Optimization on the Behavior of GFRP by Using Simulation Tool

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Abstract— Deterioration in the capacity of reinforced concrete (RC) infrastructure(e.g., spans, structures, and so on.) may result from localized damage sustained during extreme loading situations, such as seismic tremors, storms or waves. In addition, factors such as the corrosion of rebar's or ageing may also deteriorate or degrade the capacity of an RC column, thereby demanding immediate strengthening to either extend or ensure its design life is not limited. The results of a investigation into the efficiency of fiber reinforced polymers (FRP) in improving the seismic performance of an moment resisting reinforced concrete building are presented. In order to assess the effect of the transverse reinforcement, the building is detailed with different levels of transverse reinforcement representing well-confined and poorly-confined conditions. Although FRP wrapping of columns at critical regions is the main retrofitting technique considered in this investigation, the effect of increasing the beam ductility on the seismic performance of a structure is also evaluated for the code-compliant building. The results confirm that FRP wraps is capable of improving the seismic performance and ductility of the poorly-confined structure substantially, compared to the original structure.

Keywords— *Glass fibers, Carbon fibers, Aramid fibers, Basalt fibers ,FRP technique*

I. INTRODUCTION

A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as low as twenty-five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration can be mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultra-violet radiations. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

The most popular techniques for strengthening of RC beams have involved the use of external epoxy-bonded steel plates. It has been found experimentally that flexural strength of a structural member can increase by using this technique. Although steel bonding technique is simple, cost-effective and efficient, it suffers from a serious problem of deterioration of bond at the steel and concrete interphase due to corrosion of steel. Other common strengthening technique involves construction of steel jackets which is quite effective from strength, stiffness and ductility considerations. However, it increases overall cross-sectional dimensions, leading to increase in self-weight of structures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light-weight FRP Composite plates. FRPCs help to increase strength and ductility without excessive increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibers. So, concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

GOALS

To study the scope and effectiveness of FRP on old damaged structure.

II. STRUCTURAL ASSESSMENT

A structural assessment is a procedure utilize to check the adequacy, Structural integrity and soundness of a structure and their components. All building requires periodical inspection to ensure structural safety, strength and stability under normal/actual loads as well as reducing the possibilities of disproportionate collapse under unanticipated or accidental loads. Structural evaluation process involves visual observation of structural members such as columns, beams, joists, load bearing walls, slabs, roof decking, foundation and connection for any signs of structural deficiency such as cracks excessive movements, bowing deflection etc.

What Is FRP (Fibre Reinforced Polymer)

Fiber Reinforced Polymer is a composite material made of polymer matrix reinforced with fibers. The fibers are usually glass, carbon, aramid or basalt.

Composition OF FRP:

Basically, FRP is made up of four materials as below:

1. Resin

Resins, also called thermosetting, give the environmental and chemical resistance to the product and is the binder of glass fiber in the structural laminate.

There are three main groups of resin:

- Polyester Resins
- Epoxy Resins

Polyester Resin: Polyester resins are the most widely used resins in composites industry. Sometimes, referred to as Fiberglass Resins, Polyester Resins. Most polyester resins viscous, pale colored liquids consisting of a solution of a polyester in a monomer which is usually styrene.

Epoxy resins: For composite parts that demand the ultimate strength, manufacturers depend on Epoxy Resin. In addition to increased strength properties, epoxies also generally outperform other resins like polyester and vinyl ester for dimensional stability and increased bonding with other materials.

Table 1.1 Properties of Matrix Materials

Material	Density (Kg/M3)	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Failure Strain (%)
Polyester	1000-1450	20-100	2.1-4.1	1.0-6.5
Epoxy	1100-1300	55-130	2.5-4.1	1.5-9.0

2. Reinforcement: Fibers and Forms

There four common types of fibers broadly used in the FRP industry: glass, carbon, natural and aramid. Each has their advantages and applications. Similarly, reinforcements are available in forms to serve a wide range of processes, service and product requirements. 10 common materials are used as reinforcement include woven roving, mild fibers, chopped strands, continuous chopped, and thermo-formable mat.

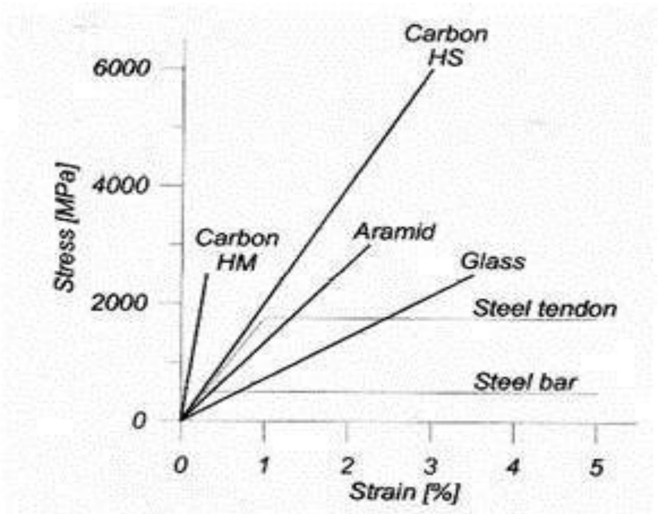


Fig.1 Properties of Different Fibers and Typical Reinforcing

Table 1.2: Mechanical Properties of Common Strengthening Material

Material	Modulus of elasticity (GPa)	Compressive strength (MPa)	Tensile strength (MPa)	Density (Kg/m^3)
Concrete	20-40	5-60	1-3	2400
Steel	200-210	240-690	240-690	7800
Carbon Fiber	200-800	NA	2500-6000	1750-1950

3. Filler:

Fillers are used as process or performance aids to impart special properties to the product. Some examples of inorganic fillers include calcium carbonate, hydrous aluminium silicate, alumina trihydrate, and calcium sulphate. In some of circumstances filler and additives can play a critical role in lowering the cost of compounds by diluting expensive resins and reducing the amount of reinforcements. Furthermore, fillers and additives improve compound rheology, fibers-loading uniformity, enhances mechanical and chemical performance, and reduces shrinkage.

4. Additives or modifier:

Additives and Modifiers perform critical functions despite their relative low quantity by weight when compared to the other ingredients such as resins, reinforcements and fillers. Some additives use in thermoset and thermoplastic composites include: low shrink/low profile (when smooth surfaces are required), fire resistance, air release, emission control, viscosity control, and electrical conductivity.

5. Advantages of FRP

Some of the main advantages of FRP can be listed below:

Low weight: The FRP is much less dense and therefore lighter than the equivalent volume of steel. The lower weight of FRP makes installation and handling significantly easier than steel. These properties are particularly important when installation is done in cramped locations. Other works like works on soffits of Structures and building floor slabs are carried out from man-access platforms rather than from full scaffolding. The use of fibre composites does not significantly increase the weight of the structure or the dimensions of the member. And because of their light weight, the transport of FRP materials has minimal environmental impact.

Mechanical strength:

FRP can provide a maximum material stiffness to density ratio of 3.5 to 5 times that of aluminium or steel. FRP is so strong and stiff for its weight, it can outperform the other materials.

Formability:

The material can take up irregularities in the shape of the concrete surface. It can be molded to almost any desired shape. We can create or copy most shapes with ease. Chemical resistance: FRP is minimally reactive, making it ideal as a protective covering for surfaces where chemical

Joints:

Laps and joints are not required. Corrosion resistance:

Unlike metal, FRP does not rust away and it can be used to make long-lasting structures.

Low maintenance:

Once FRP is installed, it requires minimal maintenance. The materials fibres and resins are durable if correctly specified, and require little maintenance. If they are damaged in service, it is relatively simple to repair them, by adding an additional layer.

Long life:

It has high resistance to fatigue and has shown excellent durability over the last 50 years. Easy to apply: The application of FRP plate or sheet material is like applying wallpaper; once it has been rolled on carefully to remove entrapped air and excess adhesive it may be left unsupported. Fibre composite materials are available in very long lengths while steel plate is generally limited to 6 m. These various factors in combination lead to a significantly simpler and quicker strengthening process than when using steel plate.

III. LITERATURE REVIEW

Several investigators carried out experimental and theoretical investigation on concrete structures with carbon glass-fiber reinforced polymer (CFRP, GFRP, HYBRID) composites to study their effectiveness. Of all materials used as an external plate reinforcement, carbon fiber reinforced polymer (CFRP) and glass fiber reinforced Polymer (GFRP) composite materials have found special favor with engineers and applicators because of their many advantages. After that over a period some researchers started doing their work on hybrid FRP (combine layer of CFRP and GFRP fibers)

HalilSezen et al (2011) conducted an experimental evaluation of axial behavior of strengthened circular RC Columns and they concluded that, concrete jacketing with WWF reinforcement and FRP Wraps increased the axial strength of the un retrofitted or base column by up to 140%, but both methods resulted in brittle failure immediately after the maximum axial capacity was reached.

Balasubramanaian et al (2007), evaluated the performance of the CFRP/GFRP wraps used for retrofitting of the beam and columns and concluded that, the performance of the RC beams was found to have improved after retrofitting using FRP wrapping.

Maria Antonietta Aiello et al (2002) analyses to study the structural behavior of concrete beams reinforced with hybrid fibre-reinforced polymer (FRP) steel reinforced cements. They observe from experiment that the increase of stiffness is more evident for beams reinforced with FRP rebar's place near the outer surface of the tensile zone and steel rebar's place at the inner level of the tensile zone.

Han liangwu et al (2009) studied the properties of high-strength concrete (HSC) circular column confined by Aramid fibre reinforced polymer (AFRP) sheets under axial compression. It was demonstrated that the strength and ductility of the Column with continuous AFRP wrapping increase greatly, various the strength of the column with discontinuous AFRP wrapping also increase, but the ductility not always notably.

Grace et al. (1999) investigated the behaviour of RC beams strengthened with CFRP and GFRP sheets and laminates. They studied the influence of the number of layers, epoxy types, and strengthening pattern on the response of the beams. They found that all beams experienced brittle failure, with appreciable enhancement in strength, thus requiring a higher factor of safety in design. Experimental investigations, theoretical calculations and numerical simulations showed that strengthening the reinforced concrete beams with externally bonded CFRP sheets in the tension zone considerably increased the strength at bending, reduced deflections as well as cracks width (Ross et al., 1999; Sebastian, 2001; Smith &Teng, 2002;

Yang et al., 2003; Aiello &Ombres, 2004). It also changed the behaviour of these beams under load and failure pattern. Most often the strengthened beams failed in a brittle way, mainly due to the loss of connection between the composite material and the concrete. The influence of the surface preparation of the concrete, adhesive type, and concrete strength on the overall bond strength is studied as well as characteristics of force transfer from the plate to concrete. They concluded that the surface preparation along with along with soundness of concrete could influence the ultimate bond strength. Thereafter, Study on de-bonding problems in concrete beams externally strengthened with FRP composites are carried out by many researchers.

Obaidat et al. (2010) studied the Retrofitting of reinforced concrete beams using composite laminates and the main variables considered are the internal reinforcement ratio, position of retrofitting and the length of CFRP. The experimental tests were performed to investigate the behaviour of beams designed in such a way that either flexural or shear failure will be expected. The FEM results agreed well with the experiments when using the cohesive model regarding failure mode and load capacity while the perfect bond model was not able to represent the debonding failure mode. The results showed that when the length of CFRP increases the load capacity of the beam increases both for shear and flexural retrofitting. FEM results also showed that the width and stiffness of CFRP affect the failure mode of retrofitted beams. The maximum load increases with increased width.

Hee Sun Kim (2011) carried on experimental studies of 14 reinforced concrete (RC) beams retrofitted with new hybrid fibre reinforced polymer (FRP) system consisting carbon FRP (CFRP) and glass FRP (GFRP). The objective of this study was to examine effect of hybrid FRPs on structural behaviour of retrofitted RC beams and to investigate if different sequences of CFRP and GFRP sheets of the hybrid FRPs have influences on improvement of strengthening RC beams. The beams are loaded with different magnitudes prior to retrofitting to investigate the effect of initial loading on the flexural behaviour of the retrofitted beam.

Grace et al., (1999) tested five continuous beams. Four different strengthening systems were examined. The first beam was strengthened only for flexure, while the second beam was strengthened for both flexure and shear. The third beam was strengthened with glass fibre reinforced polymer (GFRP) sheets, and the fourth beam was strengthened by using CFRP plates. The fifth beam was fabricated as control beam. All the beams were loaded and unloaded for at least one loading cycle before failure. The use of FRP laminates to strengthen continuous beams was effective for reducing deflections and for increasing their load carrying capacity. It was also concluded that the beams strengthened with FRP laminates exhibit smaller and better distributed cracks.

Grace et al., (2001) investigated the experimental performance of CFRP strips used for flexural strengthening in the negative moment region of a full-scale reinforced concrete beam. They considered two categories of beams (I and II) for flexural strengthening. Category I beams were designed to fail in shear and Category II beams were designed to fail in flexure. Five full scale concrete beams of each category were tested. It was found that Category I beams failed by diagonal cracking with local debonding at the top of the beams, meanwhile Category II beams failed by delamination at the interface of the CFRP strips and the concrete surface, both with and without concrete-cover failure by means shear/tension delamination. When the beams failed, the CFRP strips were not stressed to their maximum capacity, which led to ductile failures in all the beams. The maximum increase of load carrying capacity due to strengthening was observed to be 29% for Category I beams, and 40% for Category II beams with respect to corresponding control beams.

Grace et al., (2005) performed another research work where three continuous beams were tested. One of those beams was considered as the reference beam and conventional ductile flexural failure occurred. They strengthened the other two beams along their negative and positive moment regions around the top and bottom face on both sides as a U-wrap. It was concluded that the strengthened beams with the triaxial fabric showed greater ductility than those strengthened with CFRP sheets.

El-Refaie et al., (2003) examined 11 reinforced concrete (RC) two-span beams strengthened in flexure with external bonded CFRP sheets. Per the arrangement of the internal steel reinforcement, the beams were classified into two groups. Each group included one non-strengthened reference beam. It was noted that, all strengthened beams exhibited less ductility compared with the non-strengthened control beams. An optimum number of CFRP layers were found beyond which there was no further enhancement in the beam capacity. It was also investigated that extending the CFRP sheet length to cover the entire hogging or sagging zones did not prevent peeling failure of the CFRP sheets, which was the dominant failure mode of tested beams.

El-Refaie et al., (2003) tested five reinforced concrete continuous beams strengthened in flexure with external CFRP laminates. All beams had the same geometrical dimensions and internal steel reinforcement. The main parameters examined were the position and form of the CFRP laminates. Three of the beams were strengthened using different lay-up arrangements of CFRP reinforcement, and one was strengthened using CFRP sheets. The performance of the CFRP strengthened beams was compared with a no strengthened reference beam. It was found that, peeling failure was the principal failure mode for all the strengthened tested beams. It was found that the longitudinal elastic shear stresses at the adhesive/concrete interface calculated at beam failure were close to the limiting value recommended in (Concrete Society Technical Report 55, 2000). They also found that, strengthened beams at both sagging and hogging zone produced the highest load capacity

IV. OBJECTIVES

The objectives of the thesis are listed below

- i Evaluation of mechanical properties of FRP composites for flexural loading condition
- ii Characterization of FRP composite materials and selection the suitable resin and reinforcement for the fabrication of composite bridge deck panel as a flexural member
- iii Selection of proper geometrical profile for studies of GFRP bridge deck panels
- iv Fabrication of multi cellular GFRP composite Structures by hand lay-up process

V. MATERIAL SELECTION

GENERAL

FRP composites are a state-of-the-art construction material, an alternative to traditional materials such as concrete, steel and wood. Among many applications of FRP in civil infrastructures, Structures have received much attention because of their light weight, high strength-to-weight ratio, and corrosion resistance. Other advantages of FRP Structures are the reduction in bridge deck construction time and increase in service life. The attractiveness of FRP composites as construction materials derives from a set of advantages gleaned from the tailor ability of this material class through the synergistic combination of fibres in a polymeric resin matrix,

FIBRES

Fibres are the principal constituents in a fibre reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. The effectiveness of fibre reinforcement depends on the type, length, volume fractions and orientation of fibres in the matrix. Proper selection of the fibre is influenced by following characteristics.

- Density
- Tensile and Compressive strength
- MOE
- Fracture
- Fatigue performance
- Response to impact loads
- Electrical and Thermal properties
- Cost

Principal fibres in commercial use for production of civil engineering applications are

- Carbon
- Aramid
- Glass fibres

E-glass fibres have been employed. A brief description about its composition, advantages, and properties are presented below.

GLASS FIBRES

The most extensively used class of fibres in composites are those manufactured from E-glass. E-glass is a low alkali borosilicate glass originally developed for electrical insulation applications. It was first produced commercially for composite manufacture in 1940's, and its use now approaches 2 MT per year worldwide. Many different countries manufacture E-glass and its exact composition varies according to the availability and composition of the local raw materials. It is manufactured as continuous filaments in bundles, or strands, each containing typically between 200 and 2000 individual filaments of 10-30 µm diameters. These strands may be incorporated into larger bundles called roving and may be processed into a wide variety of mats, clothes, and performs and cut into short-fibre formats. Glass filaments have relatively low stiffness but very high tensile strength (~3GPa).

REINFORCEMENT FORMAT

The reinforcement fibres are generally available in the form of a tow, or in a band. In some processing operations (e.g. filament winding), tows, or rovings, of continuous fibres are converted directly into the component. Following forms of GFRP are generally available:

1. CSM (Emulsion)
2. CSM (Powder)
3. WR
4. Spray - up Rovings
5. SMC Rovings
6. Assembled Rovings
7. Direct Roving

Woven Rovings

Woven clothes and rovings are very widely used in the manufacture of laminated structures. A simple plain weave WR allows a Vf of up to 0.6 to be achieved in the laminate. Five and eight-harness satin weaves are widely used in composite laminates, especially in the lighter weights, which are more appropriate in many highly stressed designs. The tighter fibre structure in cloths renders them more difficult to infiltrate and consolidate than the random mats. WR fabrics are specifically designed to meet most demanding performance, processing and cost requirements. These fabrics deliver a unique combination of properties..

Figure 4.1: Woven rovings

Chopped Strand Mat (Emulsion)

Chopped strands are produced by cutting continuous strands into short lengths.. Strands of high integrity are called “hard” and those that separate more readily are called “soft”. Longer strands are mixed with a resinous binder and spread in a two dimensional random fashion to form CSMs. Thus a CSM is made up of random yet evenly distributed strands chopped from continuous “E” Glass fibres into 50mm length and bonded with “Emulsion binder”. It possesses excellent surface bonding efficiency. These mats are suitable for hand lay - up mouldings and provide nearly equal properties in all directions in the plane of the structure. Figure 4.2 shows a typical CSM.

Figure 4.2: CSM 450 E gsm MAT

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.

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:

- Reduce cost (Since most filler are much less expensive than the matrix resin)
- Increase modulus
- Reduce mould shrinkage
- Control viscosity
- Produce smoother surface

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.

Table 4.1 Properties of E-Glass Fibre, ISO and ER

Properties	E – Glass Fibre	ISO	ER
MOE, (in N/ mm²)	72400	3450	5000
Volume fraction, V	33.34%	66.68%	66.68%
Poisson's ratio,	0.22	0.33	0.3

VI. METHODOLOGY

GENERAL

Most modern short span Structures have concrete decks. In general, they are efficient and durable provided proper attention is paid to detailing and the standard of workmanship. Concrete is likely to be the most common deck material for some considerable time. However, some concrete Structureshave suffered corrosion, due in part to the increasing use of de-icing salts. As there is unlikely to be an economically viable replacement for rock salt for de-icing, increasing interest is being shown in materials that are corrosion resistant. In addition, rapid growth in the volume and weight of heavy goods vehicles has led to serious problems and many older Structures no longer meet current design standards.

There is, therefore, a need for methods of replacing Structuresto deal with structural deterioration and to increase load carrying capacity without extensive and expensive bridge works. It is known that the use of FRP as a primary structural material is developing rapidly in the construction industry. This chapter presents the details of flexural studies on GFRP member by employing chosen cross sectional profile. Various aspects such as design, fabrication, methodology of testing and the outcome of the study are presented in this chapter.

EXPERIMENTAL INVESTIGATIONS

Preliminary studies have been carried out on open and closed sections of GFRP purlins and steel purlins with the primary objective of assessing the suitability of GFRP as a flexural member. GFRP purlins of the following cross sections have been investigated under two point loading condition. The load cell of 50 kN capacity is used.

I section

Channel section

Angle section

Hollow rectangular section

VII. FINITE ELEMENT ANALYSIS OF GFRP GENERAL

Experimental investigations on the other hand are more suitable for strength/capacity assessment studies through destructive testing. However, such tests seldom consider the entire structure due to equipment limitations and associated costs. Furthermore, parametric studies in experimental procedures are time consuming and prohibitively expensive. Computer simulations based on advanced methods, such as the FEM, are reliable and cost effective alternatives in structural analysis for the study of structural response and performance. FEM procedures have been successfully employed in research studying the performance of FRP Structuresor their components. The general purpose finite element software ANSYS or ABAQUS can be used for the modelling and analysis of multicellular FRP composite Structures with different cross sectional profiles and that has many analytical capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear and transient dynamic analysis. In this study the finite element software ANSYS is used for the modelling and analysis of multicellular FRP bridge deck panels. A preliminary analysis was carried out on models created using ANSYS by taking IRC class A loading, to optimize the cross sectional profile that can be used for the fabrication of the experimental models.

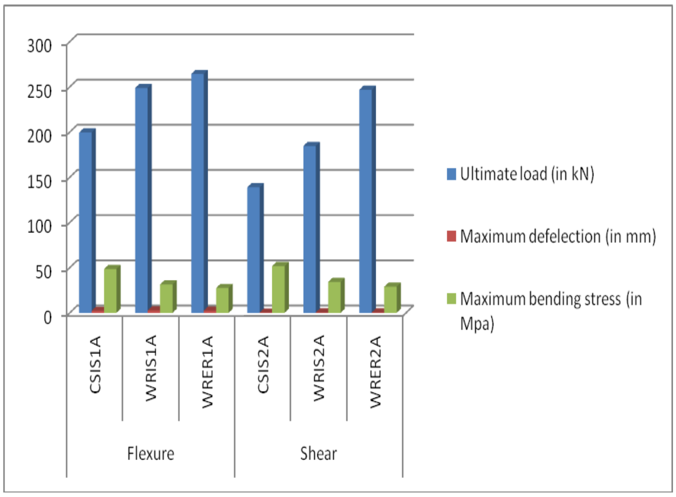
PERFORMANCE CRITERIA

From the literature review, it has been observed that the design of GFRP Structures is driven by stiffness and hence maximum deflection is the governing criteria in design. The loads imposed on the Structures 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.

The best cross section is arrived at based on the mathematical model of GFRP bridge deck developed by using ANSYS. Since bending stress is low, the deflection is considered as a parameter for further studies.

Table 6.1 Ultimate Load and Maximum deflection from ANSYS

	Models	**Ultimate Load, (in kN)**	**Maximum Deflection, (in mm)**	**Maximum Bending Stress (in Mpa)**
Flexure	CSIS1A	199.5	2.23	48.5
	WRIS1A	248.8	2.56	31.4
	WRER1A	264.2	2.34	27.5
Shear	CSIS2A	138.9	0.33	51.7
	WRIS2A	184.5	0.44	34.2
	WRER2A	246.8	0.38	28.9



Graph 6.1 Ultimate Load and Maximum deflection from ANSYS

The experimental observations are mainly included the measurement of deflections which will indirectly indicates the strength / stiffness of the member.

CONCLUSION

After its first introduction to the civil engineering field, especially for retrofit and rehabilitation purposes, significant amount of research has been conducted to develop and evaluate the concepts of flexural and axial strengthening of concrete structures with FRP materials, but limited investigations have been conducted on the use of FRP for shear strengthening. Although several analytical models have been proposed for predicting the shear contribution of externally bonded FRP, due to insufficient experimental data, these models were not calibrated accurately and hence produced diverse or in many cases contradictory estimates. As the number, experimental results increase, these models can be recalibrated to produce more reliable results.

FRP as strengthening and retrofitting material has several advantages over conventional materials. Its thickness is small and hence its application does not add weight to existing structures. It helps to preserve the cultural heritage of monumental structures. It is not corrodable.

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