

Rehabilitation and Strengthening of Bridges by using FRP composites

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Abstract

Any technology or material has its limitations. To overcome these limitations new materials and technology make their way. In civil industry to meet up the requirements of advanced infrastructure new innovative materials/ technologies has started making their way. Use of FRP composites in Rehabilitation and Strengthening of structures is becoming increasingly popular and is opening new possibilities in construction and rehabilitation of structures. In the present paper we present use of FRP for strengthening and rehabilitation for bridges. Bridges are important and critical structures and present many challenges for replacement or repair. Many of the advantages in these materials have proven to be revolutionary in terms of time constraints and durability of these structures. This paper presents three bridges which were either rehabilitated or strengthened by using FRP composites. The resulting structure was then tested for the effect after using FRP composites for Rehabilitation and strengthening.

1 Introduction

Global civilization now depend strongly on the use of automobiles and public transport systems. Transportation has become an important part of everybody's life. Bridges are one of the major lifeline structures which facilitate mobility. Bridges are supposed to be maintained properly in terms of safety as it can be catastrophic in case of accidents. It is therefore equally important to maintain and upgrade bridges integrity to keep pace with the increasing usage, higher traffic loads, and new technologies. In India presently a great no. of highway bridges and railway bridges are considered structurally deficient due to which some are often restricted to lighter traffic loads and lower speeds. Such bridges are needed to be removed or replaced. This is a giant industry that maintains infrastructure for safe travel on roads, highways, and railways.

The reasons leading to deterioration and distress of the existing bridges are almost same around the globe. The important ones are listed below¹:

- Increase in traffic flows and weight of vehicles, especially their axle loads, compared to when the bridge was designed and constructed.
- Harmful influence of environmental pollution, especially atmospheric and from water bodies, on performance of structural materials.
- Low quality structural materials also the bridge equipments such as expansion joints, bearings, waterproofing membranes etc.
- Limited maintenance program and insufficient standard of maintenance. A state of negligence towards signs of distress or ignoring preliminary signs of distress.

In all these cases the bridge can be structurally deficient or functionally obsolete or both. Therefore depending on the individual case remedial actions can be taken. It can be taken for repair, replacement, rehabilitation, strengthening or modernization.

2. Repair And Strengthening Techniques

Quality and durability of a structural repair and/or strengthening depend on pre-repair consideration, which are as important as the repairs and/or strengthening. First, before any repair and/or strengthening can be applied, the cause of or the mechanism of damage must be identified as clearly as possible through field inspection, investigation and evaluation. Normally there is more than one mechanism of damage involved, and the probable sequence of events resulting in the damage must be established during inspection and evaluation. In order to identify the damage mechanism, a preliminary inspection and investigation should be done prior to the detailed investigation, which should be done before the start of any plan for the repair and/or strengthening. The principal purpose of the preliminary investigation is to record the nature and extent of observed problems, identify the affected regions in the system, and pinpoint the deterioration mechanisms of the structures. After doing the entire exercise, correct problem is identified and according to that a suitable strengthening technique is used to overcome from that problem. There are many different strengthening techniques available for the repair,

1. Longitudinal Strengthening

- a. Steel Plating
- b. Concrete Jacketing

2. Shear Strengthening

- a. Steel Jacketing
- b. Concrete Jacketing
 - i) Epoxy Injection and Rebar Insertion
 - ii) Addition of External Shear Reinforcement

3. Post tensioning

The above conventional methods for improving the live load capacity of bridges include section enlargement, span shortening, and the use of epoxy bonded steel plates. Corrosion-related problems and difficulty of application due to the heavy weight of steel plates have limited the use of latter technique.

Recent developments in advanced fiber reinforced polymer (FRP) materials, have shown that these materials are good alternative to steel plate bonding. FRP for civil engineering structures are being increasingly studied in recent years. These materials are being used in the aerospace, automotive and shipbuilding industries for almost two decades. In general, FRP offer excellent resistance to corrosion, good fatigue resistance (with the possible exception of some glass-based FRP), low density, high stiffness and strength, and a very low coefficient of thermal expansion in the fibre orientation. FRP materials as having superior mechanical and physical properties than steel, particularly with respect to tensile and fatigue strengths. The FRP is usually considered only for special applications, such as in non magnetic structures, or for use in aggressive corrosive environments. However, the usage of FRP can be more economical than using steel plates. This is because the material costs in a rehabilitation project rarely exceed 20 percent of the total cost of the repair. Several fibre reinforced polymer (FRP) systems are now commercially available for the

external strengthening of concrete structures. Studies have shown that these materials are a good alternative to conventional methods for increasing the load carrying capacity of structural elements. usually glass, carbon or aramid, while the polymer is usually an epoxy, vinylester or polyester thermosetting plastic. Previous research studies and field applications of externally bonded FRP systems have been documented in ACI 440². available to the construction industry^{3,4}.

For strengthening applications the

- rods similar to the elaboration
- strips which are unidirectional with thickness in the order of 1 mm,
- sheets or fabrics that are flexible and have fibres in either one or at lea directions.
- These are being bonded either externally or internally to the concrete member.

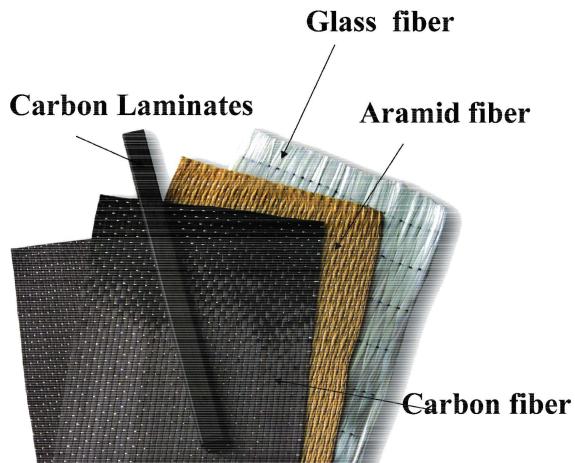


Fig 1: Different types of FRP Composites (Fiber Sheet and Laminates)

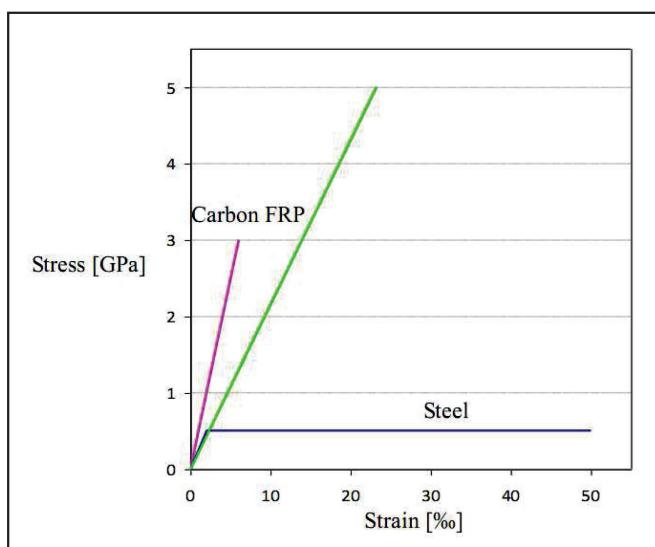


Fig 2: Comparison of stress strain curves of steel Carbon FRP. In adopting the technique of FRP

In adopting the technique of FRP Composites Systems it is possible to ⁵:

- Increase the flexural strength
- Increase the shear strength
- Increase the seismic resistance
- Increase the durability
- Increase of the flexural rigidity

External prestressing with other materials of the existing structures have always been difficult especially in view of the materials to be used, reinforcement corrosion, lateral instability, end anchorages and ofcourse space constraints. The advantages of resistance to corrosion and high specific strength make these materials ideal for reinforcing existing structures with minimum intrusion. Popular method adopted is bonding them adhesively to concrete structures. However, we can seldom fully use the superior strength properties of these FRC's due to poor capacities of concrete and interfaces formed. Pre-stressing of these materials allow us to better utilization of its properties.

External Pre-Stressing is done in two ways

- a. Using Fibre reinforced composite Laminates. This includes externally reinforcing beams and slabs from below with laminates giving the members extra flexural and shear strength. The Pre-Stressing gives the members an active upward force even when no live load is given.
- b. Column Pre-stressing:- An innovative technique and machinery for retrofitting of columns and joints of a RCC structure have been developed by us. It involves confining of column with Carbon/Epoxy or Aramid/ Epoxy Composite-Belts and Pre-Stressing it so that it confines the column in stressed position. This is new and exclusive technique which enhances the capability of FRP to confine the columns.

In the present paper we present some bridges which were rehabilitated and strengthened using FRP composites. The results after rehabilitation in these bridges show the effectiveness of this system. It can be noted that in all these projects time was the major constraint and the bridges were crucial. Rehabilitation in these projects were completed in very less time and energy. This was possible only through use of FRP composites.

3. Rehabilitation Of Rail Over Bridge At Jnpt, Navi Mumbai

Jawaharlal Nehru Port Trust (JNPT) manages one of the busiest port in india, Nhava- Sheva port. This port handles 65% of India's container traffic has a berthing period of 37 hours which is considered to be very long⁶.

This port has constructed a Rail Over Bridge at Karal Junction ([Fig. 3](#)) for efficient traffic flow. The construction of this bridge was completed and opened for traffic since 1991. This bridge consists of 37 spans of varying lengths with 36 expansion joints. The total length of bridge is 700 m. The Rail Over Bridge at Karal had heavy traffic movement and had started showing signs of distress.

Layout of the bridge is shown in Fig. 4, the portion marked by blue line is a slab-girder (T-Beam) bridge system and the pre-stressed slab system portion marked in red. The bridge was functionally designed for crossing railway line and was structurally designed for Indian Road Congress (IRC) 45R loading. As per the revised recommendations of IRC and prevailing practice, the bridge is now required to sustain IRC Class 70 R loading.



Fig. 3 ROB (Rail Over Bridge) at Karal Junction, JNPT

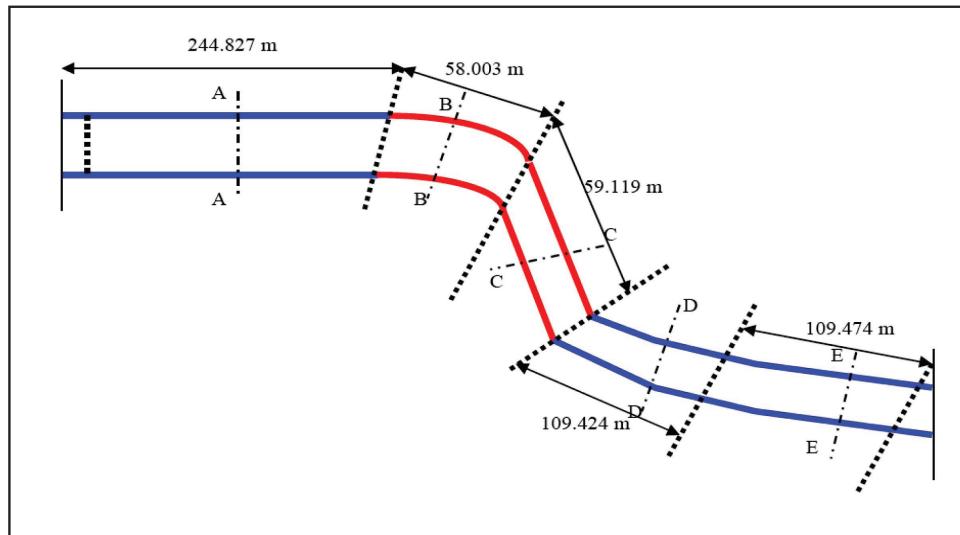


Fig. 4 Alignment of the Karal Bridge

3.1. Inspection Of Rail Over Bridge (ROB) And Observations

The inspection of the Karal ROB was carried out by Prof. R.S. Jangid from IIT Bombay along with the JNPT officials on July 12, 2007 and August 18, 2007. The inspection of the bridge involved the critical examination of the condition of superstructure, substructure, piers, abutments, expansion joint and bearings.

The bridge wearing coat and expansion joints were severely damaged after the severe July, 2005 rains. The damaged wearing coat and expansion joints were subsequently repaired and re-laid but it was observed that the bridge was not performing satisfactorily. Even, the newly designed expansion joints did not last long.

The major observations during the site visit were as follows.

1. Expansion joints were not functioning properly. In the original design of bridge there was no provision of appropriate expansion joints. It was after the rains expansion joints were provided.
2. Slab area of expansion joint was found to be damaged severely due to heavy vehicular movement. The gap between two spans has become large and concrete had deteriorated.
3. The neoprene/elastomeric bearings provided in bridge were inadequate (25mm) for heavy vehicle movements. They appeared to be bulging out and damaged.
4. There was a visible sag in the superstructure in many spans. The typical structural failure cracks i.e. vertical crack in the centre and diagonal cracks at the end in the girders were observed.
5. The new expansion joints could not last long due to excessive vibrations and the poor quality of deck concrete at the end of span.
6. The substructure/piers appeared to be sound.

3.2. Procedure For Rehabilitation

In view of above observations it seemed that the structural health of the bridge was not very good. The proposed strengthening measures for the bridge by the consulting team are as follows.

1. Strengthening of girder by steel truss system-

The girders and slabs are to be strengthened by placing additional steel truss systems, which will support the bridge deck/slab/girders with M32 high strength bolts (a system of bolts). These steel trusses were designed to take about 50% of load carrying capacity of girders. (Fig. 5(a,b))



(a)



(b)

Fig. 5 (a) Connection of Truss over Diaphragm Beam and (b) Pre-stressing Mechanism in Truss During Installation of Steel Truss System

2. Replacement of bearings-

The existing neoprene/elastomeric bearings are to be replaced by new elastomeric bearings. Shore-A-hardness hardness of rubber material to be used should be 60. (Fig 6)



Fig. 6 Replacement of damaged Bearings with new

3. Provision of new expansion joints-

It was recommended to replace the expansion joints with WaboCrete Strip Seal Expansion Joint System. It is a superior joint system, which can be rapidly installed in failed expansion joints and also is suitable for heavy vehicle bridges.

4. Pre-Stressing using C-fiber Laminate and Carbon fiber wrapping of girder and slab:

To further increase the structural strength of the bridge, it was recommended to strengthen the bridge using the Carbon fiber composite wrapping around the girder and slab. At the bottom of each girder 3 Pre-stressed Carbon Fiber Composites (CFC) laminates i.e. 2- 80/1.4mm and 1- 50/1.4mm was proposed to be placed. The load to be given to prestressed laminates should be 8-9 tons. The deck slab was also recommended to be strengthened by putting CFC laminates 80/1.4 at 50 mm c/c at the bottom. The properties of required laminates and wrap were specified. (Figures 7 and 8)



Fig 7 Pre-stressing in process and the finished laminate with anchor plates at end.



Fig 8 Enclosing the girders with Carbon Fiber Wrapping

3.3. Instrumentation And Test Procedure

The purpose of the instrumentation and testing was to obtain reliable and consistent measurement of the various key parameters such as deflection, strain and vibration of the selected spans of the bridge. It was envisaged that due to strengthening and retrofitting, strains and deflections of the girders should be reduced when standard static load is applied. Besides, there would be reduction in vibrations during application of dynamic load. Extensive measurements of all these parameters are proposed to be recorded before and after strengthening. Non Destructive Tests (NDT) namely Rebound Hammer and Ultrasonic Pulse velocity (UPV) Tests were also carried out to find whether the concrete is sound or not.

The procedure followed for taking measurements on selected spans is as follows.

Standard vehicle (Fig. 9) having distance of 3.1 meter between front and middle axel and 1.4 meter between two rear axels and weighing 32 Ton each (average weight) were used for loading each span before and after strengthening. Six different static load cases and two dynamic load cases were considered for measurements. Two standard vehicles have been placed side by side for static measurement. Fig. 10 shows position of standard vehicle in all six Static Load Cases, Case 1,2,3 are on the JNPT to Dronagiri lane and Case 4,5,6 are for Dronagiri to JNPT lane. These cases were calculated as to induce maximum flexural strains, shear strains and deflections in the girders.

Strain gauges were installed below girders at the center to measure maximum Flexural Strain generated. Strain gauges were also installed at face at an angle of 45 Deg and 1m away from the support to measure maximum shear strains on main girders. Omega Type Transducer were installed over the shear crack near the support. These transducer were to measure the crack openings when maximum shear force is applied. Accelerometers and linear potentiometers were installed below the girder at the center of span to measure vibrations and maximum deflection.

For dynamic measurements two standard vehicles were made to move over the bridge with a velocity of 25 m/s². The distance between the vehicles were kept to be 3m. Two Dynamic load cases were recorded with an initial no load signal for ambient vibrations, if any. After which, vibration signals were recorded on multi-channel vibration recorder and analyzer, for load case A. Similarly vibration signals were recorded for load case B.

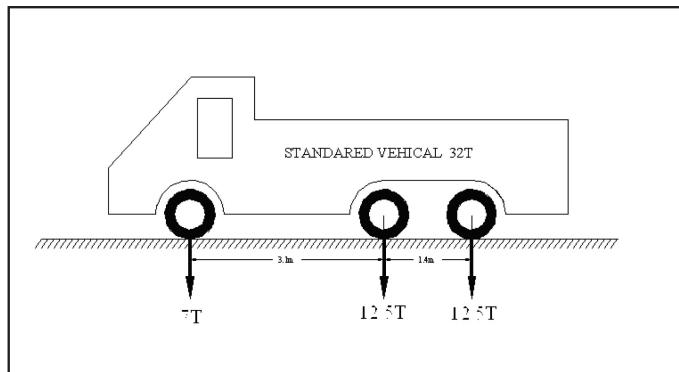


Fig. 9 Standard Vehicle (Total Load and Axel Loads)

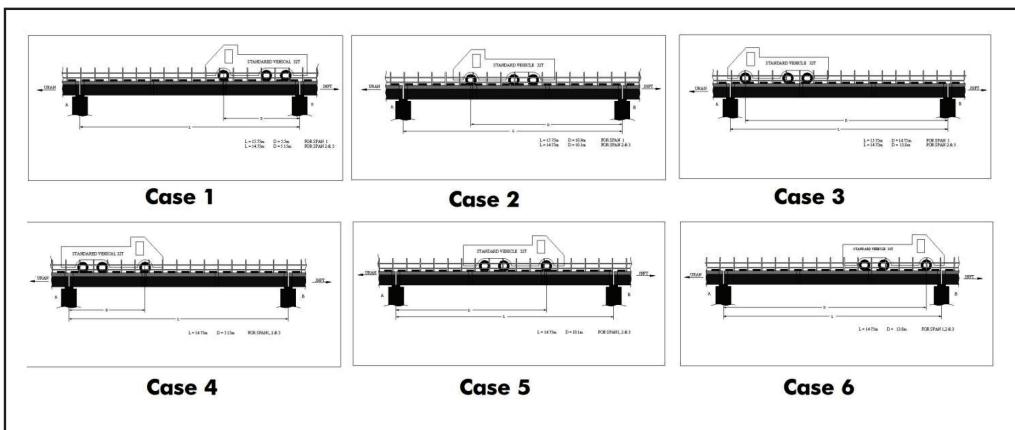


Fig. 10 Position of Vehicle in different in 6 static Load Cases

3.4. Observations And Results And Conclusions

It can be summarized that this exercise was useful to know the behaviour of these spans before and after strengthening. It can be seen that almost all the deflection and strain values show the effect of strengthening. NDT tests confirmed the good condition of concrete. An average reduction of 26% in the deflection of bridge superstructure under standard loads indicated significant improvement in the flexural stiffness of the RCC girder beams after rehabilitation. Strains measured under standard flexural loads indicate significant improvement in the flexural stiffness of the RCC girder beams after rehabilitation. An average of 53% reduction in the flexural strain was observed. An average of 56.8% reduction in the shear strain in RCC girder beams under standard loads has been observed. This shows Shear strengthening of the super structure after strengthening.

Reduction in the vibration of the superstructure was envisaged due to rehabilitation of RCC girder beams and strengthening with steel truss system. An average increment of 8.5% in fundamental frequency of vibration is achieved. In addition to this, the amplitude of acceleration has been reduced by 50%. The increase in fundamental frequency of vibration and reduction in amplitude of acceleration indicate that the significant improvement in the overall stiffness of the structure. The rehabilitation methodology used for bridge was found to be successful and yielding desired results in the most cost-effective manner

4. Mumbai Airport Runway Bridge

The bridge under consideration is the one at the Mumbai Airport, over the Mithi River. The bridge structure is a reinforced concrete structure, earlier designed for smaller aircrafts. But the bridge won't be sufficient to carry the loads of the current design of aircrafts (Fig 11). Hence a need for strengthening the bridge arose and considering all the available techniques, FRP laminate bonding was suggested. This was in view with the overall repair costs and anti corrosion properties of the FRP materials. The bridge is a T-beam type bridge with two main beams running through the length of the bridge. The superstructure of the bridge consists of T-beam bridge with T-beams at 2470 mm c/c. the beams are supported on two column piers intermediately and two abutments at either ends. The distance of the nearer pier from either abutment is 9700 mm and the center to center distance between the piers is 11700 mm. Thus the total length of the bridge is 31100 mm. The bridge behaved as a Tbeam in the mid span and as a rectangular beam at the supports. 11 bars of 32mm diameter was provided as reinforcement in the tensile zone near the mid span and 14 bars of 32mm diameter near the supports. 8 bars of 32mm diameter was provided as steel reinforcement in the compression zone.



Fig 11 Position of Mithi River Bridge below the runway

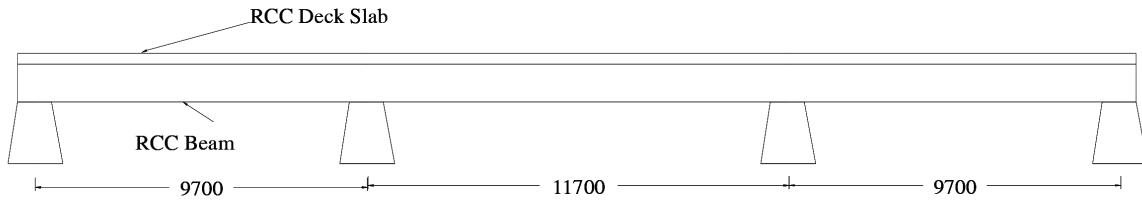


Fig. 12 Support arrangement for Girders.

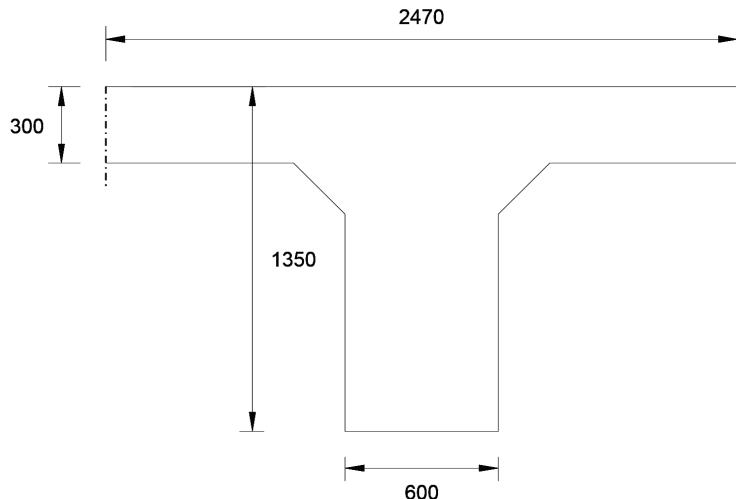


Fig. 13 Typical Cross-Section of T- Beams.

An FRP-laminate strengthening system was selected based on its application being the least intrusive with traffic and the most practical. Rehabilitation work, including erection of a full- size platform underneath the bridge, surface preparation, and installation of the laminates was conducted. The objectives of this work are

- To evaluate the capacity of the existing bridge following IS code recommendations
- To verify the capacity of the bridge against the demand posed by stipulated loads.
- To design a strengthening using FRP composites following international standards recommendations.

4.1. Loads on Superstructure⁴

Bending Moments

The bending moment values for dead loads and live loads on for the structure. The maximum support moment is found to be as 351 T-m and the maximum span moment as 356 T-m.

Shear Forces The shear force values for the structure. The maximum shear force in beam is found to be as 247 T. In addition to this the slab shall be checked against a punching shear force due to ESWL of 54 T.

4.2. Design of Strengthening

The design of strengthening of beam is again performed following working stress methodology. Carbon laminates are used for the purpose of strengthening of beams against bending moment. The design of strengthening is performed following the recommendations given in various international codes on FRP strengthening namely, ACI code, CEB-FIP code and Eurocode 8.

1. For strengthening of Mid-Span T-beams after calculations it was proposed to use 5 no. 100x1.4mm C-laminate on the soffit of the beam in the middle 6000mm span as shown in **Fig 14.**

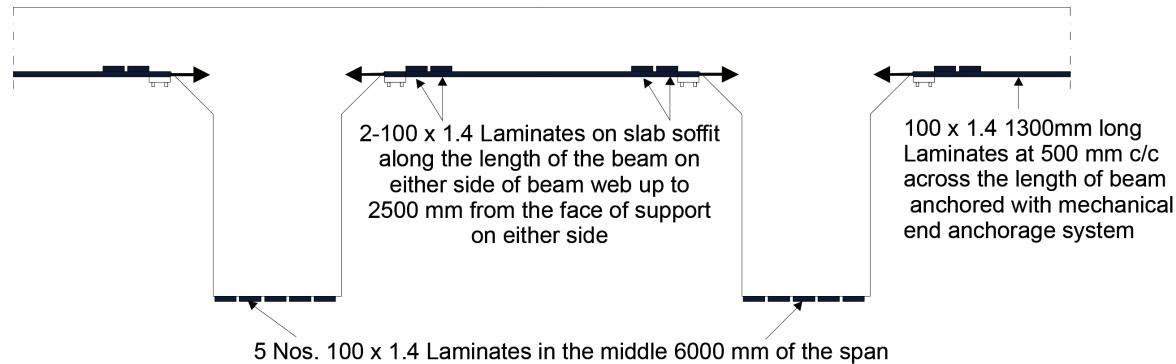


Fig 14: Procedure for strengthening the T-Beams for Flexural Strengthening

2. For end-span Strengthening Rectangular Beams were designed with 4 nos. C- laminates. two on each side of beam and very close to beam at the slab soffit along the length of the beam up to 2500 mm from the face of the support on either side. It is shown in **Fig 15.**

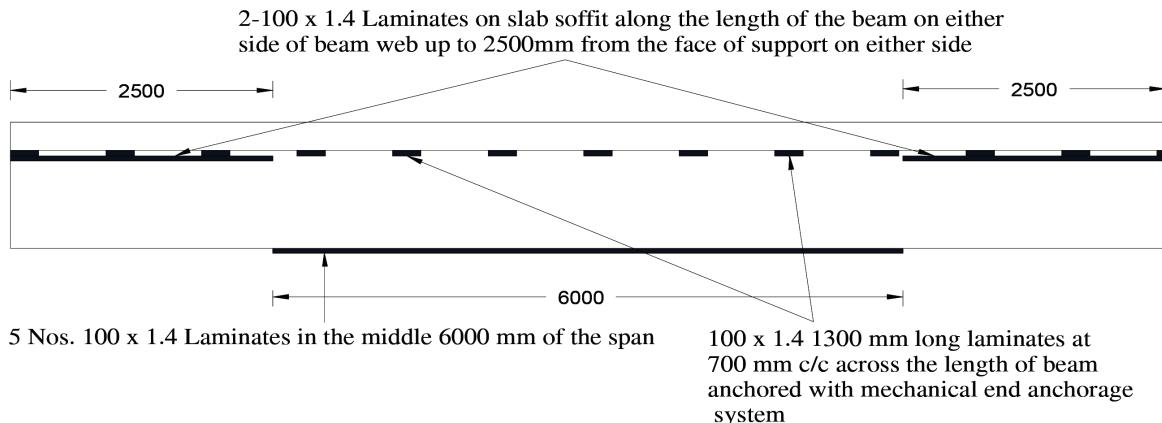


Fig. 15: Flexural strengthening of Superstructure and shear strengthening of slab

3. For Shear strengthening the beam design was done as per EuroCode 8 part 3. It was recommended to provide 2 ply C-Fibre sheet 430 gsm U-wrap up to 4000 mm from the face of support on either side of beams. This wrap was also acting as end anchorage for laminates.
4. Although the slab is safe against bending moment as well as both types of shear, still as an additional safety feature it is recommended to provide 100 x 1.4, 1300 mm long laminates at 500 mm c/c. The laminates should be anchored at the end with mechanical end anchorage system.

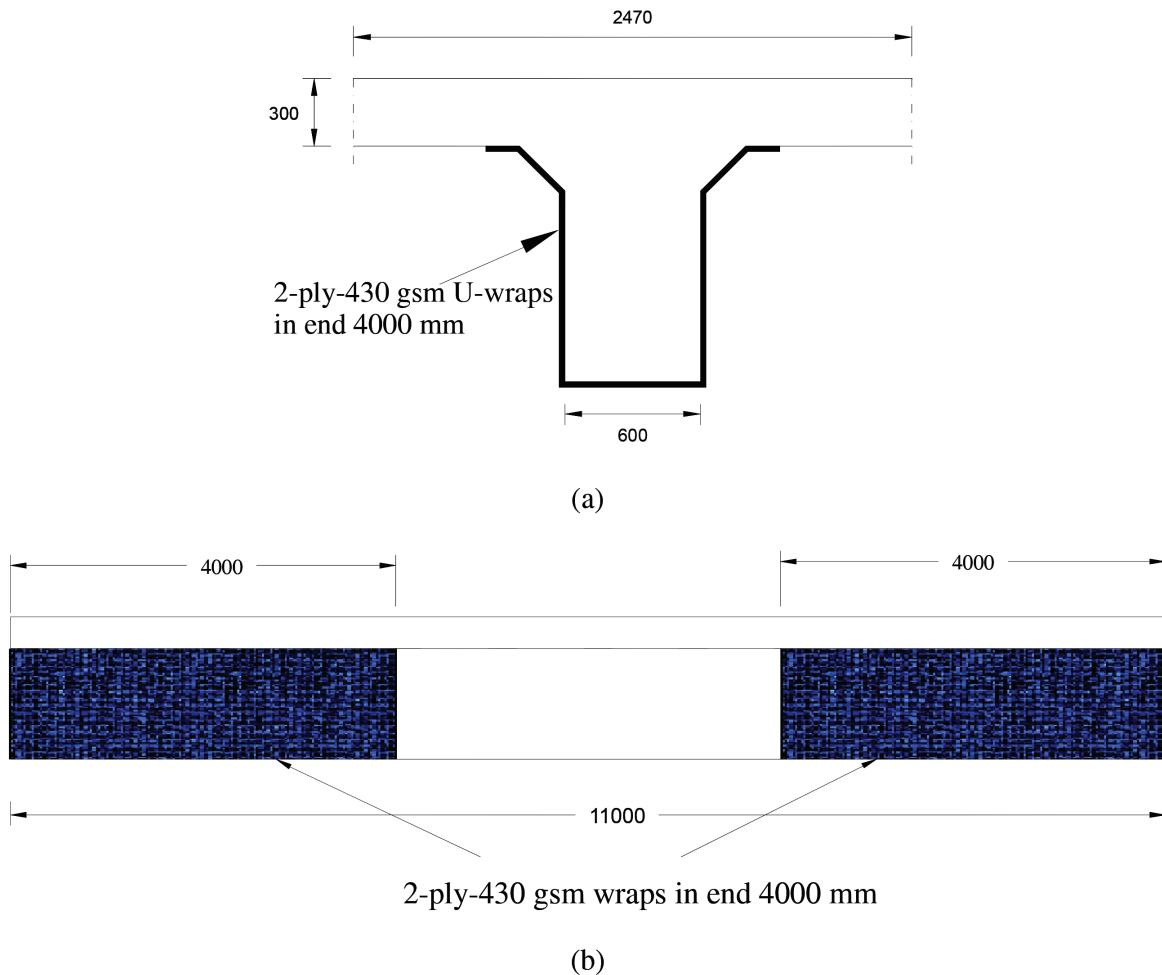


Fig. 16 (a) Flexural strengthening of Superstructure and (b) shear strengthening of slab

4.3. Methodology and Installation Of FRP

Areas of the beams with visible cracking were first repaired (by removing loose concrete and replacing it with new patching concrete, and filling the cracks with a cement based grout material) and those with uneven surfaces ground to a smooth finish. Sharp edges around the beam corners were then rounded, and the bridge underneath was sand-blasted and pressure washed with water to remove any loose surface materials that could lead to de-bonding of the laminates. After the surface was dry, laminate locations on the beams and flange soffits were clearly marked. A 15 mm gap was provided between U-jackets laminates to allow an avenue for moisture to escape.

A primer was applied followed by putty at the locations where the FRP laminates were to be installed. The primer is expected to penetrate the concrete surface, increase its strength, and improve laminate bonding to the surface. After primer application, gaps and pinholes greater than 1 mm can be seen on the concrete surface. The putty application smoothed the surface by filling the gaps and pinholes.



Fig. 17 Application of FRP laminates to the T-Beam at the site

4.4. Results And Conclusions

Flexural Strengthening

The flexural strengthening of beams is achieved by externally applying Carbon Fiber Laminates.

The design recommendation is to provide:

1. Carbon Laminates 100x1.4 at 450 mm c/c along the length of the beam at the soffit of the slab of Tbeam up to 2500 mm from the face of the support on either side.
2. Carbon Laminates 100x1.4 at 500 mm c/c across the length of the beam at the soffit of the slab as main reinforcement to slab up to 300 mm from the face of the beam on either side.
3. 5 Nos. Carbon Laminates 100x1.4 along the length of the beam at the soffit of the beam as main reinforcement to beam in the middle 6000 mm of the beam.

Shear Strengthening

The shear strengthening of beams is achieved by providing Carbon U- Wraps on the beams as shown in [Fig. 10](#). The design recommendation is to provide 2-ply-430 gsm, C-240 as U-wraps on beams at L/3 from the face of the support on either side.

Load tests were conducted before and after installation of the laminates to evaluate effectiveness of the strengthening system and investigate its influence on structural behavior of the bridge. The FRP techniques were easily implemented and showed satisfactory performance.

5. Flyover Nh 7, Strengthening Of Over Pass Skew Box.



Fig 18: The NH 7 Highway Site

The two flyovers, originating from National Highway 7, were constructed in record time of 6 months.

After a few months the skew slab had developed a sag and on inspection hair cracks were observed. The cracks were inserted with glass pieces to check whether the cracks are live or stable.

After some days it was observed that many glass pieces had fallen down and many have become loose. It was inferred that the cracks were live and hence need to be taken care immediately.

The following was proposed as repair and strengthening measures.

For repairing the slab epoxy grouting with Teflon nozzles was proposed to close the cracks.

For strengthening of slab following two techniques were proposed

- Full concrete jacketing of the slab by removing the existing loose c it with new layer of concrete and reinforcement.
- Strengthening of slabs using Carbon Fiber technology according to the design submitted by the consultant.

Finally it was decided to go with Carbon Fiber technology to rehabilitate the bridge



Fig 19 a) The markings and anchor bolts at place. b) Pre-Stressing of Slabs in “Cross-Traffic movement” direction with C-fiber Laminate c) Prestressing in the “Traffic movement” direction.



Fig 20: The Final view of the two Skew Box of two Bridges.

6. Conclusion And Future Of Frp For Bridge Applications

The high strength, high fatigue resistance, lightweight, and corrosion resistance of composites are highly desirable characteristics for bridge applications. Currently, these new materials are a direct technology transfer from the aerospace industry, and they are far more advanced than those required by civil applications. Most of the advanced composite materials that are cured at high temperature produce high quality components and possess excellent characteristics. In bridge applications, resins as the binders for the fibre and adhesives for joints and connections that can adequately cure at ambient temperature and still offer comparable quality and characteristics are more desirable and practical. More research is needed to develop the most effective and durable resin formulations. More efficient manufacturing and effective production methods for large volume panels and higher modulus materials are needed to make it more cost effective for composites to compete in the civil infrastructure. At the present time, the direct use of fibre composites from the aerospace industry is not cost effective as compared to conventional materials in bridge applications.

In the paper rehabilitation and strengthening of three bridges by using FRP composites were considered. The results were tested and found to be satisfactory in all the cases. In ROB at JNPT static and dynamic load tests were carried out and it was found that the strains and accelerations were reduced substantially. In the case of Mithi River Bridge at Mumbai Airport load tests were carried out to test whether it will be able to take the load of larger aircrafts and the results were positive. The bridge at NH7, Bangalore showed substantial reduction in live cracks and no distress is seen to present date. These results have proven the effectiveness of these FRP materials for usage in civil structures especially in the case of bridges.

The main concern with FRP composites is long-term durability because the materials do not have sufficient historical performance data in bridge applications. There is a concern among bridge engineers for the long-term integrity of bonded joints and components under cyclic fatigue loading. There are concerns with improper curing of the resins and moisture absorption and/or ultraviolet light exposure of composites that may affect the strength and stiffness of the structural system. Certain resin systems are found ineffective in the presence of moisture. In the case of a glass fibre composite, moisture absorption may affect the resin and allow the alkali to degrade the fibres.

If the cost constraint is kept aside, the fiber wrapping system has been proved to be a system which has many added advantages over conventional strengthening processes. It has been proved in laboratory as well in real civil projects that this system is effective and is useful in real life. As the economy is moving ahead and infrastructure development is catching its pace, demand for fiber reinforced polymer in civil construction is slowly increasing and becoming acceptable.

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