Analytical Study on Various Types of FRP Beams by using AVSYS

***A.Vijayakumar, **Dr.D.L.Venkatesh babu, ***R. Jayaprakash**
*(Assistant Professor, Department of Civil Engineering, Jansons Institute of Technology, Coimbatore, Tamilnadu, India)
** (Principal, United Institute of Technology, Coimbatore, Tamilnadu, India)
*** (PG student, Department of Civil Engineering, Tamilnadu College of Engineering, Coimbatore, Tamilnadu, India)

ABSTRACT

Fibre reinforced polymer (FRP) is one of the best retrofitting materials for strengthening due to a number of advantages, such as excellent strength to self-weight ratio, large fatigue resistance capacity, etc. Presently, many different types of FRP models are used in analysis, thereby creating erroneous analytical results. Reinforced concrete (RC) beams with carbon and glass fibre-reinforced polymer (CFRP and GFRP) composites offer an attractive solution to enhance the behaviour of concrete in terms of strength and ductility, as well as altering the mode of rupture of such structural members. However, very little is known about their performance. Thus, this paper presents to investigate the behaviour of FRP beams. In order to calculate the bending moment, the model considers an exponential function in the stress–strain diagram of RC in both tension and compression parallel to the fibres. A four-point bending test configuration was conducted as short-term experiments to determine the load–displacement relationships of RC beams with CFRP and GFRP sheets/plates adhered to the tensile side. Therefore, this study is carried out to assess and to compare a comprehensive finite element analytical model of FRP that can properly consider the properties of FRP as a retrofit material. After reviewing available FRP models currently used by researchers in the field, two analytical FRP models are selected to assess the behaviour of FRP sheet /plate to concrete structure; using the selected FRP models, noise analysis of FRP sheet and FRP is carried out to confirm mesh sensitivity for convergence. In addition, finite element analysis of FRP RC beam is under performed to select the most appropriate FRP model and to validate the analysis technique. All of the analysis results for four selected FRP models are compared to verify and select the optimum model. Finally, a discussion about the study results with respect to code response criteria is presented.

Key words: Bending moment, Ductility, Fibre reinforced polymer, Retrofitting, Strength.

1. Introduction

The maintenance, rehabilitation and upgrading of structural members, are perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget. Structural strengthening may be required due to many different situations.

Investigation of the behaviour of FRP retrofitted reinforced concrete structures has in the last decade become a very important research field. In terms of experimental application several studies were performed to study the behaviour of retrofitted beams and how various parameters influence the behaviour.

The effect of number of layers of CFRP on the behaviour of a strengthened RC beam was investigated [1]. They tested simply supported beams with different numbers of CFRP layers. The specimens were subjected to a four-point bending test. The results showed that the load carrying capacity increases with an increased number of layers of carbon fibre sheets.

Investigation of the effect of internal reinforcement ratio on the behaviour of strengthened beams has been performed [2]. Specimens with different internal steel ratio were strengthened in flexure by CFRP sheets. The authors reported that the flexural strength and stiffness of the strengthened beams increased compared to the control specimens. With a large reinforcing ratio, they also found that failure of the strengthened beams occurred in either interfacial debonding induced by a flexural shear crack or interfacial debonding induced by a flexural crack.

A test programme on retrofitted beams with shear deficiencies was done [3]. The experimental results indicated that the contribution of externally bonded CFRP to the shear capacity of continuous RC beams is significant.

There are three main categories of failure in concrete structures retrofitted with FRP that have been observed experimentally [4 - 6]. The first and second type consist of failure modes where the composite action between concrete and FRP is maintained.

Typically, in the first failure mode, the steel reinforcement yields, followed by rupture of CFRP as shown in Fig 1(a). In the second type there is failure in the concrete. This type occurs either due to crushing of concrete before or after yielding of tensile steel without any damage to the FRP laminate, Fig 1(b), or due to an inclined shear crack at the end of the plate, Fig 1(c). In the third type, the failure modes involving loss of composite action are included. The most recognized failure modes within this group are debonding modes. In such a case, the external reinforcement plates no longer contribute to the beam strength, leading to a brittle failure if no stress redistribution from the laminate to the interior steel reinforcement occurs.

Fig 1(d)-(g) show failure modes of the third type for RC beams retrofitted with FRP. In Fig 1(d), the failure starts at the end of the plate due to the stress concentration and ends up with debonding propagation inwards. Stresses at this location are essentially shear stress but due to small but non-zero bending stiffness of the laminate, normal stress can arise.

Fig 1(e) the entire concrete cover is separated. This failure mode usually results from the formation of a crack at or near the end of the plate, due to the interfacial shear and normal stress concentrations. Once a crack occurs in the concrete near the plate end, the crack will propagate to the level of tensile reinforcement and extend horizontally along the bottom of the tension steel reinforcement. With increasing external load, the horizontal crack may propagate to cause the concrete cover to separate with the FRP plate. In Fig 1(f) and (g) the failure is caused by crack propagation in the concrete parallel to the bonded plate and adjacent to the adhesive to concrete interface, starting from the critically stressed portions towards one of the ends of the plate. It is believed to be the result of high interfacial shear and normal stresses concentrated at a crack along the beam. Also mid span debonding may take concrete cover with it.

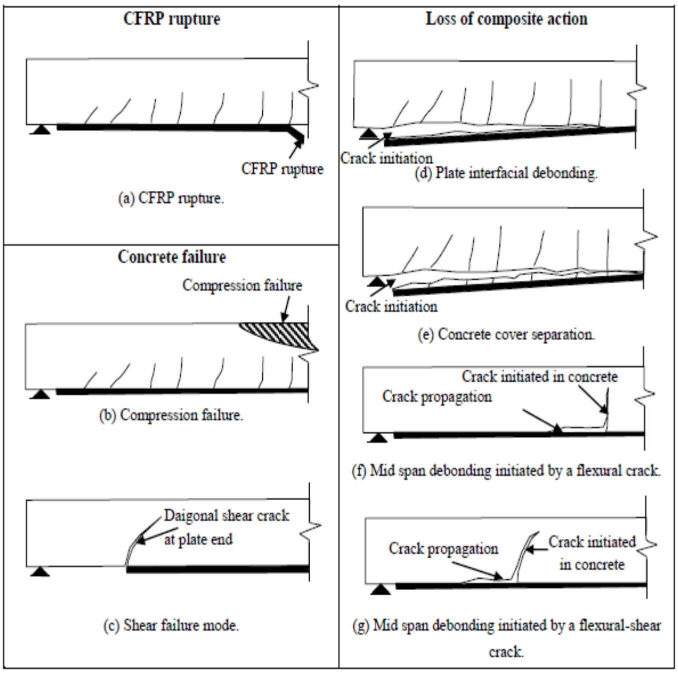


Figure 1: Failure modes in beam retrofitted in flexure.

Researchers have observed new types of failures that can reduce the performance of CFRP when used in retrofitting structures [7]. These failures are often brittle, and include debonding of concrete layers, delamination of CFRP and shear collapse. Brittle debonding has particularly been observed at laminate ends, due to high concentration of shear stresses at discontinuities, where shear cracks in the concrete are likely to develop [8]. Thus, it is necessary to study and understand the behaviour of CFRP strengthened reinforced concrete members, including those failures. Several researchers have simulated the behaviour of the concrete– CFRP interface through using a very fine mesh to simulate the adhesive layer defined as a linear elastic material [9]. However, they have not used any failure criterion for the adhesive layer. Most researchers who have studied the behaviour of retrofitted structures have, however, not considered the effect of the interfacial behaviour at all [10].

The selection of the most suitable method for strengthening requires careful Consideration of many factors including the following engineering issues:

- Magnitude of strength increase;
- Effect of changes in relative member stiffness;

- Size of project (methods involving special materials and methods may be less cost-effective on small projects);
- Dimensional/clearance constraints (section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space);
- Environmental conditions (methods using adhesives might be unsuitable for applications in high-temperature environments, external steel methods may not be suitable in corrosive environments);
- In-place concrete strength and substrate integrity (the effectiveness of methods relying on bond to the existing concrete can be significantly limited by low concrete strength)
- Accessibility
- Operational constraints (methods requiring longer construction time might be less desirable for applications in which building operations must be shut down during construction)
- Availability of materials, equipment, and qualified contractors
- Construction cost, maintenance costs, and life-cycle costs; and
- Load testing to verify existing capacity or evaluate new techniques and materials.

1.2 Objective and Scope of the present work

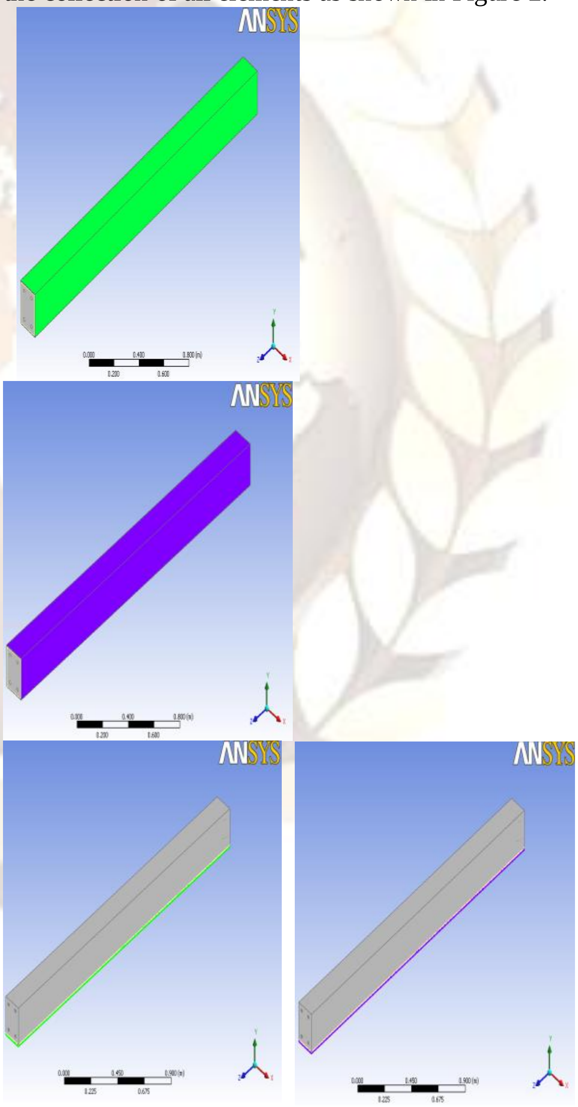
The purpose of this paper is to provide analytical data on the response of RC beams strengthened in shear using GFRP sheets/plates and CFRP sheets/plates. The analytical program aimed at raising the strength of the shear deficient beams to that of the fully strengthened by GFRP sheets/plates and CFRP sheets/plates to provide single layer wrapping for beams. The analysis aimed at understanding the best wrapping style for retrofitting the deficient beams. The objective of this investigation is to study the effectiveness of CFRP sheets/plates and GFRP sheets/plates supplied by Fibre Reinforced Systems (FRS) in increasing the flexural strength of concrete beams.

The objective is achieved by conducting the following tasks: (i) Flexural testing of concrete beams strengthened with single layers of GFRP sheets/plates and CFRP sheets/plates. (ii) Calculating the effect of single layers of GFRP sheets/plates and CFRP sheets/plates on the flexural strength. (iii) Evaluating the failure modes (iv) Developing an analytical procedure to calculate the flexural strength of concrete beams strengthened with FRP composites (v) comparing the two different experimental and analytical results.

In the scope of the present study to FEM modelling of the control RCC beam under the static point loads have been analyzed using ANSYS software and the results so obtained have been compared to available GFRP/CFRP sheets and plates result from the work done. Finally, comparison between the analytical results and experimental results the salient conclusion and recommendations of the present study.

2. Finite Element Modelling

The basic concept of FEM modelling is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions or at a set of nodal points. The response of the mathematical model is then considered to be the discrete model obtained by connecting or assembling the collection of all elements as shown in Figure 2.



CFRP-Sheet GFRP-Sheet
CFRP-Plate GFRP-Plate

Figure 2 Various Configuration of the beam elements

2.1 Material Models

The program system ANSYS offers a variety of material models for different materials and purposes. The most important material models in ANSYS for RCC structure are concrete and reinforcement. These advanced models take into account all the important aspects of real material behaviour in tension and compression. In this study; the GFRP/CFRP material modelling used for retrofitted RCC beams.

2.2 Material Properties

DESCRIPTION	GFRP SHEET	GFRP PLATE	CFRP SHEET	CFRP PLATE	ADHESSIVE EPOXY RESIN	CONCRETE
THICKNESS/ SIZE	4mm	12mm	4mm	12mm	2mm	150mm x 230mm
DENSITY	2000 kg/m^3	1600 kg/m^3	1900 kg/m^3	1300 kg/m^3	1050 kg/m^3	2400 kg/m^3
YOUNG'S MODULUS	70 GPa	50 GPa	200 GPa	100 GPa	3 GPa	23 GPa
POISSON'S RATIO	0.26	0.28	0.22	0.26	0.35	0.2

2.3 Concrete Modelling

Solid65 element was used to model the concrete. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. A schematic of the element is shown in Figure3. Same cracking approach has been used in modelling the concrete in the present study.

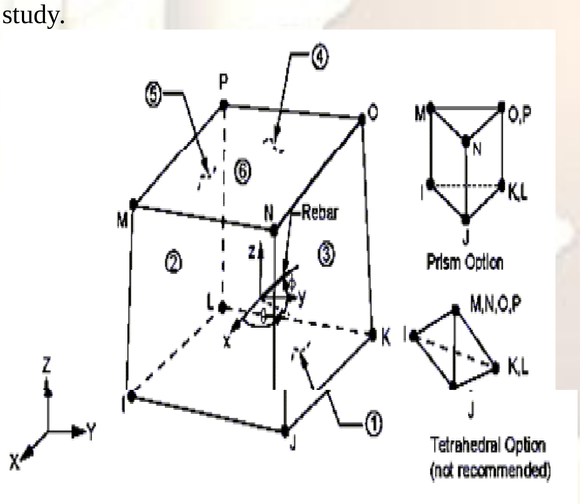


Figure 3 Solid65 element geometry

2.4 Reinforcement Modelling

Modelling of reinforcing steel in finite elements is much simpler than the modelling of concrete. A Link8 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions. This element is also capable of plastic deformation. This element is shown in Figure4. A perfect bond between the concrete and steel reinforcement considered. However, in the present study the steel reinforcing was connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes. The same approach was adopted for FRP composites.

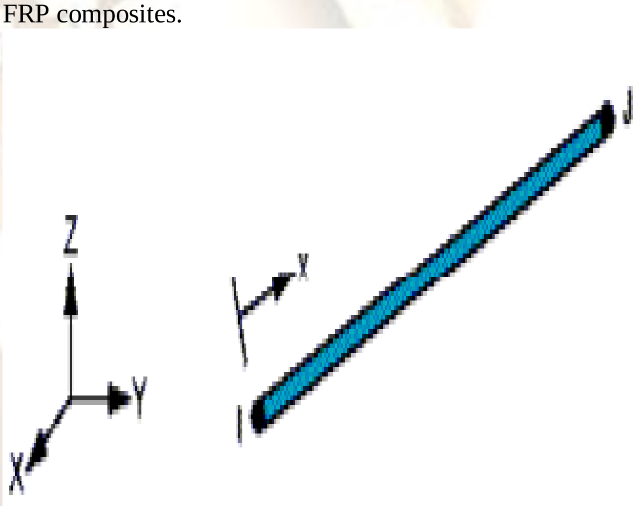


Figure 4 Link8 element geometry.

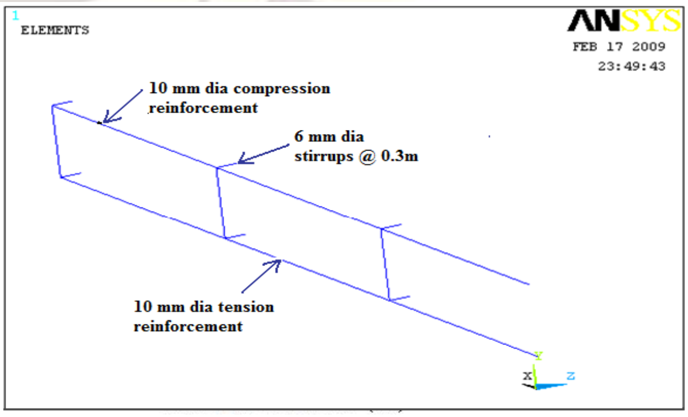


Figure 5 Geometry of the reinforcement

2.5 FRP Plate

FRP plates were added at support and loading locations in the finite element models (as in the actual beams) in order to avoid stress concentration problems. An elastic modulus equal to 50,000 N/mm^2 to 100,000 N/mm^2 and Poisson's ratio of 0.28 were used for the plates. The steel plates were assumed to be linear elastic materials. A Solid 45 element was used to model steel plates.

2.6 FRP Laminates

FRP composites are materials that consist of two constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent is the reinforcement, which is embedded in the second constituent, a continuous polymer called the matrix. The reinforcing material is in the form of fibres, i.e., carbon and glass, which are typically stiffer and stronger than the matrix. The FRP composites are orthotropic materials; that is, their properties are not the same in all directions.

3. Numerical Analysis

In order to validate the numerical representation of the reinforced concrete beams strengthening with fibre reinforced polymer composites, the finite elements representation using ANSYS program has been applied to practical sections and the results will be compared with the experimental results reported by previous researches.

Numerical analysis is performed using the ANSYS finite element program to predict the deflection of rectangular reinforced concrete beam strengthened by fibre reinforced plastics applied at the bottom of the beam. In the numerical analyses, simply supported reinforced concrete beam is considered. Three-dimensional finite element model was developed to examine the structural behaviour of the strengthened beam. A quarter of the full beam was used for modelling by taking advantage of the symmetry of the beam and loadings. See Figure 6 to 9.

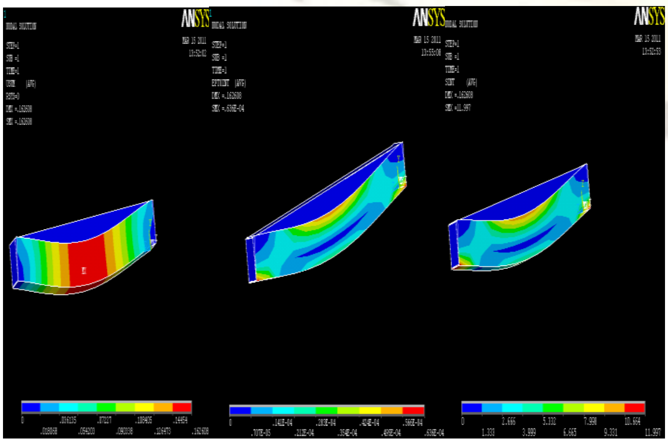


Fig.6.(a) CFRP-Plate Fig.6.(b) CFRP-Plate Fig.6.(c) CFRP-Plate
Deflection Strain Stress

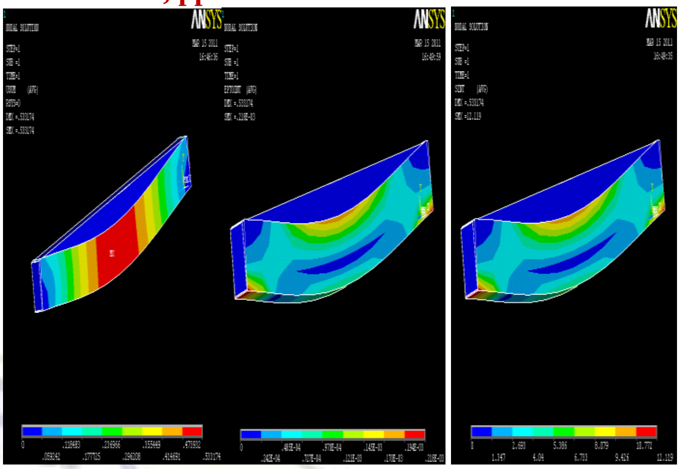


Fig.7.(a) CFRP-Sheet Fig.7.(b) CFRP-Sheet Fig.7.(c)CFRP-heet Deflection Strain Stress

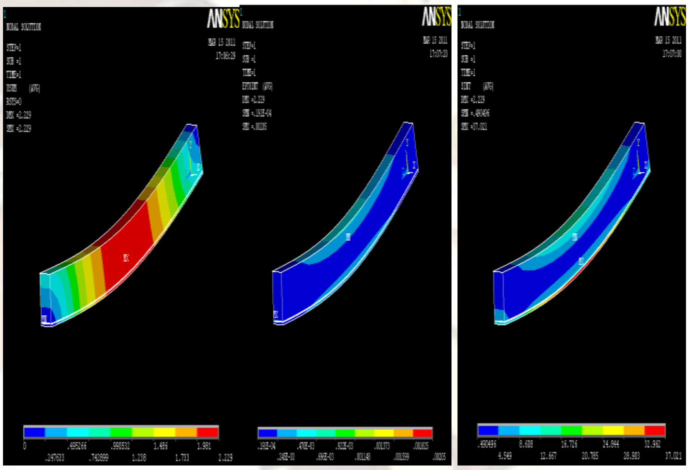


Fig.8.(a) GFRP-Plate Fig.8.(b) GFRP-Plate Fig.8.(c) GFRP-Plate Deflection Strain Stress

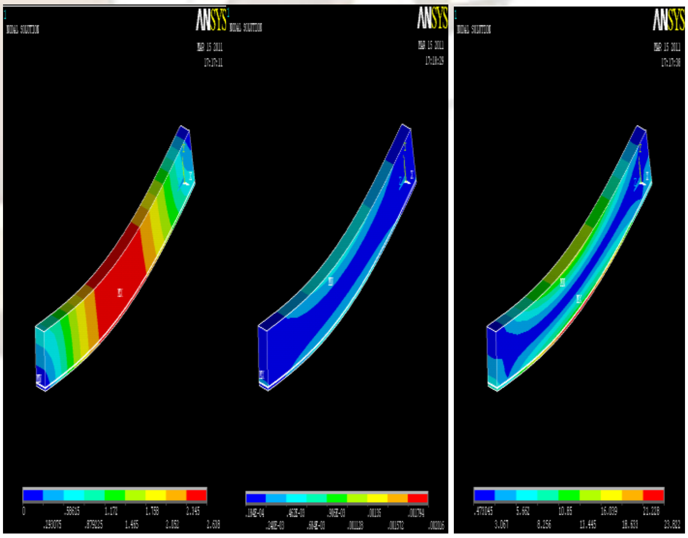


Fig.9.(a) GFRP-Sheet Fig.9.(b) GFRP-Sheet Fig.9.(c) GFRP-Sheet Deflection Strain Stress

4. Discussion of Results

4.1 Load Deflection Curve

The experimental and numerical load-deflection curves obtained for the beams are illustrated in Figure 10 and 11. The curves show good agreement in finite element analysis with the experimental results throughout the entire range of behaviour and failure mode, for all beams the finite element model is stiffer than the actual beam in the linear range. Several factors may cause the higher stiffness in the finite element models.

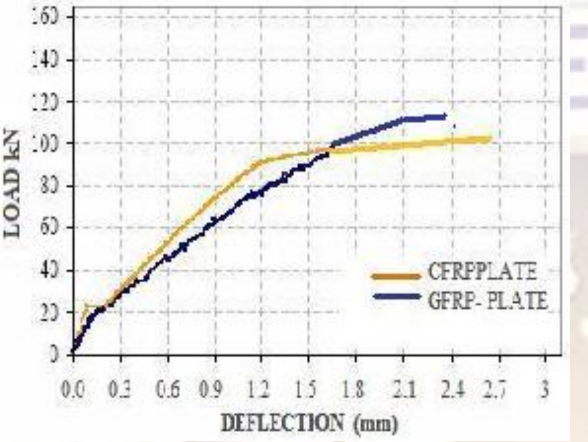


Fig.10. Deflection Curve for GFRP/CFRP-Plate bonded Beams

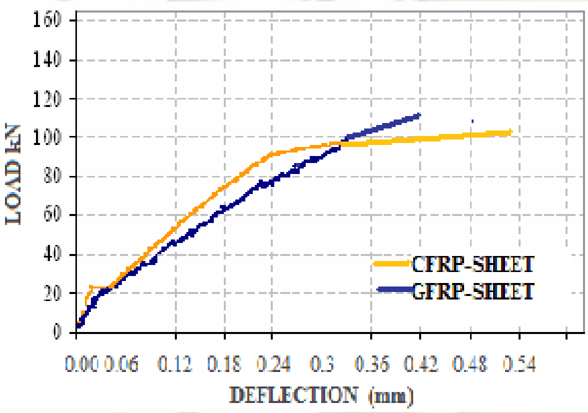


Fig.11. Deflection Curve for GFRP/CFRP- Sheet Wrapped Beams.

5. Conclusions

The numerical solution was adopted to evaluate the ultimate shear strength of the reinforced concrete beams reinforced with FRP laminates in simple, cheap and rapid way compared with experimental full scale test. The general behaviours of the finite element models show good agreement with observations and data from the experimental full-scale beam tests. The addition of FRP reinforcement to the control beam shifts the behaviour of the control beams from shear failure near the ends of the beam to flexure failure at the mid span. The results obtained demonstrate that carbon fibre polymer is efficient more than glass fibre polymer in strengthening the reinforced concrete beams for shear.

REFERENCES

1. Esfahani, M., Kianoush, M., & Tajari, A. Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets. Engineering Structures 2007; 29: 2428-2444.
2. Pham, H., & Al- Mahaidi, R. Experimental investigation into flextural retrofitting of reinforced concrete bridge beams using FRP compoistes. Composite Structures 2004; 66: 617-625.
3. Camata, G., Spacone, E., & Zarnic, R. Experimental and nonlinear finite element studies of RC beams strengthened with FRP plates. Composites: Part B 2007; 38: 277-288.
4. Coronado, C. A., & Lopez, M. M. Sensitivity analysis of reinforced concrete beams strengthened with FRP laminates. Cement and Concrete Composites 2006; 28: 102-114.
5. Ebead, U., & Marzouk, H. Tension - stiffening model for FRP strengthend RC concrete two-way slab. Materials and Structures 2004; 193-200.
6. Lundquist, J., Nordin, H., Täljsten, B., & Olafsson, T. Numerical analyis of concrete beams sterengthened with CFRP- A Study of anchorage lengths. In: FRP in Construction, Proceeding of The International Symposium of Bond Behaviour of FRP in Structures. 2005; 247-254.
7. Esfahani M, Kianoush M, Tajari A. Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets. Eng Struct 2007; 29:2428–44.
8. Teng JG, Smith ST, Yao J, Chen JF. Intermediate crack-introduced debonding in beams and slabs. Construct Build Mater J 2003;17(6–7):447–62.
9. Hu H-T, Lin F-M, Jan Y-Y. Nonlinear finite element analysis of reinforced concrete beams strengthened by fibre-reinforced plastic. Compos Struct J 2004; 63:271–81.
10. Lundquist J, Nordin H, Täljsten B, Olafsson T. Numerical analysis of concrete beams strengthened with CFRP – a study of anchorage lengths. In: FRP in construction, Proceeding of the international symposium of bond behaviour ofFRP in structures; 2005. p. 247–54.