbon fibres for all the three girder of 16.5mm, 22.5 mm and 28.5mm. In the case of 16.5 meter the deformation of the girder when there was no fibre, was found 8.55 mm. with the single layer of carbon fibre it was 6.55 mm, as doubled the layers for this girder the deformation came to 5.54 mm and in the three time CFRP wrapped girder the deformation was found 3.53 mm. for the second girder whose length was 22.5 meter the deformation was 12.99 in no fibre strengthening case. The deformation was reduced and reached to 11.93 mm when single layer CFRP was applied similarly, it further sink to 9.82 mm and 8.75 mm for two and three layer lamination of the girder. The third girder with span length 28.5 meter was examined wrapped similarly by one, two and three layer of carbon fibre and the deformation was noticed 13.03 mm, 8.31 mm and 5.87 mm respectively.

4.4.3 Von-Mises Stress in the girder of Pusa bridge

Figure 4.13 the von-Mises stress of any structure describe its ability of yielding before discomfiture. The figure 4.13 consist the behaviour of composite laminated girders. The stress in single layered laminated girder the von Mises stress was found 24.8 MPa for the longest span which was 28.5m. Respectively for double and triple layer it was 24.77 MPa and 12.06 MPa. For shorter span length i.e. 22.5m and 16.5m the von Mises stress was reported 19.82 MPa and 13.66 MPa when girder was double coated by composite fibre and 20.10 MPa and 12.88 MPa for triple lode composite layer.

In the Case where glass fibre was not attached with girder and only strengthened by one, two and three layers of carbon fibre are being discussed in figure 4.14. In the case of triple layered wrapping of fibre the von mises stress on the girder length 28.5 m, 22.5 m and 16.5 m was 21.12 MPa, 20.10 MPa and 12.88 MPa, respectively. If the strengthening was done using double-layered carbon fibre then the stress was observed 24.14 MPa, 19.85 MPa and 13.63 MPa for descending length of all three girders. When the layers of carbon downed to a single layer, the stress in the longest girder was 24.84 MPa while in the girders of 22.5 meter and 16.5 meter, the stress was 19.71 MPa and 17.67 respectively.

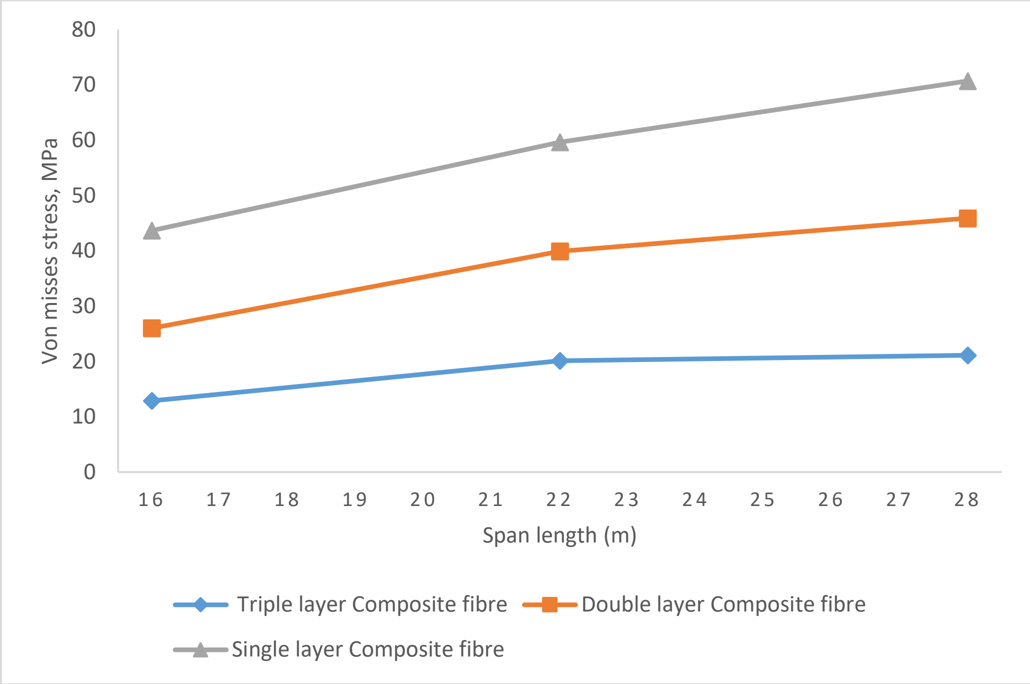

Figure 4. 13 Max Von Mises stress vs span length for different fibre layer combination

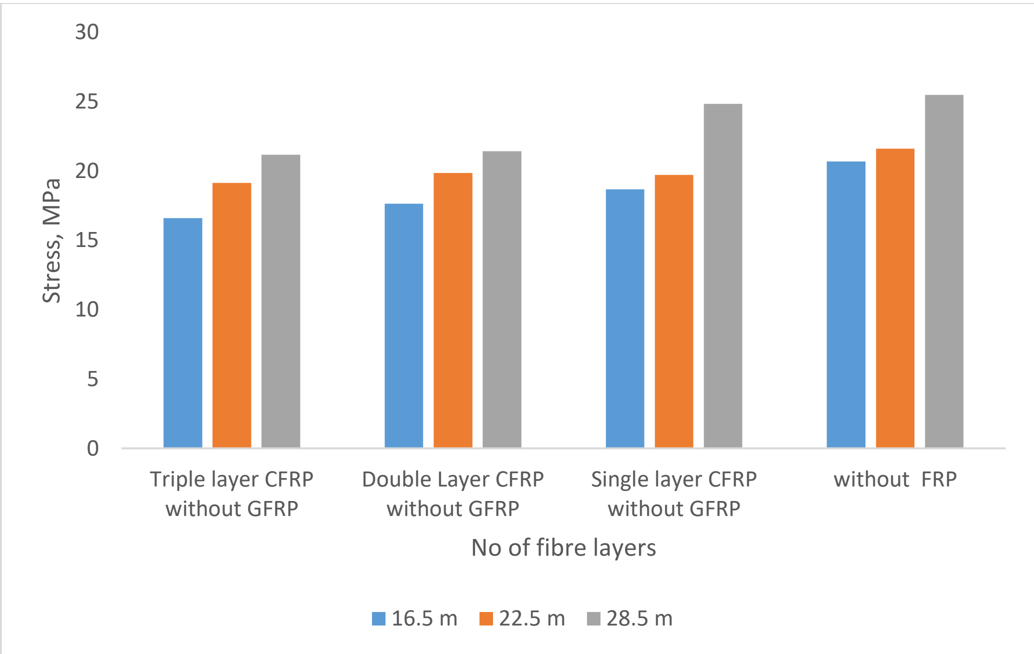

Figure 4. 14 Max Von Mises stress vs fibre layer with varying length of girder

4.4.4 Strain energy in the girder of Pusa bridge

Figure 4.15 explains the effect of lager variation of fibre on the different size of girder. The single layer composite fibre produces the 34654.8 Joule strain energy for 28. 5 meter girder. After doubling the composite layer strain energy comes to 33633.14 Joule and in the case of triple-layer fibre the strain energy was found 7846.14 Joule. In the 22.5m and 16.5 meter long spans the strain energy reported 9342.54 joule and 1730.1 joule when doubling the both carbon and glass fibre wrapping. Figure 4.16 explains about the case where only carbon fibre used for retrofitting the girder. In this analysis the strain energy in the unstrengthened beam was found 33388.24 Joule 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 28.5 meter girder was found 33170 joule and in other two girders it was 9423.54 joule and 1754.1 joule for 22.5 meter and 16.5 meter respectively. If we see the difference in the length of girder, then the difference in the strain energies is more than 3three times each other. The similar pattern was noticed in the double and tripled layer laminated girder 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 22.5 meter un-retrofitted girder the strain energy was found 9594.34 Joule and decreasing very minutely when the number of layers was increased to double and triple. A similar pattern was continued in the 16.5m long girder.

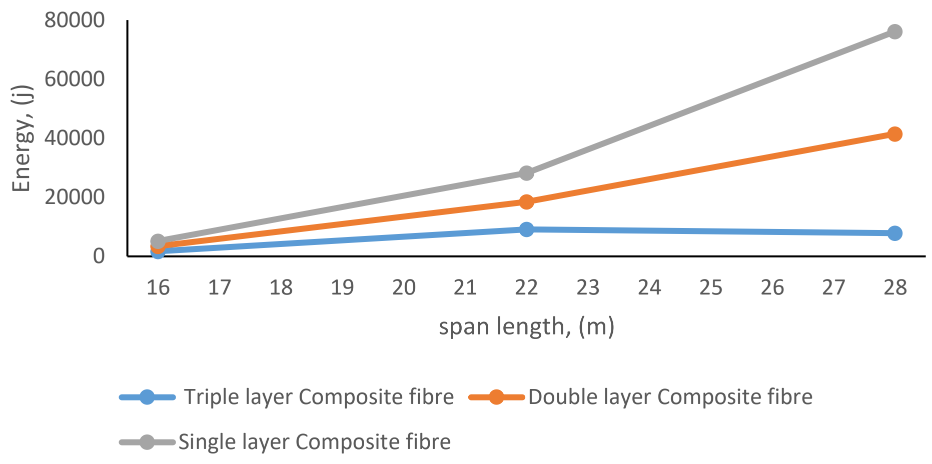

Figure 4. 15 Strain Energy vs span length for different fibre layer combination

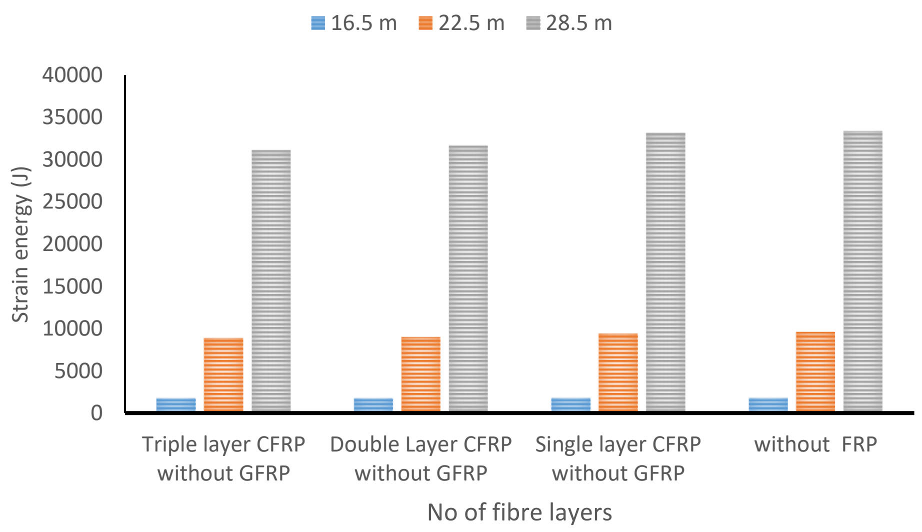

Figure 4. 16 length of girder vs strain Energy with varying fibre layer

4.4.5 Maximum compressive stress in girder

When all the five girders were retrofitted by both carbon and glass fibre the maximum compressive stress was found 9.17 MPa for 28.5 meter span in single layer fibre and reduced this by approximately 50.5 percent when the layers were tripled in the same beam. For the girder of 22.5 meter length it was 5.24 MPa for the longest span and reduced to 5.35 MPa when increased the layer of the girder to three. For the 16.5 meter span and single layer lamination, the stress was 2.24 MPa and reduced to 2.22 MPa when it was wrapped by the triple layer. The compressive stress in the double layer lamination is found as 8.73 for 28.5 meter span and 5.13 MPa while 5.13 MPa and 2.23 MPa for 22.5 and 16.5 meter span (Figure 4.17).

In the case of carbon laminated girder of length 28.5 meter, the compressive stress was found 7.70 MPa for single layer and reduced it to 7.61 MPa for triple layer lamination. When the girder became slightly smaller of length 22.5 m then the compressive stress for single layer was found 4.6 MPa and reduced to 4.5 MPa for three layer laminated girder. For the 13.67 meter long girder, the compressive stress was 2.24 MPa in single laminated cases and 2.20 MPa for triple layer lamination (Figure 4.18).

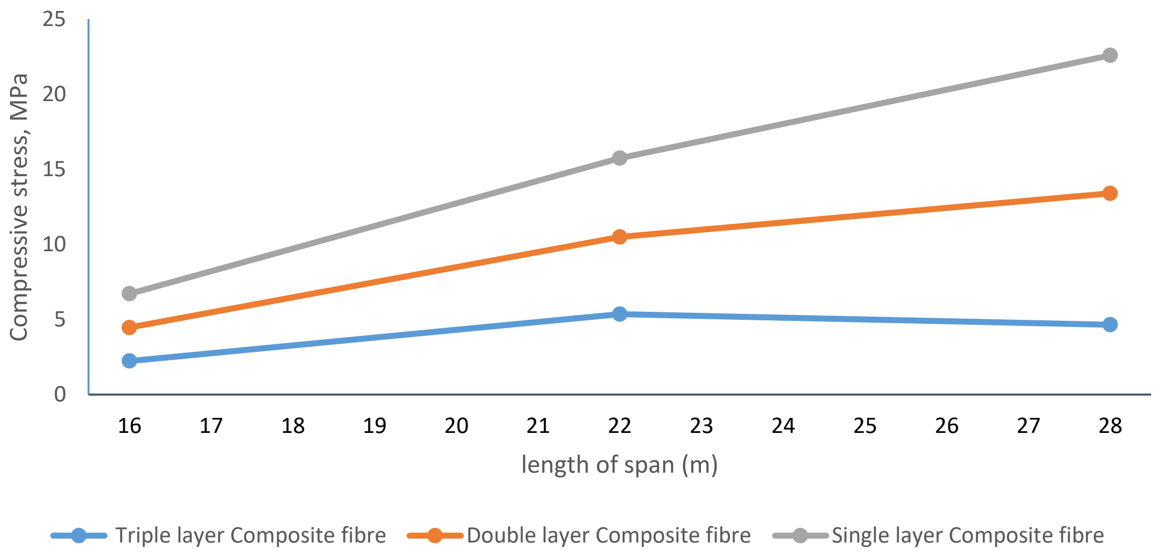

Figure 4. 17 Compressive stress vs span length for different composite layer combination

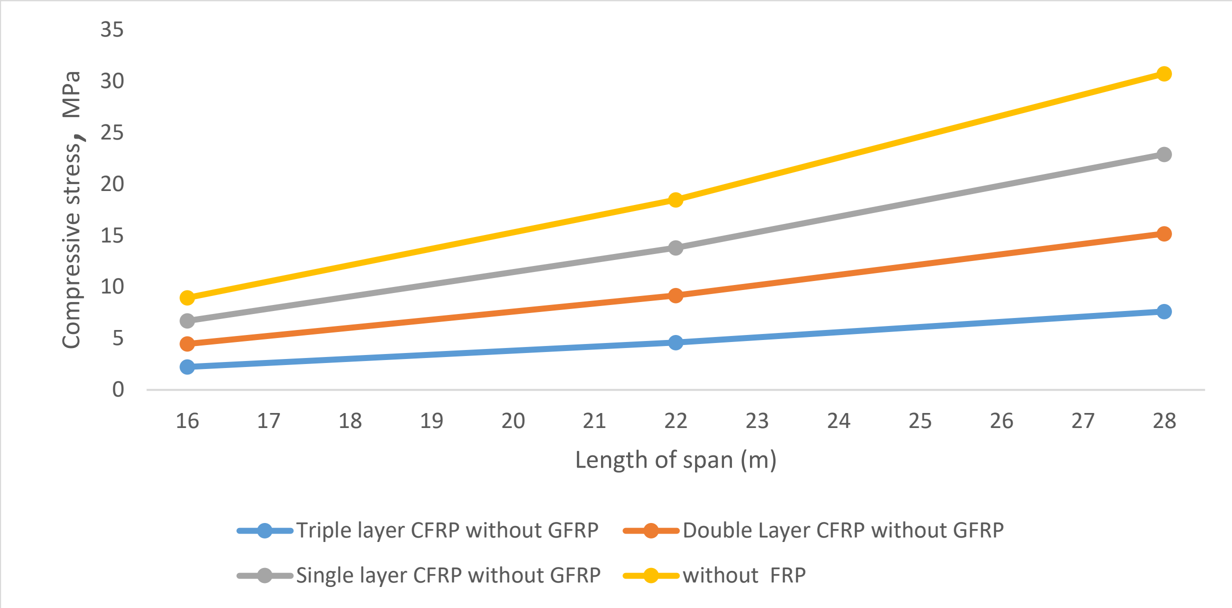

Figure 4. 18 Compresive stress vs span length for different CFRP combination

4.4.6 Frequency of girder in different Modes

The variation in frequency for different mode when the length of girder and no of fibre layer is varying are presented here;

i. **Frequency of girder in Mode 1**

To find out the natural frequency of girder 5 mode shape, have analyzed use and for each mode, the cases of composite fibres and without glass fibre have been discussed. In figure 4.20 for mode 1 the frequency of single-layer composite fibre of largest girder i.e. 28.5 meters was found 5.4 Hz, and of second girder, it is found 8.16 Hz and for smallest girder it was found 14.95 Hz.

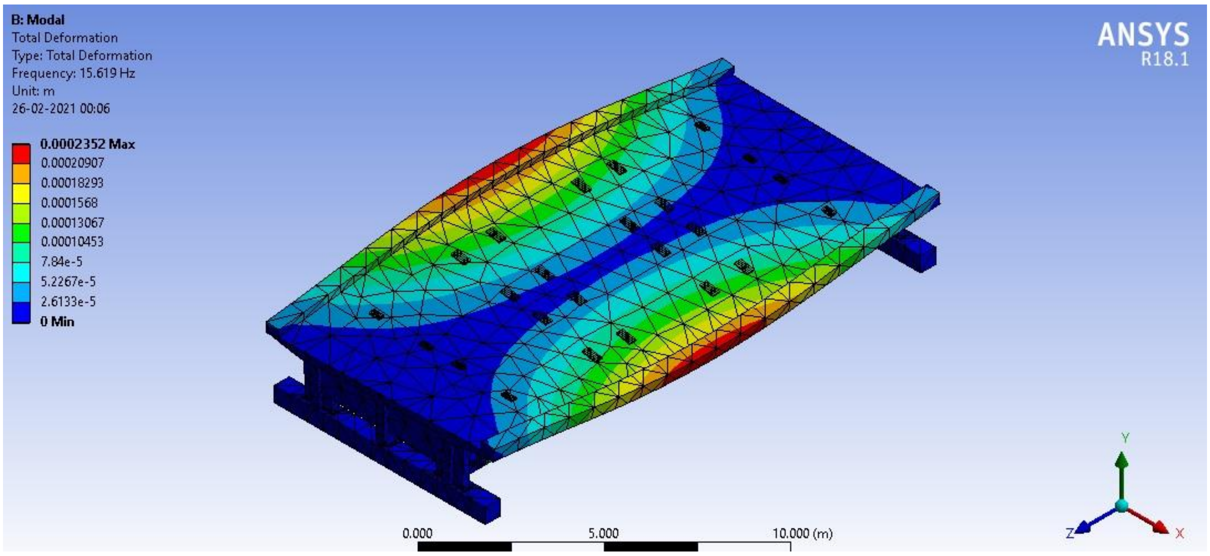

Figure 4. 19 Deformed model of Pusa bridge in mode 1

To find out the vibration (mode shape, natural frequency) the modal analysis of any structure is advantageous. It can represent any structure's motion under dynamic loading because of lateral force originated by electrostatic impellers. In figure 4.20 and figure 4.21 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 4. 21 Consists the frequency of girder of different length and wrapped with carbon fibre only. The frequency of un-laminated largest girder was found 14.95 Hz while for 22.5m and 16.5m girders it was 7.97 Hz and 5.28 Hz respectively. With the triple layer of carbon fibre in the longest girder of span 28.5m the frequency was found 15.62 Hz and for 22.5m and 16.5 meter girders, the frequency was reported as 8. 99 Hz and 6.46 Hz.

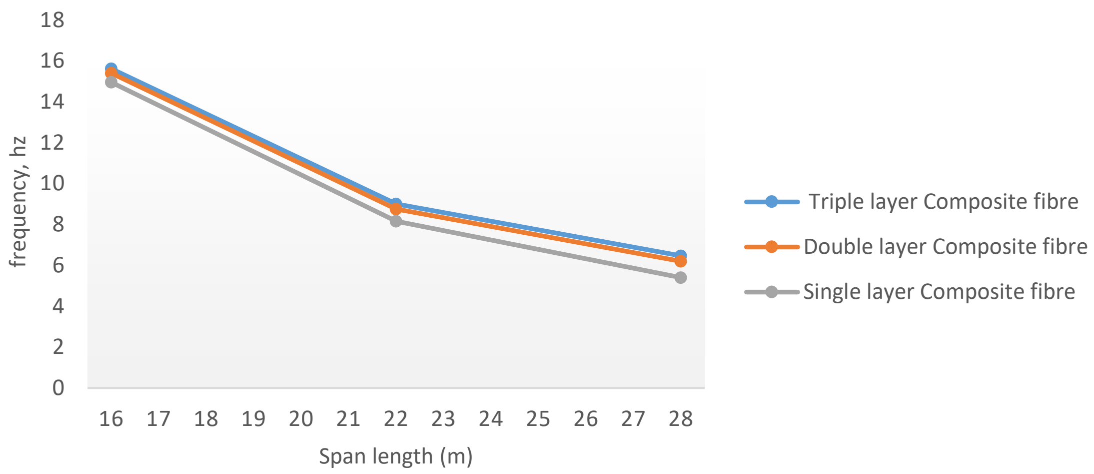

Figure 4. 20 Frequency vs span length for different composite layer combination

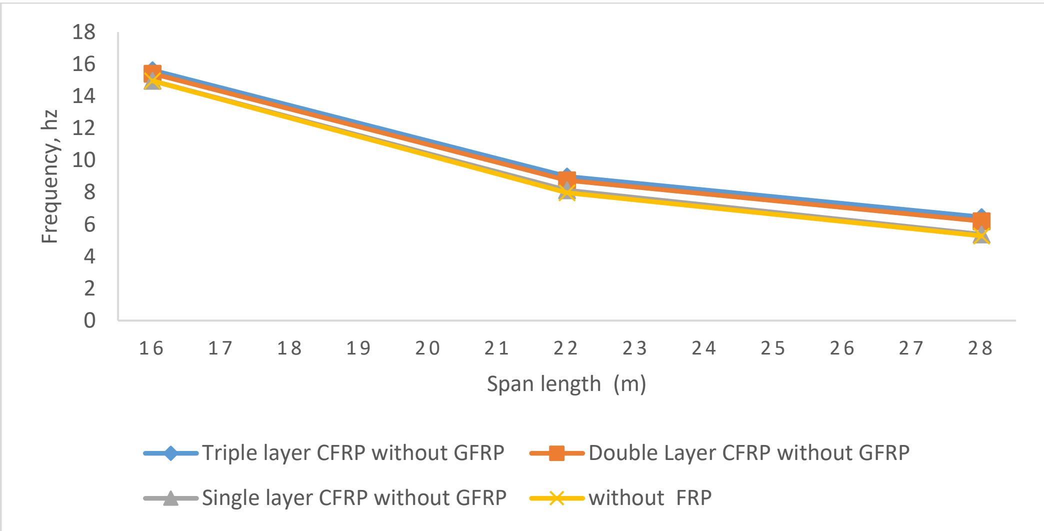

Figure 4. 21 Frequency vs span length for different CFRP layer combination

ii. **Frequency of girder in mode 2**

Figure 4. 23 describes the vibrations of girder in mode 2. for single-layer composite laminated girder of length 28.5m the frequency was found 4.98 Hz, In girder length 22.5m and 16.5 meters it was found as 8.09 Hz and 15.689 Hz. 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 fig 4.24. In this figure the frequency of triple layer carbon fibre laminated girder of length 28.5 meter was found 5.04 Hz. While other girders of length 22.5 meter and 16.5 meter was noted 8. 20 Hz and 15.75 Hz. the frequency in doubly laminated girder of 28.5 Meter, 22.5 meter and 16.5 meter was relieved as 5.01 Hz, 8. 16 Hz and 15.73 Hz. when the strengthening of girder reduces to the single layer carbon fibre then the frequency in mode 2 was 4.98 Hz in 28.5 meter long girder, 8.09 Hz in 22.5 meter long girder and 15.69 Hz in shortest sample girder. In the case where all girders are un-laminated the frequency was found as 4.96 Hz for 28.5m length, 8.05 Hz for 22.5 meter and 15.68 Hz for 16.5 meter girder (Figure 4.24)

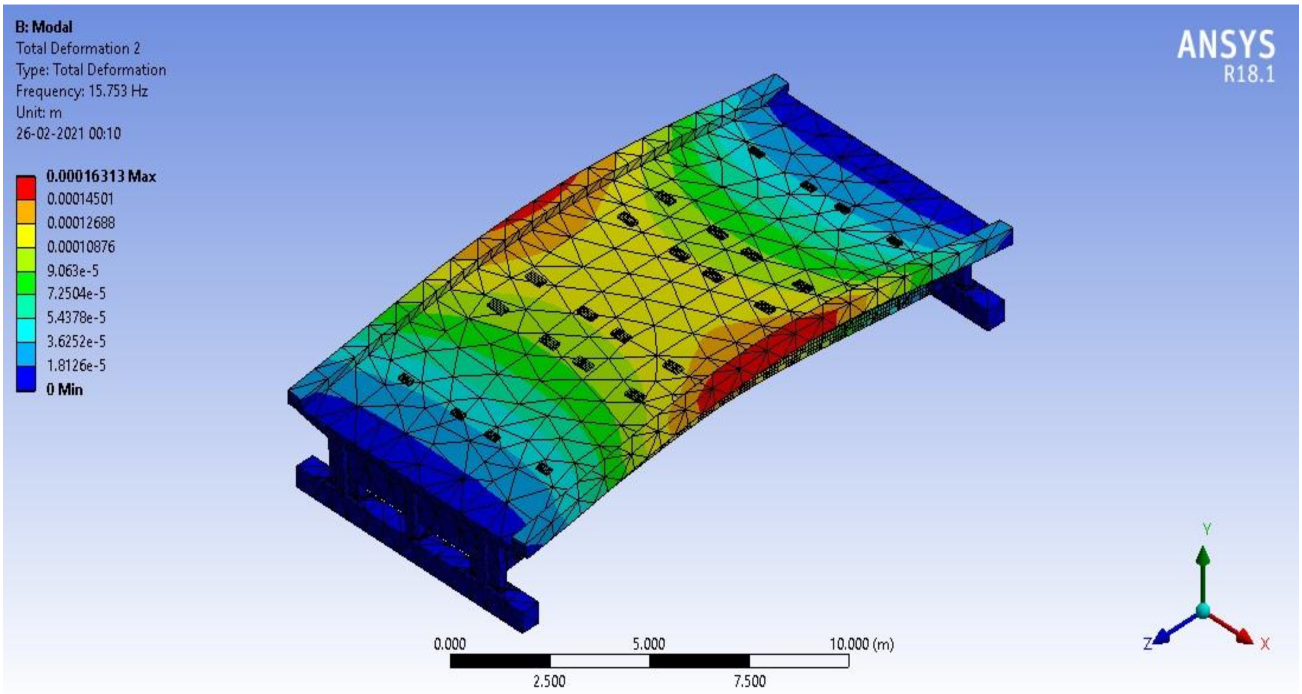

Figure 4. 22 Deformed model of deck slab in mode 2

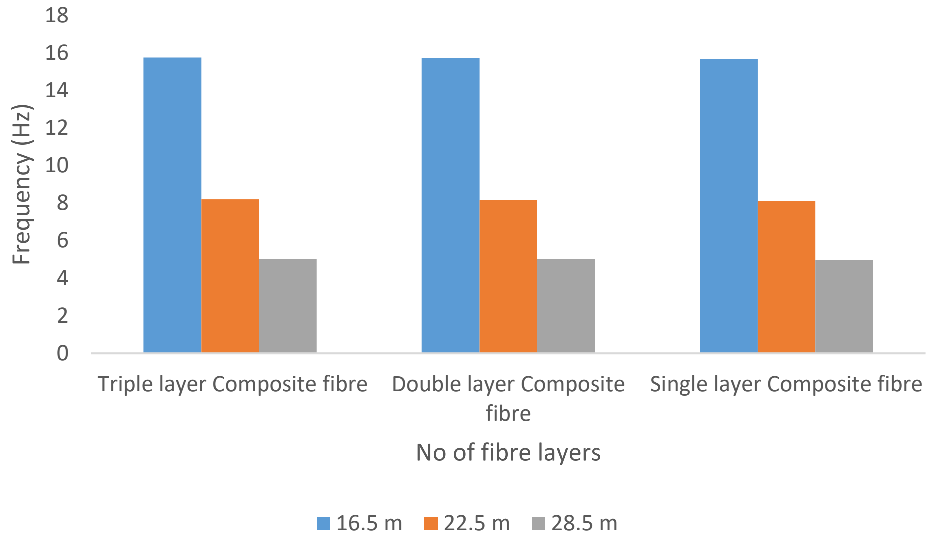

Figure 4. 23 frequency vs nos of fibre layer in mode 2 for different span length

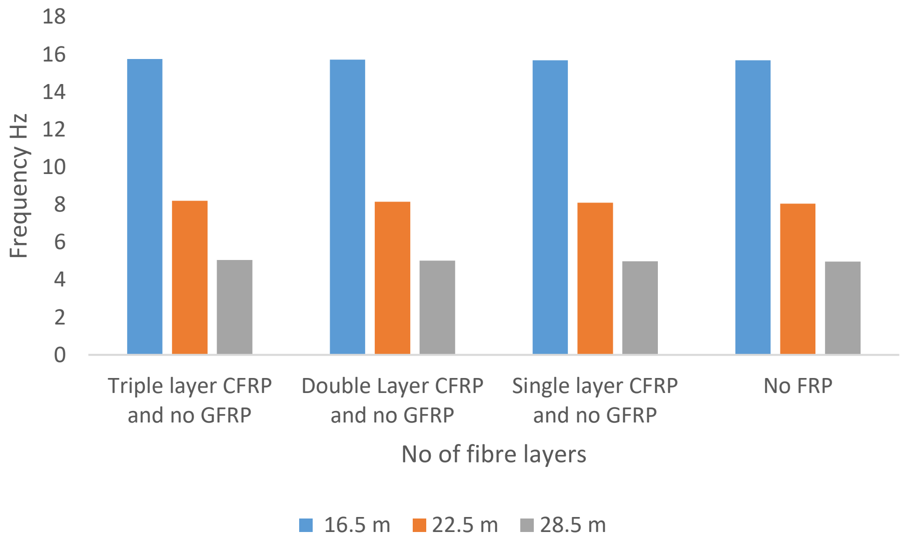

Figure 4. 24 Frequency (mode 2) vs no of fibre layer for different span length

iii. **Frequency of girder for mode 3**

Figure 4.26 and 4.27, describes 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 4.26 it can be seen that the Single layer Composite fibre when applied in longest span then the frequency obtained Comes to 14.10 Hz and when it was applied to 22.5 meter and 16.5 meter long girder the frequency was reported 18.82 Hz and 28.95 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 28.5 meter was 14.95 and 15.04 respectively and for span 22.5 meter and 16.5 meter it was confirmed to 19. 68 Hz, 20.03Hz and 29.04, 29.06 Hz, respectively. Analysis of modal frequency depicts about the dynamic properties of the tested structure. The primary objective of this analysis was to find out the mode shape and frequency of girders.

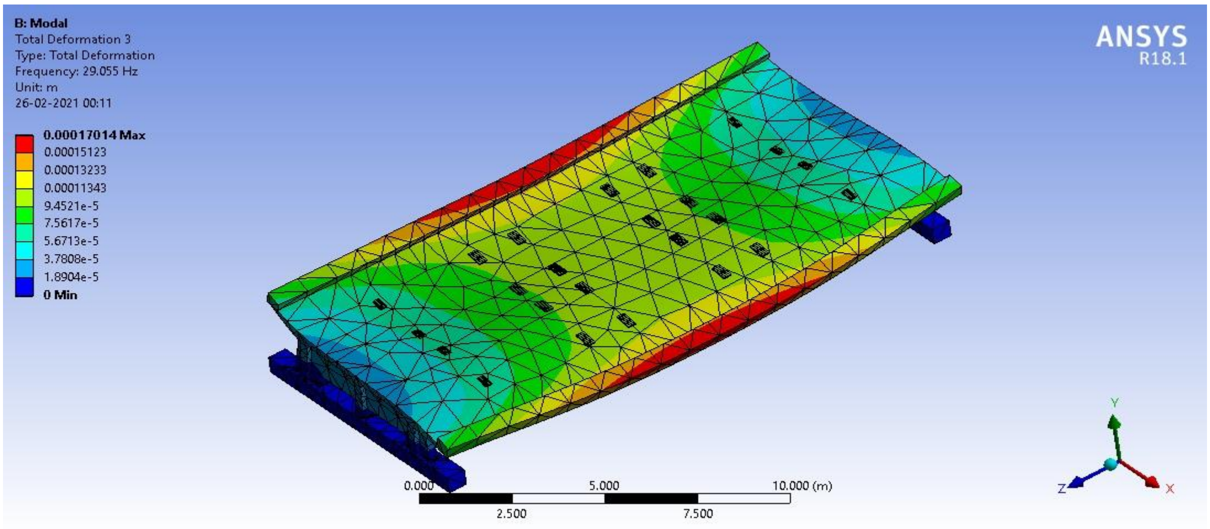

Figure 4. 25 Deformed model of deck in mode shape 3

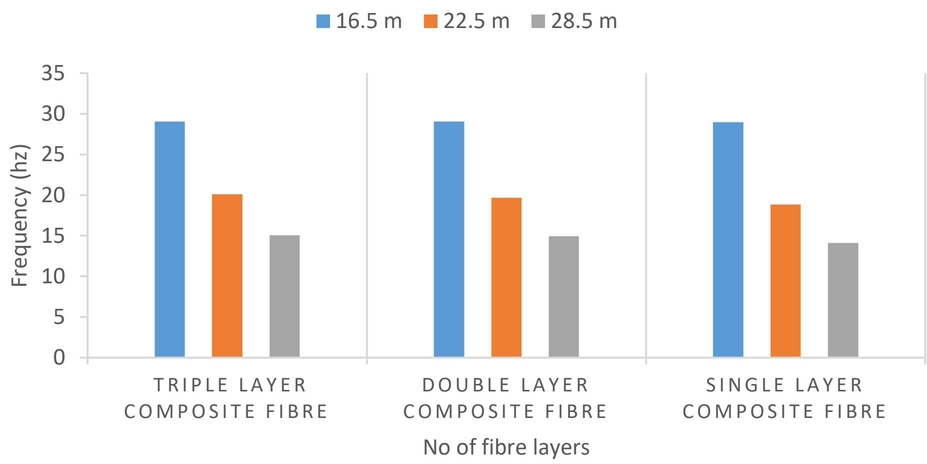

Figure 4. 26 frequency vs. nos. of fibre layer in mode 3 for different span length

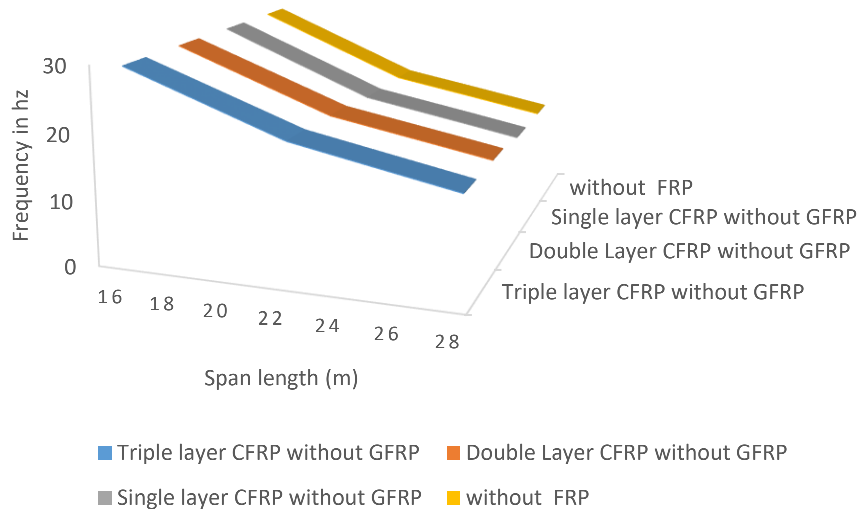

Figure 4. 27 Frequency (mode 3) vs. span length for different CFRP layer combination

iv. **Frequency of girder for mode 4**

Figure 4.29 and figure 4.30 Contain frequency in mode 4 with and without glass fibre while carbon fibre was always in flexure. Figure 4.29 the single layer Composite fibre wrapped girder showed more than 2.5 times frequency in the the shortest girder than the longest girder of case. This trend was continued in double and triple layered girder too. In figure 4.30 the frequency of single layered carbon strengthened girder of span length 28.5 meter was noted as 11.27 Hz while girder of length 22.5 meter and 16.5 meter was found a 17.08 Hz and 29.84 Hz respectively. When the Carbon fibre layered was increased in all the girder the frequency obtained in 28.5 meter, 22.5 meter and 16.5m girder was 12.22 Hz, 17.61 Hz, and 29.46 Hz respectively. Similarly the frequency in all the three carbon swaddled girders in descending order was found at 12.8 Hz, 17.73 Hz and 29.7 Hz.

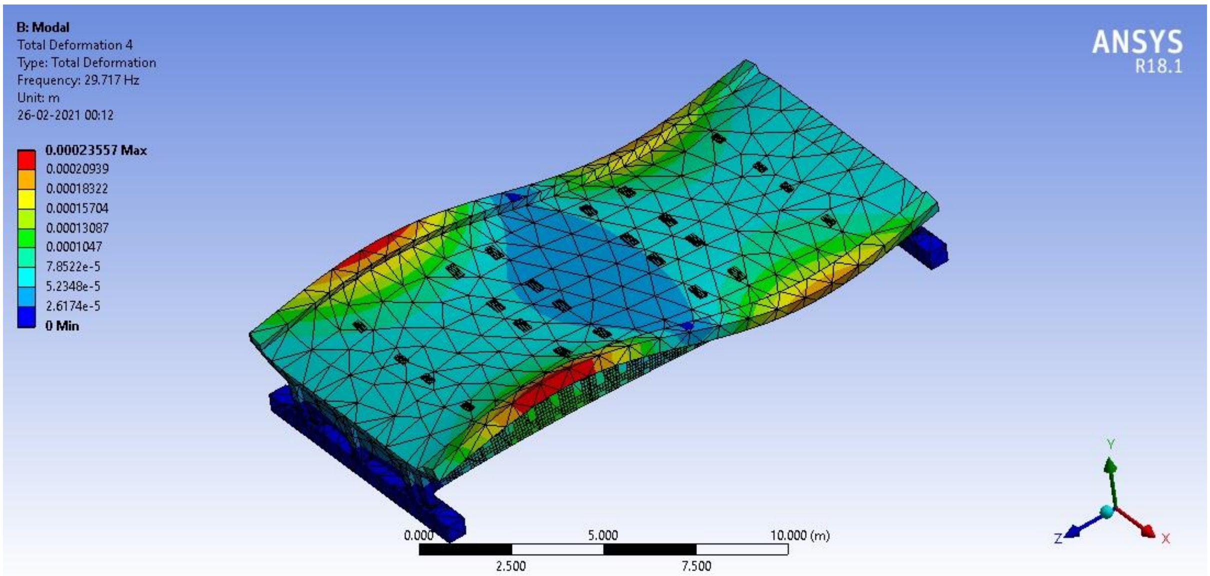

Figure 4. 28 Deformed model of Pusa bridge in mode 4

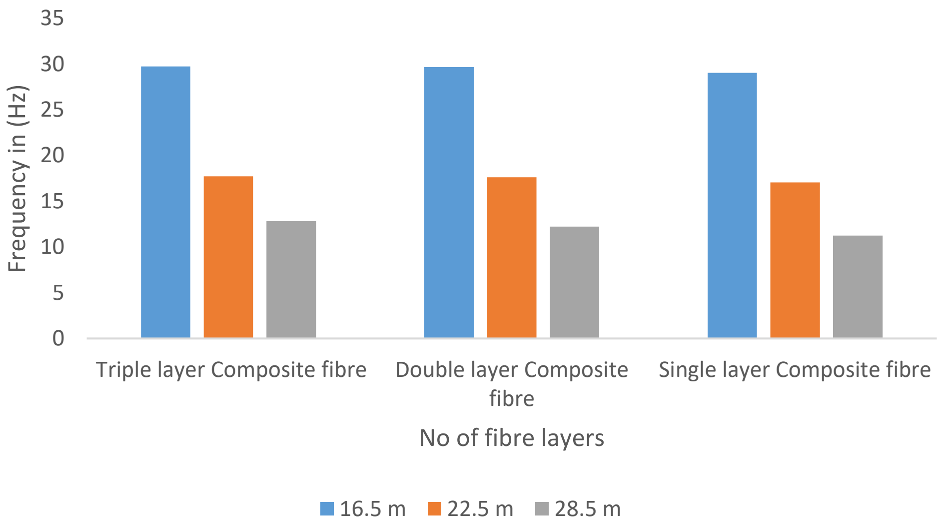

Figure 4. 29 Frequency vs Nos of fibre layer in mode 4 for different span length

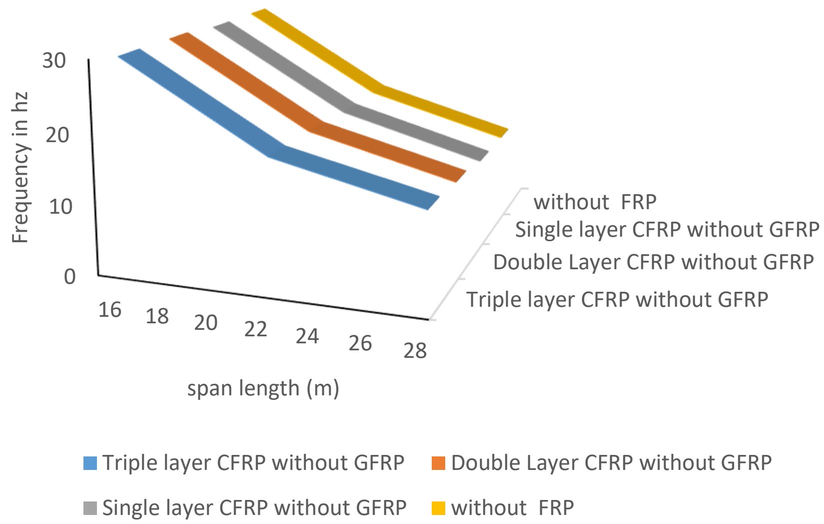

Figure 4. 30 Frequency (Mode 4) vs span length for different CFRP layer combination

v. **Frequency of girder for mode 5**

Figure 4.32 and figure 4.33 represents the frequency of laminated girder in mode shape 5. In figure 4.32 the single layer composite fibre on the girder of length 28.5 meter showed the frequency of 12.94 Hz and the girder of 22.5m and 16.5m showed the 18.78 Hz and 29.52 Hz respectively. The double layered composite fibre of longest girder showed the frequency of 13.06 Hz and other two girder in descending order showed 18.96 and 29.70 Hz respectively. Similar stance was observed in triple Layered girders of all the three spans. In figure 4.33 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. 28.5 meter 22.5 meter and 16.5 meter was applied and frequency was measured for mode shape 5. The frequency for the largest and second-largest girder was 12.94 Hz and 18.78 Hz. The frequencies in the smallest girder after lamination of single layer was found the highest and it was 29.52 Hz. For the double layer, the 28.5 meter girder frequency was noted 13.06 Hz and the girder with 22.5-meter span and 16.5 meter span reported their frequency 18.97 Hz and 29.73 Hz, respectively. A similar Easel was noticed for next added layer of FRP.

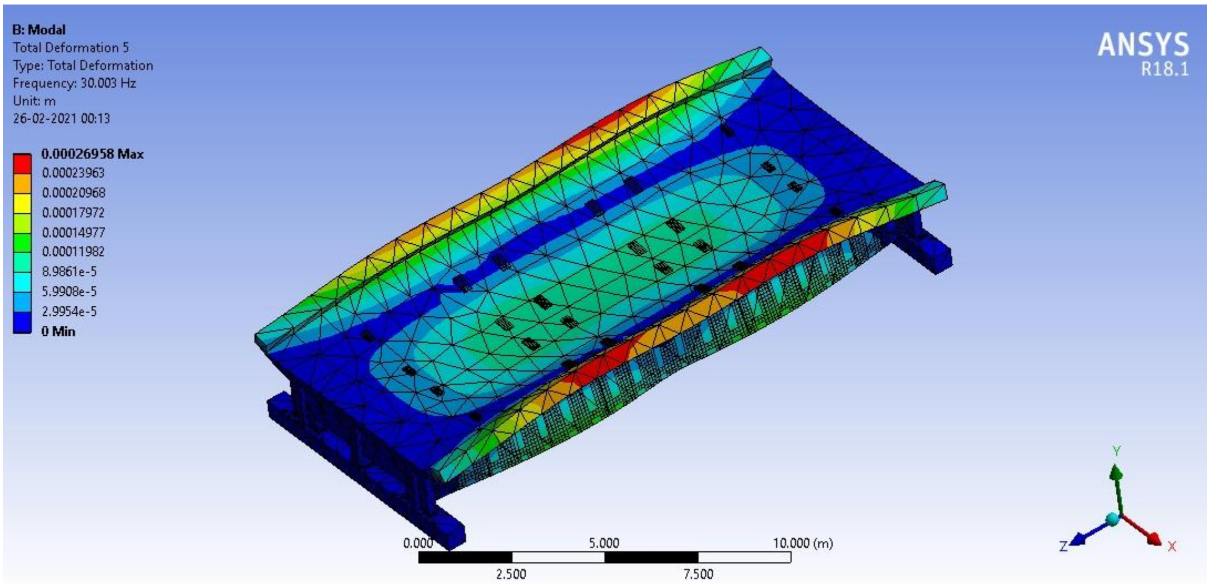

Figure 4. 31 Deformed model of Pusa bridge in mode 5

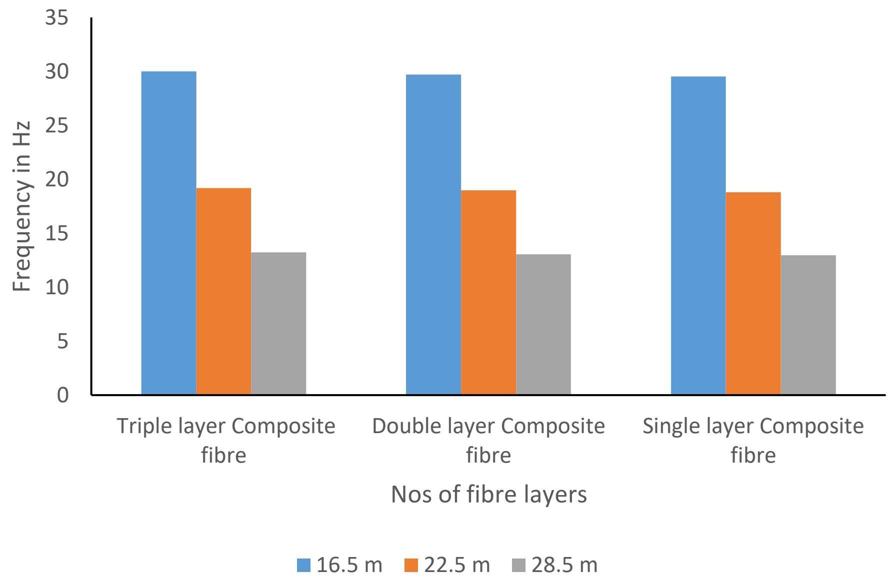

Figure 4. 32 frequency vs nos. of fibre layer in mode 5 for different span length

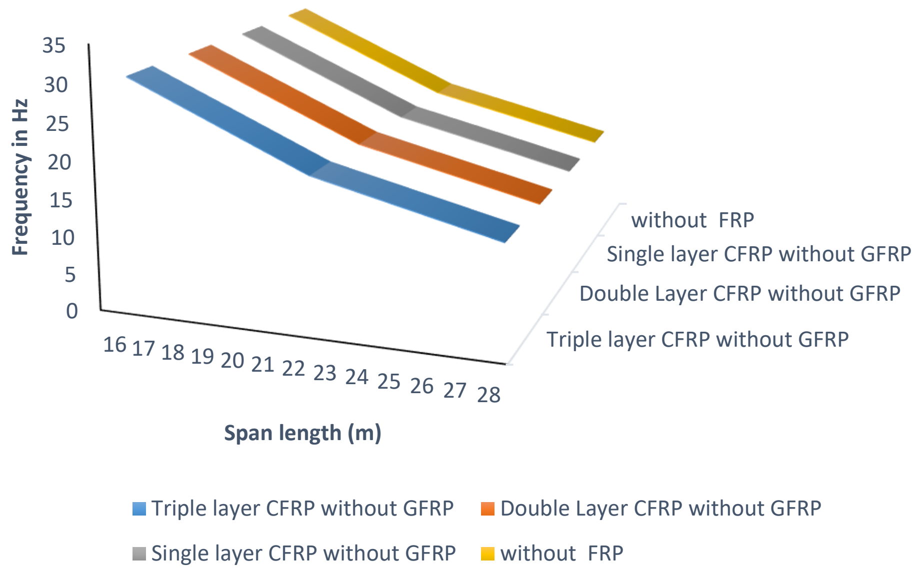

Figure 4. 33 Frequency vs span length in mode 5 for different CFRP layer combination

4.4.7 Von-Mises strain in the girder

Figure 4.34 and Figure 4.35 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 4.34 the single, double and triple-layer composite fibre stratum on all the three girder of the 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 22.5 meter and 16.5 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 4.35 consist the Von-Mises strain of girders which was laminated only using the carbon fibre only. The single-layered girder of 28.5 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

22.5 meter and 16.5 meter respectively. The similar trend was observed in the double and triple layered girder.

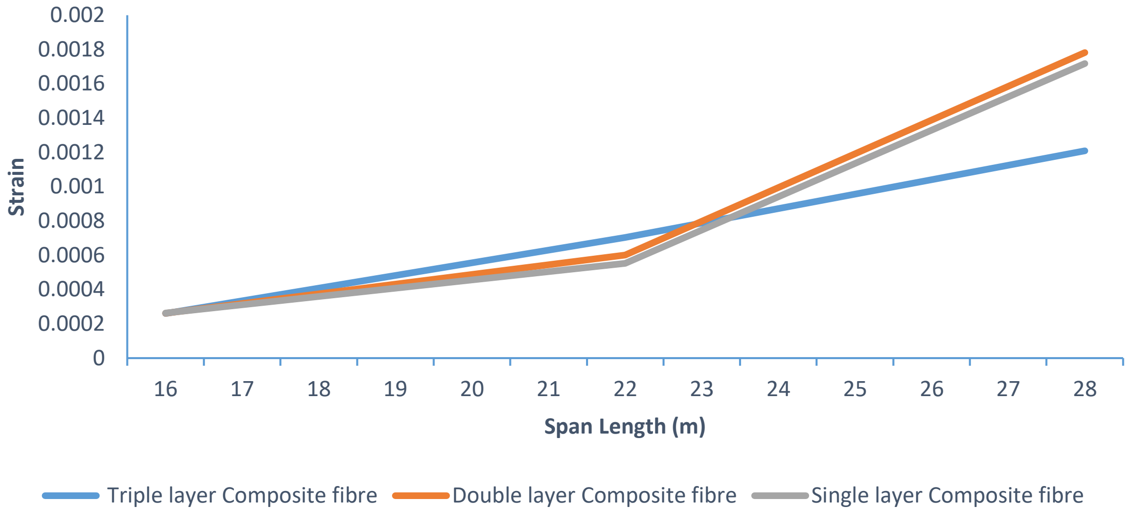

Figure 4. 34 Max. Von-Mises strain vs span length for different composite layer

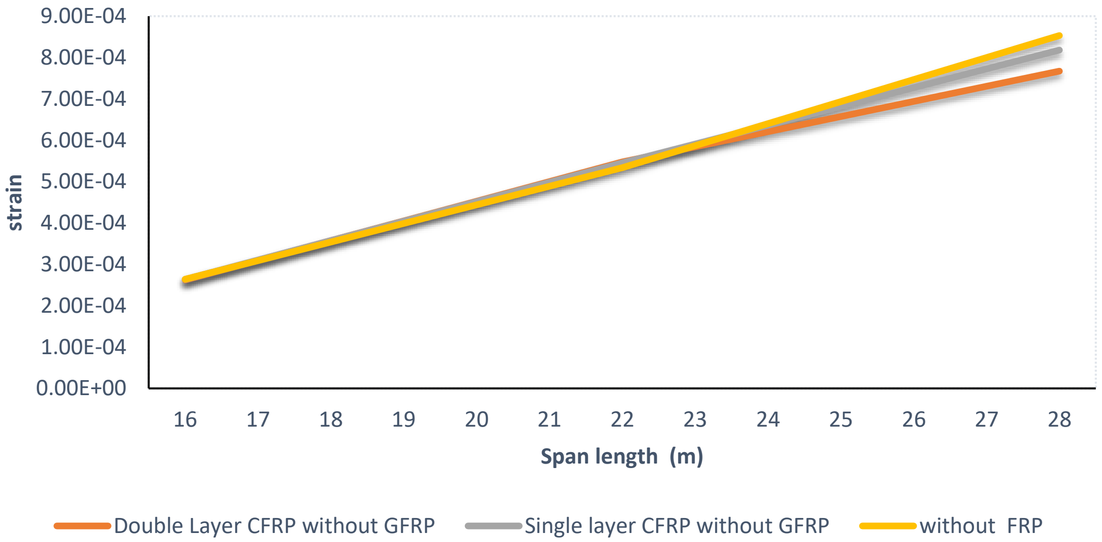

Figure 4. 35 Max von misses strain vs span length for different composite layer

4.4.8 Maximum tensile stress in the Pusa bridge girder

It is well known that the concrete is weak in tension especially 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 4.36 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 28.5 meter was singly wrapped have stress of 11.36 MPa, 6.8 Mpa for the 22.5 meter long girder and 3.22 MPa for 16.5 meter girder. As the strengthening of all girder was completed and tested again the maximum reduction was obsereved in the longest girder about 100 percent. In double coated lamination the stress in longest girder of 28.5 meter length it is 11.20 MPa, in 22.5 meter lomg girder it is 6.71 MPa and in shortest girder it is 3.21 MPa. In the three-layered girder case the maximum stress was not occurred in longest one as it happened in the fore cases. Here the maximum stressed girder was the second largest i.e. 22.5 meter long girder.

Figure 4.37 proved that without glass fibres there would be no such increment in the tensile strength of concrete. The reduction in the tensile stress in all the girder was not as found in composite fibres.

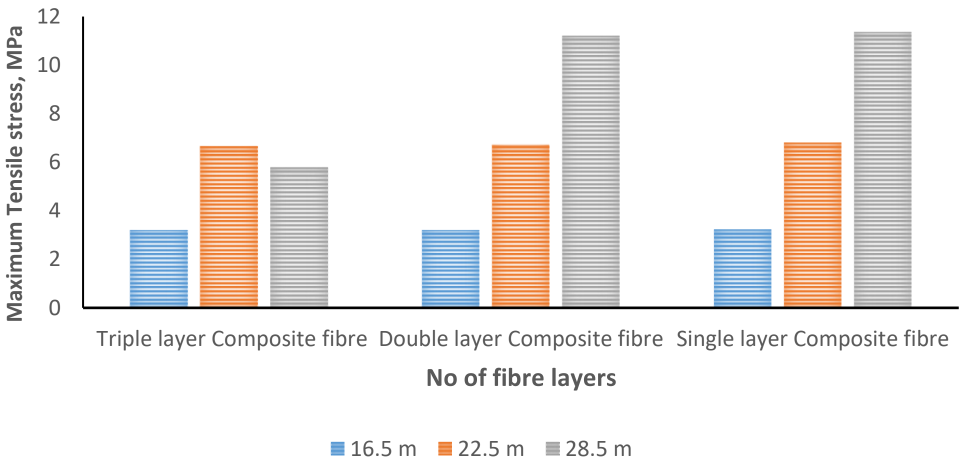

Figure 4. 36 Max tensile stress vs no of fibre layer for different span length

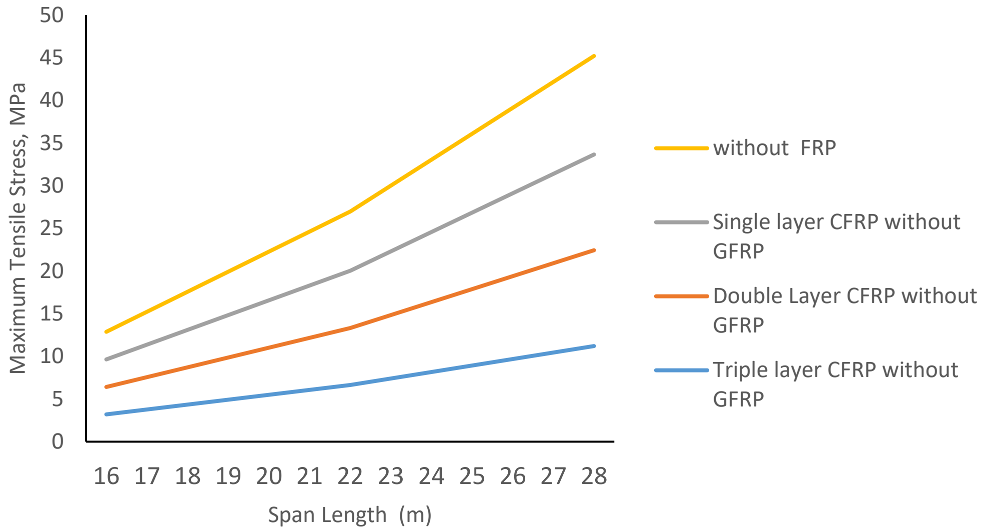

Figure 4. 37 Max tensile stress vs span length for different CFRP layer combination

4.5 Recommendation and procedure of strengthening

Following are the conclusion and recommendations based on the analysis of the girder using FEM. Composite fibre of carbon fibre reinforced polymer, (CFRP) in shear zone and glass fibre reinforced polymer (GFRP) in tension zone for R.C. girder should be used for strengthening. Flexural and shear capacity can be enhanced by using this state-of-art. Since the section has lost its strength in flexure and shear. The strength of R.C. girders in flexure can be improved by providing carbon fibre laminates at the bottom face of bottom flange and shear strength can be enhanced by applying glass fibre sheet at side of beam. Hence the cover should be intact with the structure so all loose cover should be removed and reinforcement lied in this area should be make visible and appropriately cleaned with anti-corrosive paint. New cover should be provided by applying micro concrete. The voids should be filled with non-shrinkable cement grouts with pressure grouting by sealing all cracks at concrete surface. All wide cracks should be repaired by cement grout. Fine cracks can be repaired by doing epoxy grout.

Following procedures have been adopted for repair and strengthening of Distressed R.C. girders.

1. All loose concrete including loose covers were removed from the bottom flange. The cover below reinforcement was checked for hollowness and removed as there had already been delamination occurred inside the concrete. The reinforcement was adequately exposed and cleaned with rust remover. Anti-corrosive paint was applied. Bonding agents over old concrete was applied for better bonding between new and old concrete.

2. New concrete cover was provided by doing micro-concrete. The section of lower flange has been made slightly larger.

3. Strengthening of girders of span 1 and 4 was done using fibre reinforced polymer, CFRP and GFRP as per the finding of analysis. Flexural capacity was enhanced by providing two 100 mm wide 1.4 mm thick carbon laminates at the bottom face of the bottom flange of each R.C. girders as shown in figure 38 and figure 39.

4. Shear capacity was enhanced by providing double layer of 300 GSM glass fibre 500 mm wide 300 mm c/c as shown.

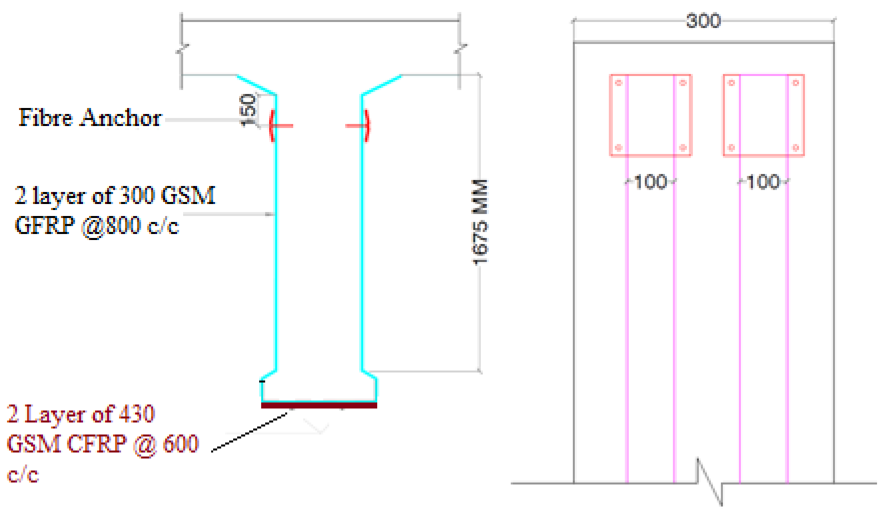

Figure 4. 38 cross section of strengthening scheme of Girder

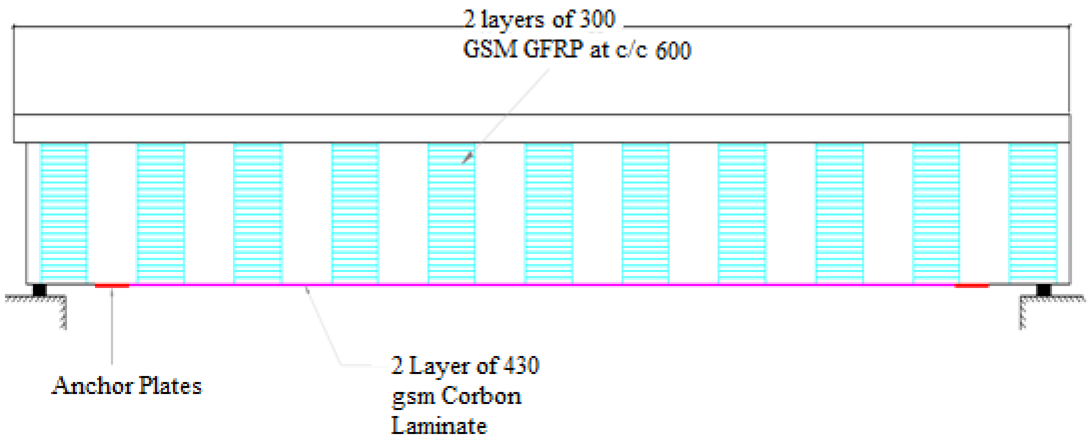

Figure 4. 39 Side view of strengthening scheme of Girder

Figure 4. 40 Treatment of exposed reinforcement and Anti-corrosive paint

Figure 4. 41 Girders strengthened by fibre reinforced polymer

4.6 Load Testing of bridge

4.6.1 Measuring instruments

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 deck locations to capture all girders' behavior for maximum loaded critical conditions. The trucks were placed back to back as shown in figure 4.47 , to generate maximum absolute bending moment and deflection in the girders.

The deflection at the center was measured below each girder for every load combination by installing LVDTs at the center of girders as shown in Figure 4.42. Recovery was also measured after placing the loads and removing them after sufficient time. A variety of four and two loaded trucks each weighing approximately 31 tones were used for load test as under

4.6.1.1 Case I: Static Load Test with Two Truck

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

- Centre Loading- The trucks were placed back to back at the center as shown in figure 4.43 to create a maximum bending moment in the 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 as shown in figure 4.44. 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 as shown in figure 4.45. In this case the maximum load is coming on right girder.

4.6.1.2 Case II: Static Load Test with Four Truck

Four trucks were placed back to back symmetrically on the deck for span 1 and 4, strengthened by using carbon fiber reinforced polymer in both bending and shear.

4.6.1.3 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 Figures 21 to 25 for a set of two/four trucks placed back to back. (Figure 4.46)

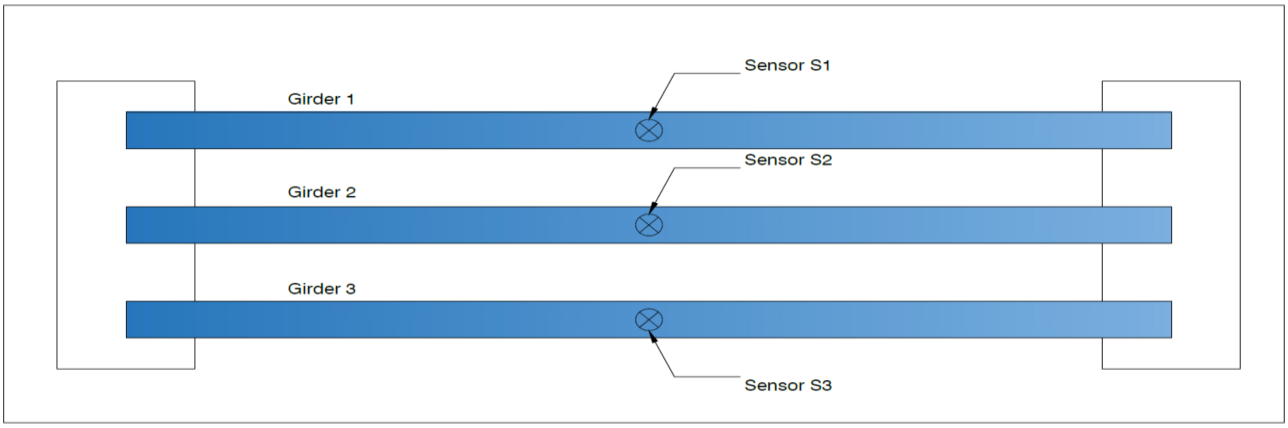

Figure 4. 42 Arrangement of sensors (LVDTs) at the center of each girder

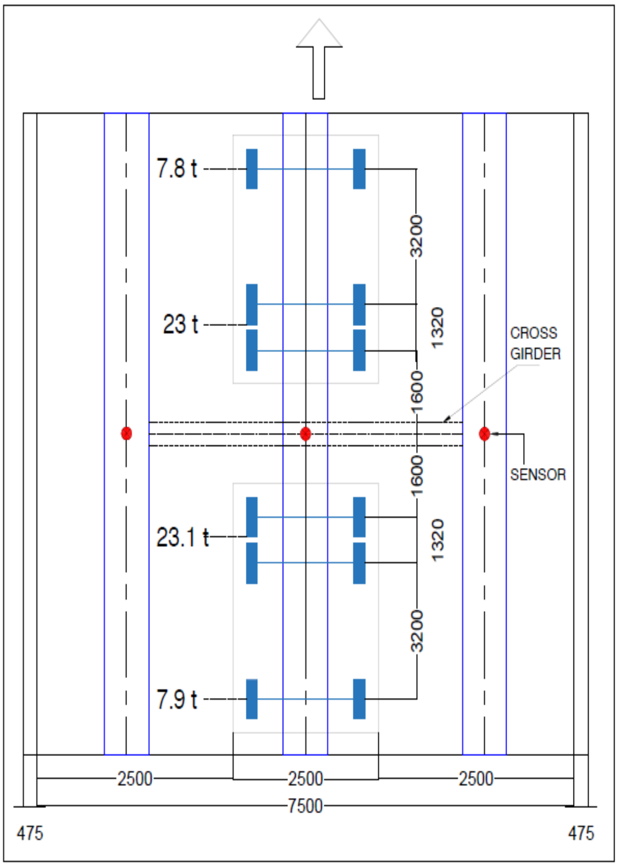

Figure 4. 43 Arrangement and axle load of two trucks for center (top view)

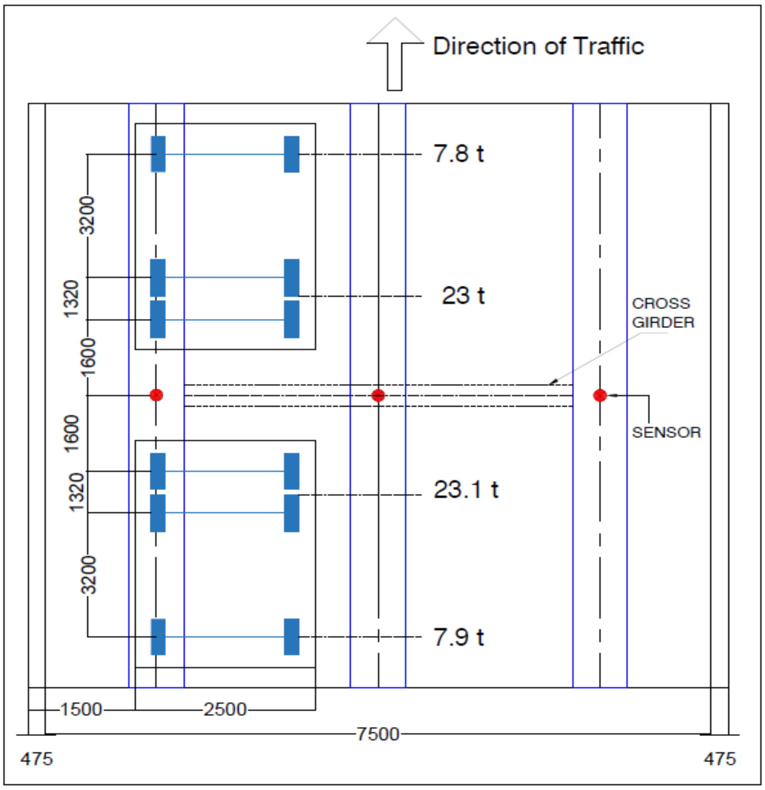

Figure 4. 44 Arrangement and axle load of two truck for left lane

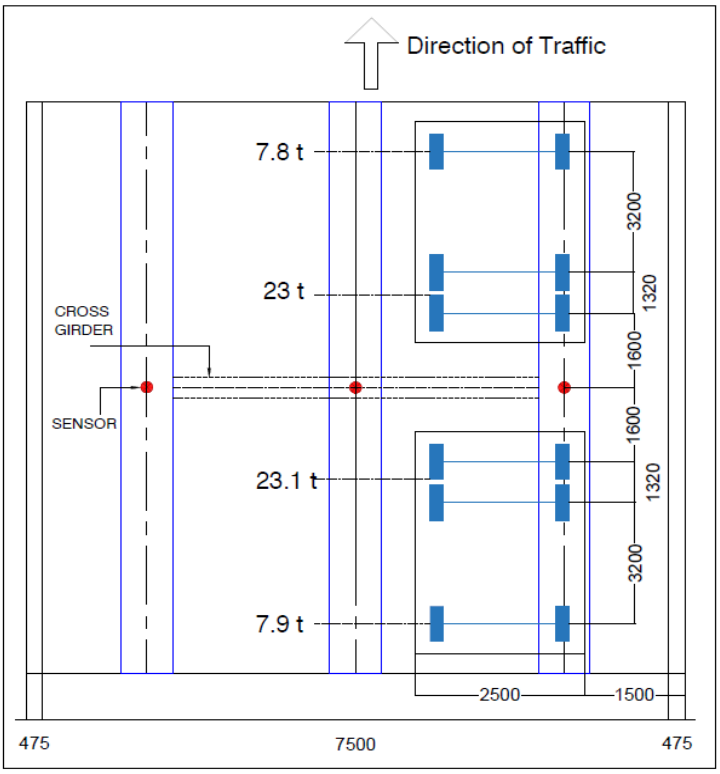

Figure 4. 45 Arrangement and axle load of two truck for right lane

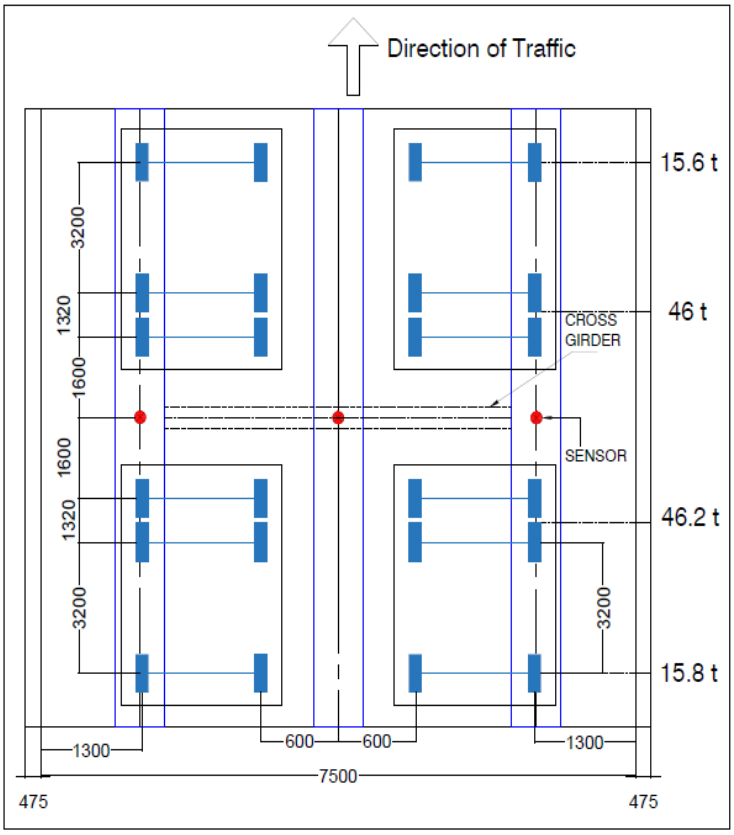

Figure 4. 46 Arrangement and axle load of four truck for case ii static load testing

Figure 4. 47 Loaded trucks placed for static load testing

Linear Variable differential transducer, LVDTs were placed at the bottom face of each girder's lower flange at the center to measure the deflection. The deflection at the center of each girder was taken by placing two loaded trucks of approximately 31 tones each back to back to create severe loading conditions by placing more loads at the center. The measured deflection is given in table-1.

Table 4. 1 Deflection readings for static load for two truck

Sr. No.	Position of Both Trucks	Girder No.	Deflection Observed in mm			
			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

Table 4. 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 4. 3 Deflection readings for dynamic load test for two truck

Sr. No.	Position of Both Trucks	Girder No.	Deflection Observed in mm			
			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

4.7 Result and discussion

The Pusa bridge is consisting three girder and four span of 22.5 meter lengh. The length of every girder is same and of 22.5m. Numerical analysis of three different girder of 16.5 meter, 22.5 meter and 28.5m length is performed. The analysis of simulated girder and field testing of Pusa bridge can be concluded as-

1. The highest degression in deflection was about 110 percent in the longest girder which is of 28.5 meter when the layer of composite fibre was tripled. This indicates that the

effectiveness of the fibre wrapping is more in the longer girder compared to the short girder.

2. The strain energy was reduced by 400 percent in the three layerd 28.5 meter long girder when compared to single-layer lamination.
3. The natural frequency of triple-layer 16.5 long girder is three times higher than of 28.5 girder in mode shape 2.
4. The von misses strain is decreased by 30 percent. Which indicates that yielding capacity after lamination is increased.
5. The load test with four truck loaded conditions was done on all span with a total load of 113.6 tones was applied with 92.2 tons placed at the center by placing trucks back to back. This loading arrangement will produce a more critical load than putting one lane 70R and two lanes class A loading.
6. The maximum deflection in girders of spans 1 and 4 are 4.30 mm and 5.14 mm, respectively. The maximum deflection is within the permissible limit of L/1500 as prescribed in IRC SP:37 as the girder length is 16.5m.
7. The Maximum deflection measured in different load positions is 3.32 mm in girder 1 of span 3. The Maximum deflection in spans 1, 2, 3, and 4 are 2.83 mm, 3.30 mm, 3.32 mm, and 3.02 mm. Maximum deflection in all girders is within the permissible limit of L/1500 as prescribed in IRC SP:37 as the girder length is 16.5 m.
8. The deflection in girders of span 1 and 4 is comparatively lesser as these girders are repaired and strengthened with FRP, whereas girders of span 2 and 3 are only repaired with concrete. It is also noted that girders of 1 and 4 were severely damaged in comparison to girders of span 2 and 3. This indicates that the strengthening with FRP has increased the capacity of severely damaged girders of spans 1 and 4 considerably.

9. Full recovery was measured after the removal of loads in all spans in two truck-loaded conditions.
10. The Minimum recovery in girders of span 1 and 4 after removing load is 95.1% and 91.8%, which is more than 75% as prescribed in IRC 51 for RCC structure.
11. The deflection was also measured in the girders in dynamic loading conditions by passing two loaded trucks over the bridge. The deflection measured are given in table-3. The maximum deflection observed in girders of spans 1, 2,3 and 4 is 1.85 mm, 2.24 mm, 2.12 mm and 1.82 mm. 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 was noticed as these girders are also strengthened by FRP system.
12. It is recommended to consider two pre-stress laminates of at least 100 mm width and 1.5 mm thick in the flexure zone if I girder is less than 20-meter length with. And three pre-stress laminates of the same dimension for more than 20 meters I girder.

4.8 Summary

The road bridge at Pusa was damaged due to environmental effects and high vehicle frequency. If the loading condition persists or increases in the future without adequate dilapidated structure, the bridge may become operational or lead to forbidding events. Therefore, to ensure safety, adequate strengthening is required regularly. As in the Pusa bridge, the bottom of the girder is damaged, and the girder side also spalled at several locations. Also, the strength of concrete in the tension zone is comparatively lesser than the shear zone, so strengthening fibre polymer in this area is essential. In the finite element analysis, the strength of three-layer wrapped girder is shown double yielding strain than single-layer wrapping. So it is recommended to three layer fibre wrapping in the girder having low design steel.