# A REVIEW PAPER ON OPTIMIZATION ON THE BEHAVIOUR OF GLASS FIBER REINFORCED PLASTIC BRIDGE DESK PANELS BY USING SIMULATION TOOL

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**ABSTRACT**

*FRP strengthening of continuous beams. In the present study, an Numerical investigation is carried out to study the behaviour ofGFRP under static loading. The beams are strengthened with externally bonded glass fibre reinforced polymer (GFRP) sheets and also with unbonded GFRP using steel bolt system. Different scheme of strengthening have been employed. The experiment consists of (150×250×2300) mm. In recent years, high-performance Fibre Reinforced Polymer (FRP) composite materials have been identified as an excellent candidate for rehabilitating deteriorated bridges. One of the most promising applications for this high-performance material is bridge decking. In this pursuit for suitable materials, the FRP composites, has been demonstrated with great success for bridge applications, to solve some of the persistent problems associated with conventional construction using steel, reinforced concrete and pre-stressed concrete through extensive laboratory testing. FRP plate elements are used in bridge construction predominantly as deck slabs mainly because of their low self-weight, high corrosion and fatigue resistance, and very little installation time, resulting in minimal traffic interruption. Potential applications for FRP decks are new design, replacement of under-strength decks in existing bridges*

**Keywords***:* *ANSYS 13.0; GFRP; deboning failure;*

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## INTRODUCTION

Bridges are the vital components of infrastructure development of a nation and they are composed of several components such as decking slabs, girders, trusses, bearings, abutments and piers. Bridge deck is a structural component that distributes and transmits the live loads to the girders and then to the substructure of a bridge. The bridge decks are the most severely affected components, thereby demanding maximum maintenance. The causes for the frequent maintenance may be mainly attributed to corrosion and the subsequent deterioration. In addition to these factors, there has been a large increase in traffic loads. Consequently, the bridges constructed earlier are now subjected to loads higher than their design limits. Maintenance of bridge infrastructure is thus a growing concern worldwide. Conventional materials and technologies with a fairly successful history of past usage, although suitable for bridge deck applications, lack in durability and fatigue for demanding applications, and in some cases are susceptible to rapid deterioration. The extent of this phenomenon and the economic considerations initiated the development of new technologies in order to reduce corrosion of steel. Various techniques such as cathodic protection, epoxy-coated bars, and galvanized steel were employed, but the new protection techniques have not completely succeeded in mitigating corrosion. This emphasized the need for high-performance construction materials and hence directed the research towards the development of new materials and systems.

The deteriorating state of transportation infrastructure systems is a serious concern worldwide. The study of life-cycle analysis estimates indirect costs to the user due to traffic delays and lost productivity at more than 10 times the direct cost of repair. There is a growing interest among engineers to find cost-effective and durable technologies for bridge repair, rehabilitation and replacement. Different solutions are available to overcome this problem.

In recent years, high-performance Fibre Reinforced Polymer (FRP) composite materials have been identified as an excellent candidate for rehabilitating deteriorated bridges. One of the most promising applications for this high-performance material is bridge decking. In this pursuit for suitable materials, the FRP composites, has been demonstrated with great success for bridge applications, to solve some of the persistent problems associated with conventional construction using steel, reinforced concrete and pre-stressed concrete through extensive laboratory testing. FRP plate elements are used in bridge construction predominantly as deck slabs mainly because of their low self-weight, high corrosion and fatigue resistance, and very little installation time, resulting in minimal traffic interruption. Potential applications for FRP decks are new design, replacement of under-strength decks in existing bridges, and the provision of temporary running surfaces.

FIBRE REINFORCED POLYMER COMPOSITES

FRP is a composite material made by combining two or more different materials. Composites exhibit the best qualities of the constituents and offer some qualities that neither constituent possesses, so that the resulting material has more useful applications than the constituent materials alone. Properties that are improved by composites include strength, durability, stiffness and fatigue life. A composite may be of any one of the following types: (1) Fibrous type having long fibres of one material embedded in a matrix of another material (2) Laminated type composed of layers of two or more different materials that are bonded together (3) Particulate type consisting of particles of one or more materials suspended in a matrix of another material. The FRP Composites considered in this work are herein limited to laminated type fabricated with thin fibres or filaments and bonded together in layers or lamina with a polymer matrix. The mechanical and physical properties of FRP are controlled by its constituent properties and by structural configurations at the micro level. Therefore the analysis and design of any FRP structural member requires a good knowledge of the material properties, which are dependent on the manufacturing process and the properties of constituent materials.

APPLICATION OF COMPOSITES IN STRUCTURAL APPLICATIONS

The applications of composite in infrastructure can be classified into two broad areas namely structural rehabilitation and new construction, as shown in Figure 1.1.

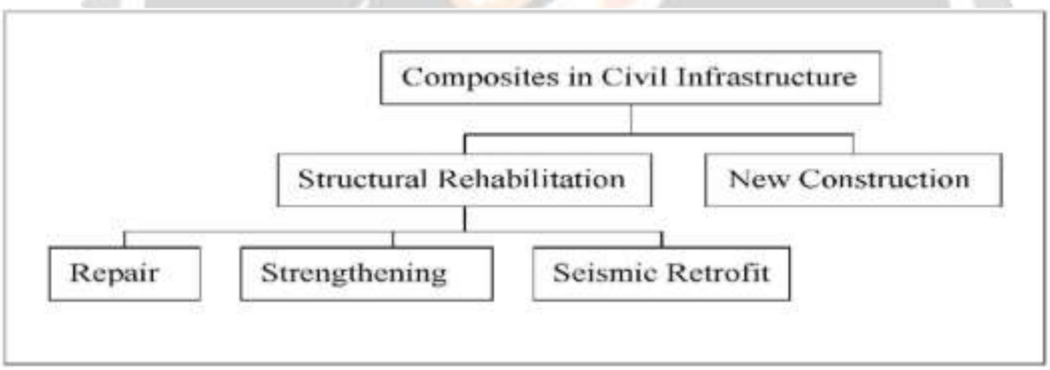



Figure 1.1 Application of composites in civil infrastructure

The rehabilitation and retrofit of existing concrete structures with polymer matrix composites can be accomplished by the application of composite overlays or strips, or by external post-tensioning using composite

cables, tendons or bars. In the area of new construction with fibre-reinforced composites the following applications have been identified.

- Reinforcement for concrete with rebars, jackets, bonded plates or fabrics
- Prestressed tendon and cable reinforcement for concrete
- Structural shapes used for beams, columns and bridge decks

FRP Composite Materials for Bridge Applications

The applications of composites in bridges include construction of new bridges using composite bridge structural systems and repair or retrofit existing bridge structures. The first pedestrian FRP Bridge was built by the Israelis in 1975. Since then, others have been constructed in Asia, Europe, and North America. Many innovative pedestrian bridges have been constructed throughout the United States using pultruded composite structural shapes which are similar to standard structural steel shapes. Because of the light- weight materials and ease in fabrication and installation, many of these pedestrian bridges were able to be constructed in inaccessible and environmentally restrictive areas without having to employ heavy equipment. Some of these bridges were flown to the sites in one piece by helicopters; others were disassembled and transported by mules and assembled on site. The advancement in this application has resulted in the production of second generation pultruded shapes of hybrid glass and carbon FRP composites that will increase the stiffness modulus at very little additional cost.

ORGANISATION OF THE THESIS

This thesis provides the introduction about FRP composite materials, methods of fabrication of composites and its application in the construction of bridges. Different cross sectional profiles of FRP composite bridge deck panels available in the literature are reported. Overall review of literature on FRP composite bridge deck panels. The various aspects include characterization, preparation of GFRP members, structural performance under static, fatigue and dynamic loadings, fire resistance, durability, analytical studies etc

## LITERATURE REVIEW

**Srivastava et.al (1999)** investigated the effects of water immersion on mechanical properties such as flexural strength; Inter-laminar shear strength and impact energy of aluminium tri-hydrate and polyethylene filled and unfilled quasi-isotropic glass fibre reinforced epoxy vinylester resin composites (GFRP). Inter-laminar shear strength and flexural strength were obtained with the variation of immersion time (0, 98, 158, 190 and 240 days) and weight percent of filler content (0, 5, 10 and 15). The author has concluded that the flexural strength, Inter-laminar shear strength and impact energy increased with increasing filler content in GFRP composites.

**Ghosh Karbhari et al (2007)** provided details of investigation of strengthening efficiency of FRP rehabilitated bridge deck slabs through tests conducted on slab sections cut from a bridge just prior to demolition. The deck sections (one unstrengthened, and two strengthened using FRP composites) were subjected to routine traffic prior to removal and testing. The specimen strengthened with wet layup based fabric strips had a strength enhancement of around 73% and the specimen strengthened with pultruded strips had a strength enhancement of around 59%, as compared to the control specimen.

**Bjorn Taljsten (2004)** presented a short summary on past and ongoing research in the area of plate bonding and concluded that considerable improvements in flexural behaviour can be achieved by employing innovative techniques such as prestressed NSRM (near surface mounted reinforcement) of rectangular carbon fibre rods and the use of cementitious bonding agents in combination with advanced composite materials.

**Alampalli Sreenivas and Kunin (2002)** described the replacement of a two lane reinforced concrete bridge superstructure in New york (Bennetts Creek bridge) which was deteriorated significantly by the use of deicing salts, by a FRP bridge superstructure. The superstructure was fabricated by VARTM from an E-glass stitched bonded fabric and vinyl ester resin and used a cell core system. It was designed for standard AASHTO loadings using a FEA method. Proof load tests with HS25 truck loading was conducted with the trucks placed at pre-marked positions on the bridge to maximize bending moment.

**Harries et. al (2007)** studied the implication of RC to GFRP deck replacement on superstructure stresses and concluded that GFRP decks behave in a fundamentally different manner than RC decks and that the substructure forces will be uniformly reduced due to the lighter resulting superstructure. GFRP decks exhibited reduced composite behaviour and reduced transverse distribution of forces as compared to comparable RC decks, thereby offsetting the beneficial effects of a lighter deck structure and resulting in increased internal stresses in the supporting girders.

**Chiewanichakorn et al (2006)** studied the behaviour of a truss bridge, where an FRP deck replaced an old deteriorated concrete deck experimentally and validated through finite element models. Finite element model of the Bentley Creek Bridge was developed using the pre-processor package, MSC PATRAN and the analysis was performed using the general purpose FEA package, ABAQUS to determine fatigue life of the bridge when subjected to dynamic loading caused by AASHTO fatigue live load. Fatigue life of all truss members, floor-beams and stringers were determined based on a fatigue resistance formula in the AASHTO-LRFD design specifications.

**Gilbert Nkurunziza et al (2005)** provided details of the durability tests conducted by the authors and others on the latest generation of GFRP bars subjected to stresses higher than the design limits, combined with aggressive mediums at elevated temperatures, and have concluded that the strength reduction factors adopted by current codes and guidelines are conservative.

**Atsuhiko Machida and Kyuichi Maruyana (2012)** discussed the issues and solutions in developing design codes and standards for the use of fibre-reinforced polymer (FRP)-reinforced concrete structures and have compared different codes developed for strengthening of concrete structures with FRP. Methods of structural analysis; determination of design values; examination of flexural and shear capacity; precautions to ensure ductility or deformability; and calculations of deformation and development length have been presented. Authors concluded that all the three codes, JSCE, ACI and fib, use the same concept and adopt limit state philosophy, but differ in their exact expressions for calculating the respective strengths.

**Kawada and Kobiki (2005)** described the characteristics of a stress-corrosion crack in glass fibre reinforced plastics (GFRP) as a part of the study on long-term durability of polymer-matrix composites in hostile environments. Fragmentation tests were conducted on ECR-glass/vinylester and an E-glass/vinylester to investigate the degradation mechanism using a single fibre composite. Effects of environmental solution diffusion into a matrix on interfacial shear strength were also evaluated with immersion time. The maximum interfacial shear strength was observed to be influenced by matrix Young's modulus. It was observed that the interfacial shear strength decreased as a function of the water absorption rate and it depended on the mechanical degradation of the matrix, and the interfacial shear strain decreased with time under the constant strain condition.

**Bisby et al (2005)** presented a review of the research conducted to investigate the fire performance of FRP materials for infrastructure applications. Details were also provided on the investigation to assess the performance of FRP-strengthened reinforced concrete slabs, beams, and columns in fire. It was mentioned that the FRP strengthened concrete structures can be protected to provide sufficient fire endurance and satisfactory fire performance for these members can be ensured, provided they are appropriately designed and adequately insulated

**Amjad et al (2015)** analysed a hybrid GFRP - concrete multicellular bridge superstructure using the FE analysis software, ABAQUS, with the primary objective of examining the accuracy of FEA and to propose simple methods of analysis for predicting the static flexural behaviour of the hybrid FRP-concrete bridge superstructure. In the study, three trapezoidal GFRP (E-glass and Vinlyester) box sections bonded together to make up a one-lane superstructure, and a layer of concrete placed in the compression zone of those sections has been considered. It has been concluded that a linear FEA can accurately predict the static behaviour of the bridge superstructure under design live loads.

**Sreenivas et. al (2015)** studied the structural behaviour and failure modes of a glass fibre reinforced polymer web core skew bridge superstructure, using the standard FE analysis package ABAQUS and MSC PATRAN, and investigated the shear transfer capacity and the local buckling behaviour of the bridge superstructure. The conclusion based on the study is that the FRP bridge design is controlled by stiffness as reported by other researchers and when the superstructure deflection meets the AASHTO requirement, the allowable live load is approximately 2 times of HS-25 live load. It was established that when the superstructure deflection meets the AASHTO requirement, the Tsai-Hill index is far below the limit state (unit value).

**Upadyay and Kalyanaraman (2013)** considered the various factors that affect the FRP box-girder behaviour and developed a simplified, approximate and computationally efficient procedure for the analysis of single cell FRP box-girder bridges made of blade angle or T stiffened panels and validated the results by comparison with values available in literature and results obtained from FEA (MSC NASTRAN package). They considered the stresses due to longitudinal bending moment, shear force, torsion, distortion, shear-lag and transverse bending as well as instability of the flange under compression and web under shear to propose the simplified analysis method. It was mentioned that the simplified procedure is adequately accurate and very fast for effectively analyzing the FRP box sections in the preliminary and optimum design stages.

**King et al (2012)** outlined the Load and Resistance Factor Design (LRFD) of Fibre Reinforced Polymer composite (FRP) panel highway bridge deck. The deck would be of a sandwich construction where 152.4 mm × 152.4 mm × 9.5 mm square pultruded glass FRP (GFRP) tubes are joined and sandwiched between two 9.5 mm GFRP plates. The deck would be designed by Allowable Stress Design (ASD) and LRFD to support AASHTO design truckload HL-93. It was mentioned that there are currently no US standards and specifications for the design of FRP pultruded shapes including a deck panel therefore international codes and references related to FRP profiles will be examined and AASHTO-LRFD specifications will be used as the basis for the final design. Overall, years of research and laboratory and field tests have proven FRP decks to be a viable alternative to conventional concrete deck. Therefore, conceptualizing the design of FRP bridge decks using basic structural analysis and mechanics would increase awareness and engineering confidence in the use of this innovative material.

## SCOPE OF THE PRESENT INVESTIGATION

The main scope of the present investigation is to study experimental and analytical behaviour of hand lay-up multicellular GFRP composite bridge deck panels under static and fatigue loading conditions. The investigation is required because the number of advantages that the composite material posses compared to that of the other materials (steel and concrete) used in construction.

The scope of the study is to assess the composite behaviour of GFRP composite bridge deck system for the flexural and shear loading. The research results reported herein support the notion of employing a design approach, for a composite floor system, which is consistent with current practice related to concrete decking. The scope also includes that the choosing of proper geometry and material properties for FRP bridge-decks.

## FUNCTIONAL RELATIONSHIP OF POLYMER MATRIX TO REINFORCING FIBRE

The matrix gives form and protection from the external environment to the fibres. Chemical, thermal, and electrical performance can be affected by the choice of matrix resin. But the matrix resin does much more than this. It maintains the position of the fibres. Under loading, the matrix resin deforms and distributes the stress to the higher modulus fibre constituents. The matrix should have an elongation at break greater than that of the fibre. It should not shrink excessively during curing to avoid placing internal strains on the reinforcing fibres. If designers wish to have materials with anisotropic properties, then they will use appropriate fibre orientation and forms of uni-axial fibre placement. Deviations from this practice may be required to accommodate variable cross section and can be made only within narrow limits without resorting to the use of shorter axis fibres or by alternative fibre re-alignment. Both of these design approaches inevitably reduce the load-carrying capability of the molded part and will probably also adversely affect its cost effectiveness. On the other hand, in the case of a complex part, it may be necessary to resort to shorter fibres to reinforce the molding effectively in three dimensions. In this way, quasi-isotropic properties can be achieved in the composite. Fibre orientation also influences anisotropic behaviour.

## MATRIX RESINS

There are mainly three different types of matrix materials- organic polymers, ceramics and metals. Thermosetting polymer resins are the type of matrix material commonly used for civil engineering applications. Polymers are chain like molecules built up from a series of monomers. The molecular size of the polymer helps to determine its mechanical properties. Polymeric matrices have lowest density, hence, produce lightest composite materials. A major consideration in the selection of matrices is the processing requirement of the selected material. The most common thermosetting resins used in civil engineering applications are polyesters, epoxies, and to a lesser degree, phenolics. ISO and ER have been used in the study. Polyester resins are relatively inexpensive, and provide adequate resistance to a variety of environmental factors and chemicals. Epoxies are more expensive but also have better properties than polyesters. Some of the advantages of epoxies over polyesters are higher strength, slightly higher modulus, low shrinkage, good resistance to chemicals, and good adhesion to most fibres. The matrix resin must have significant levels of fibres within it at all important load-bearing locations. In the absence of sufficient fibre reinforcement, the resin matrix may shrink excessively, can crack, or may not carry the load imposed upon it. Fillers, specifically those with a high aspect ratio, can be added to the polymer matrix resin to obtain some measure of reinforcement. However, it is difficult to selectively place fillers. Therefore, use of fillers can reduce the volume fraction available for the load-bearing fibres. Another controlling factor is the matrix polymer viscosity.

## PARTICULATE FILLERS

Particulate fillers are not reinforcements in the sense that stiffness and strength of the resin are greatly enhanced, but they are widely used in composite formulations. Typical fillers are the various forms of chalk (calcium carbonate), silica aerogels, glass ballotini**,** glass and polymer micro balloons, and carbon black. Their main function is to modify the matrix resin and especially to improve the surface finish. Since resins are very expensive, it will not be cost effective to fill up the voids in a composite matrix purely with resins. Fillers are added to the resin matrix for controlling material cost and improving its mechanical and chemical properties. Fillers are added to a polymer matrix for one or more of the following reasons:

Particulate fillers are not reinforcements in the sense that stiffness and strength of the resin are greatly enhanced, but they are widely used in composite formulations. The three major types of fillers used in the composite industry are the calcium carbonate (Chalk), kaolin, and alumina trihydrate. Other common fillers include mica, feldspar, wollastonite**,** silica, talc, and glasses. When one or more fillers are added to a properly formulated composite system, the improved performance includes fire and chemical resistance, high mechanical strength, and low shrinkage. Other improvements include toughness as well as high fatigue and creep resistance. Some fillers cause composites to have lower thermal expansion and exotherm coefficients. Wollastonite filler improves the composites' toughness for resistance to impact loading. Aluminum trihydrate improves the fire resistance or flammability ratings. Some high strength formulations may not contain any filler because it increases the viscosity of the resin paste. High viscosity resins may have a problem wetting out completely for composite with heavy fibre reinforcement.

## PERFORMANCE CRITERIA

From the literature review, it has been observed that the design of GFRP bridge deck panels is driven by stiffness and hence maximum deflection is the governing criteria in design. The loads imposed on the bridge decks include dead load, which includes the self-weight and weight of future surface wearing course, and the live load imposed in the form of wheel load. These loads should be factored up suitably to account for impact and variation in material properties. The deflection produced by this factored load must be less than the limiting value of deflection. AASHTO has set up a deflection limit of Span / 800 for FRP bridge deck panels.

## IRC CLASS A LOADING

According the specifications given by the Indian Roads Congress (IRC 6 - 2000), IRC class A loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. The IRC class A train of vehicles is shown in Figure 6.1

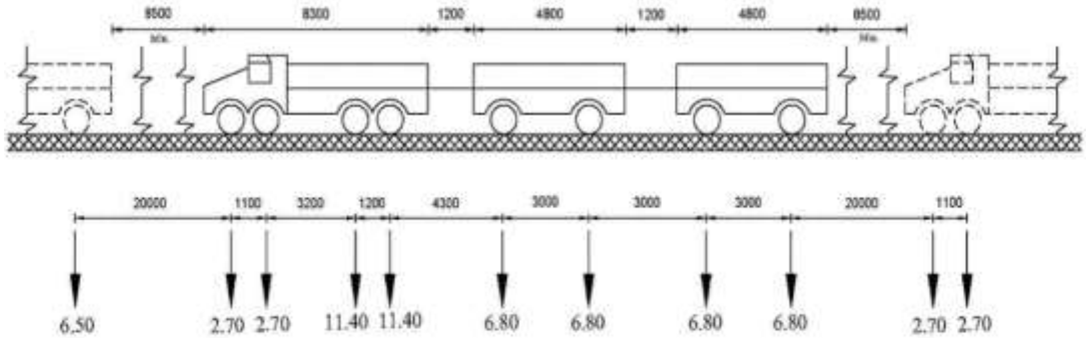


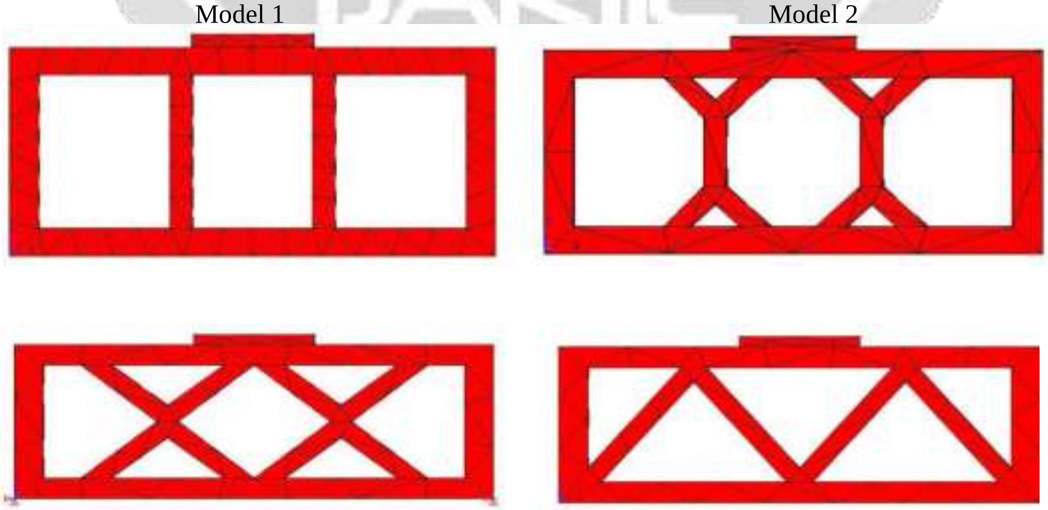

**Figure 6.1 IRC class A train of vehicles (axle loads in tones, linear dimensions in m)**

To obtain the maximum bending moment and shear force, the maximum wheel load should be considered as shown in Figure 6.2. The ground contact area for the maximum axle load of 114 kN as specified in IRC 6 - 2000 is 500 mm perpendicular to the direction of motion and 250 mm parallel to the direction of motion. The minimum clearance to be ensured between the outer edge of the wheel and the inner face of the kerb is 150 mm for all carriage way widths. The width of a single lane carriage way is 3.75 m and that of two lane carriage way is 7.5 m as per IRC 5 - 1998. The ground contact area for the maximum axle load and the distances between the wheels in both directions has been indicated

## SELECTION OF CROSS SECTIONAL PROFILES

Multi-cell box sections are commonly used in deck construction because of their light weight, efficient geometry, and inherent stiffness in flexure and torsion. Also, this type of deck has the advantage of being relatively easy to build. It can either be assembled from individual box-beams or manufactured as a complete section. Various cross sectional profiles of multicellular bridge deck panels available in the literature were selected and analyzed for IRC Class A wheel load using ANSYS, the standard FEA software. The cross sections considered for analysis are shown in Figure 6.4.

Model 1 Model 2



Model 3 Model 4

**CONCLUSION**

A comprehensive outcome of the investigations carried out for static and fatigue behaviour multicellular GFRP composite bridge deck panels under IRC wheel loads is presented in this dissertation. The objectives have been directed primarily towards the study of the following aspects;

**FUTURE SCOPE**

Although the work presented in the dissertation is extensive, still some more studies are to be done in this area for further understanding. The possible research investigations are given below: Stress versus number of cycles to failure (S-N curve) could be developed for GFRP bridge deck panel Durability studies could be conducted on GFRP specimens at different scales and ages Real time monitoring could be conducted to demonstrate the efficacy of the methodologies developed Appropriate codal provisions are to be brought out to the material/structural/construction engineering community

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