

Shear Capacity of Concrete with Elastic FRP Reinforcement

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ABSTRACT: This paper presents an investigation of the shear capacity of elastic fibers reinforced concrete beams consisting of various types and combinations of fibers. The application of fibre-reinforced polymer (FRP) composites for strengthening structural elements has become an efficient option to meet the increased cyclic loads or repair due to corrosion or fatigue cracking. Hence, the objective of this study is to explore the existing FRP reinforcing techniques to care for damaged structural beam elements. The use of Fiber Reinforced Polymer (FRP) bars to reinforce concrete structures has received a great deal of interest in recent days due to their high tensile strength, corrosion resistance and good non-magnetization property. Whether to pick FRP bars due to their low modulus of elasticity over conventional steel, to be used in beams, is the major concern of a designer. FRP bars show low strength in shear as they are more elastic than steel. Recently, researchers have developed a number of models to predict the shear strength of FRP-reinforced concrete, but none of them have yet been capable of determining the results satisfactorily. Here a comparative study among different codes and models as suggested by the researchers has been conducted to predict the shear strength of FRP reinforced concrete beams. To facilitate the comparison a database of beams has been presented, which are collected of shear span-to-depth ratio, a/d ranged. The accuracy of the hardening model with variable strain ranges, which were simulated using ABAQUS software, was verified using the experimental results.

KEYWORDS: Fiber Reinforced Polymer (FRP), ABAQUS software

I. INTRODUCTION

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. Additional strength may be needed to allow for higher loads to be placed on the structure. Strengthening may be needed to allow the structure to resist loads that were not anticipated in the original design. Fiber reinforced polymer (FRP) has been widely used in concrete structure reinforcement due to its high strength, light weight and good durability. Now the main form of FRP materials are sheets and plates, which are usually externally bonded on the surfaces of the structure members. This outwardly bonded FRP needs the reinforced members to provide flat and continuous surfaces for the strengthening. In addition, FRP shall be pasted according to the stress direction of the strengthened member. When it is used for structural components with complex appearance such as beam-column joints, there are some problems such as construction difficulty, poor bonding quality and poor constraint effect. External bonding of FRP composites constitutes a popular technique to strengthen concrete structures worldwide. Two types of debonding failure are commonly observed in strengthened RC members:

- Sheet-end
- Intermediate crack induced debonding.

The use of externally bonded fiber reinforced polymer (FRP) reinforcement to strengthen RC structures is becoming an increasingly popular retrofit technique. The light weight and formability of FRP reinforcement make these systems easy to install. And since the materials second-hand in these systems are non-corrosive, non-magnetic, and generally resistant to chemicals, they are a brilliant option for external reinforcement. FRP is a composite material generally consisting of carbon, aramid, or glass fibers in a polymeric matrix (e.g. epoxy resin). Among many options, this reinforcement may be in the appearance of preformed laminates or flexible sheets. The laminates are stiff plates or shells that come pre-cured and are installed by bonding the plate to the concrete surface with epoxy. The sheets are either dry or pre-impregnated with resin (pre-preg) and cure after installation onto the concrete surface. This installation technique is known as wet lay-up. The use of externally bonded fiber reinforced polymer (FRP) reinforcement to strengthen RC structure is becoming an increasingly popular retrofit technique. The light weight and formability of

FRP reinforcement make these systems easy to install. And since the materials used in these systems are non-corrosive, non-magnetic, and normally resistant to chemicals, they are an excellent option for external reinforcement.

1.1 Fibre Reinforced Concrete

Fiber Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Fiber reinforced concrete is of different types in addition to properties with many advantages. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers. Fiber is a small piece of reinforcing material possessing certain characteristics properties. They be capable of be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fiber is the relative amount of its length to its diameter. Typical aspect ratio ranges from 30 to 150. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed in addition to randomly oriented. Fibers include steel fibers, glass fibers, and synthetic fibers in addition to natural fibers. Within these dissimilar fibers that character of fiber reinforced concrete changes with varying concretes, fiber resources, geometries, distribution, orientation and densities.

1.2 Necessity of Fiber Reinforced Concrete

1. It increases the tensile strength of the concrete.
2. It reduces the air voids and water voids the inherent porosity of gel.
3. It increases the durability of the concrete.
4. Fibres such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibres have a significant influence on the creep performance of rebars/tendons.

1.3 Research Methodology

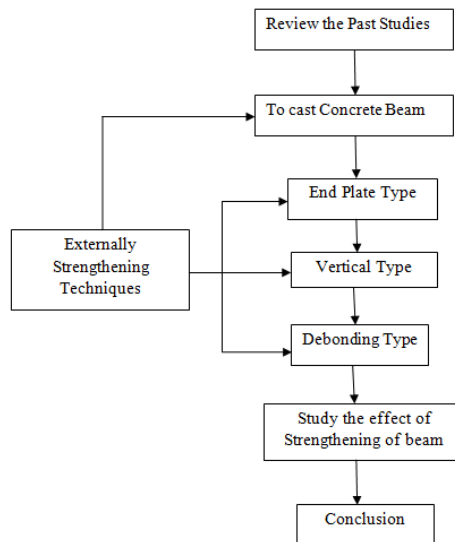


Fig.1: Flowchart Of Methodology

This methodology is an attempt to study the effect of CFRP strengthened RC beams under four point bending test. Two categories of beams are casted such as normal beam and second and strengthened beam. Each category of the beams is designed to measure the effect of CFRP on flexural strengthening. Failure prototype of the beams are also shown and compared with available models. CFRP sheets are applied at the bottom of the beams for various techniques such as end plate type, vertical, debonding type of FRP sheet assuming minimum exposure of the structural member. At the end, it is found effect of strengthening beam and ultimate strength significantly.

II. LITERATURE REVIEW

- **Numerical Study on FRP Retrofitted RC Beam Suffering From IC Debonding, Apr 2019.**

Fiber reinforced plastic (FRP) also called fiber reinforced polymer. It is a composite material made of polymer matrix reinforced with fibers. The fibers are usually glass, carbon, agamid, and basalt. FRP are commonly used in the aerospace, automotive, marine and construction industries. Fiber Reinforced Polymer (FRP) plates can be bonded to the tension face of a reinforced concrete beam to increase its flexural capacity. Many studies have been done and found that premature failure by deboning of the FRP plate occur before reaching the ultimate flexural capacity of the plated section and the most commonly reported deboning failure mode is commonly referred to as intermediate crack induced due to interfacial deboning or simply intermediate crack (IC) deboning.

- **Size Effect on the Shear Failure of High-Strength Concrete Beams Reinforced with Basalt FRP Bars and Stirrups, 2019.**

Six large-scale high-strength concrete beams reinforced with basalt fiber reinforced polymer (BFRP) bars and stirrups and three corresponding beams without stirrups were constructed and tested for shear failure under four-point bending. The main parameters considered were the beam effective depth (300, 500, and 700 mm) and the stirrup spacing. The test results indicated that the size effect on shear failure could not be eliminated completely, as the initial shear crack, shear crack width, shear resistant components analysis, strain in the BFRP stirrups, and normalized shear strength were still related to the beam depth. The ACI 440-15 strain limit of 4000 ms could be relaxed with the condition that the serviceability requirement is satisfied. Furthermore, based on a collected database from the literature, an accurate and conservative equation was proposed to predict the FRP stirrup strain limit. The proposed equation includes the effects of all influencing parameters, which is more reasonable than the constant strain limit used by most design codes.

- **Double Shear Test on Bonding Mechanical Properties of Sprayed FRP and Concrete Substrate, 2019.**

To study the bonding mechanical properties of the interface between sprayed FRP and concrete substrate, seven double shear specimens were made to do the double shear tests. The failure mode, load and deformation, shear strength and deformation, distribution of strain and stress were studied. Furthermore, the influence of three main factors including fiber volume ratio, thickness of sprayed FRP and bonding length were analyzed in the paper as well. The results show that the thickness of sprayed FRP and bonding length have great influence on the bonding mechanical properties, while fiber volume ratio has little. The bonding interface that participate in bearing shear load can only develop to a certain length and then move from loading end to the other end with the development of debonding. The study can provide reference to the further research on sprayed FRP material used in concrete structure reinforcement.

- **Contribution of Externally Bonded FRP to Shear Capacity of Flexural Members, 1998.**

Fiber reinforced polymer (FRP) materials are continuing to show great promise for use in strengthening reinforced concrete (RC) structures. These materials are an excellent option for use as external reinforcing because of their light weight, resistance to corrosion, and high strength. Externally bonded FRP sheets have been used to increase moment capacity of flexural members and to improve confinement in compression members. Investigations into the use of externally bonded FRP sheets for use in shear strengthening have also been conducted and have shown this to be a viable strengthening method. The objective of this study is to review the current research on shear strengthening with FRP and propose design algorithms to compute the contribution of FRP to the shear capacity of RC flexural members. Methods for computing the shear capacity based on the stress level to cause tensile fracture of the FRP sheet and based on delaminating of the sheet from the concrete surface are presented. Areas which have the potential for further development are also discussed.

III. METHODOLOGY

1) Externally Bonded FRP to Shear Capacity of Flexural Members

The behavior of externally bonded FRP sheets used to increase the moment capacity of flexural members. One limit to increasing the moment capacity is that eventually the shear capacity of the member is exceeded. In these situations, it has been shown that externally bonded FRP sheets may be used to increase the shear capacity as well. However, few studies have specifically addressed shear strengthening and design algorithms for computing the shear contribution of FRP sheets are not yet clear. One of the difficulties with defining the shear contribution of FRP sheets is the wide variety of possible FRP shear reinforcement configurations. Figure 3.1 shows several of these configurations. There are options in deciding which surfaces will be bonded (Figure 3.1-a), whether to use continuous reinforcement or a series of strips (Figure 3.1-b), and whether mechanical anchorage is necessary (Figure 3.1-e). In addition, FRP is an

anisotropic material characterized by high strength in the direction of the fiber orientation. The fibers may, therefore, be oriented in directions to best reinforce shear cracks (Figure 3.1-c) or it may be beneficial to create pseudo-isotropy by orienting the fibers in two perpendicular directions (Figure 1-d). The aim of this study is to review the current research on shear strengthening with bonded FRP reinforcement and to present simple design algorithms for computing the contribution of FRP to shear strength of RC members. The research focuses on carbon FRP (CFRP) and seeks to address several of the CFRP shear reinforcement configurations. The current procedures do not address every aspect of FRP shear reinforcement, however research into comprehensive design procedures is continuing at the University of Missouri – Rolla (UMR).

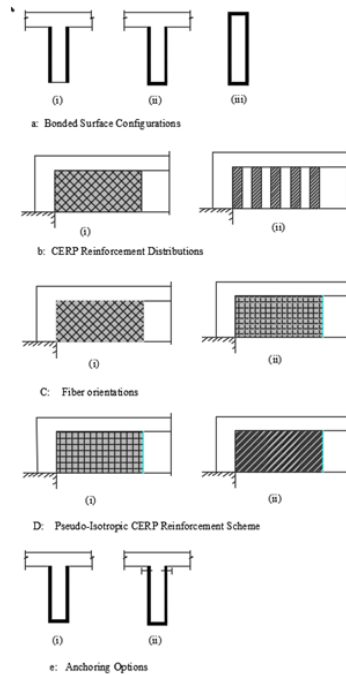


Fig.2: FRP Shear Reinforcement Configurations

➤ **Shear Strength of RC Beams Strengthened with FRP Reinforcement**

The nominal shear strength of a RC beam may be computed by the basic design equation presented in ACI 318-95 and given below as Equation (1).

$$V_n = V_c + V_s \dots \dots \dots (1)$$

Where,

V_n = Nominal shear strength

V_s = Nominal shear strength provided by steel shear reinforcement

V_c = Nominal shear strength provided by concrete

In this equation the nominal shear strength is the sum of the shear strength of the concrete (which for a cracked section is attributable to aggregate interlock, dowel action of the longitudinal reinforcement, and the diagonal tensile strength of the uncracked portion of concrete) and the strength of the steel shear reinforcement. In the case of beams strengthened with externally bonded FRP sheets, the nominal shear strength may be computed by the addition of a third term to account for the contribution of the FRP sheet to the shear strength. This is expressed in Equation (2).

$$V_n = V_c + V_s + V_f \dots \dots \dots (2)$$

Where,

V_n = nominal shear strength

V_s = nominal shear strength provided by steel shear reinforcement



V_c = nominal shear strength provided by concrete

V_f = nominal shear strength provided by FRP shear reinforcement

➤ **The Contribution of FRP Reinforcement to Shear Capacity (V_f)**

In order to compute the nominal shear strength as given in Equation (2), it is necessary to quantify the contribution of CFRP reinforcement to the shear capacity (V_f). The contribution of CFRP depends on several parameters including the stiffness of the CFRP sheet, the quality of the epoxy resin, the compressive strength of the concrete, the number of layers of CFRP sheet, the wrapping scheme, and the fiber orientation angle. It has been difficult to establish one formula to compute V_f because the parameters are numerous and there is a lack of adequate experimental results. This study presents two equations that may be used to obtain V_f and suggests taking the lower of the two results as the shear strength contribution of the CFRP reinforcement. These two equations represent two possible failure modes.

➤ **Design Approach Based on the Effective FRP Stress**

The design approach based on fracture of the CFRP sheet is quite similar to the approach used to compute the contribution of steel shear reinforcement. The stress in the sheet at ultimate must be calculated in the vertical direction and multiplied by the area of sheet that crosses a potential shear crack. However, instead of the ultimate condition being governed by a yield point, as with steel, the rupture point of the CFRP sheet must be considered. Triantafillou (Oct 1997) noted that CFRP sheets used for shear strengthening rupture at stress levels below their ultimate strength due to stress concentrations in the sheet. If the level of strain at rupture is considered as the effective strain, ϵ_{fe} , the contribution of externally bonded FRP sheets to the shear capacity of an RC beam may be computed from Equation (3).

$$V_f = \rho_f E_f \epsilon_{fe} b_w 0.9d(1 + \cos \beta) \sin \beta \dots\dots\dots (3)$$

Where,

V_f = nominal shear strength provided by FRP shear reinforcement

ϵ_{fe} = the effective FRP strain

b_w = width of the beam cross section

E_f = elastic modulus of FRP (GPa)

ρ_f = FRP shear reinforcement ratio = $(2t_f / b_w) (w_f / s_f)$

This equation, as presented by Triantafillou, is in the Eurocode format. The shear reinforcement ratio, ρ_f , is the FRP shear reinforcement ratio as defined in the appendix, and the angle β is the angle between the orientation of the principal fibers in the sheet and the longitudinal axis of the beam. This equation may be rewritten in ACI code format as Equation (4).

$$V_f = \frac{A_f f_{fe} (\sin \beta + \cos \beta) d_f}{s_f} \dots\dots (4)$$

Where,

A_f = area of CFRP shear reinforcement = $2 t_f w_f$

f_{fe} = effective tensile stress in the FRP sheet in the direction of the principal fibers

d_f = effective depth of the CFRP shear reinforcement (usually equal to d for rectangular sections and $d-t_s$ for T-sections)

s_f = spacing of FRP strips

➤ **Determination of the Effective Strain**

A relationship between effective strain and axial rigidity was found and is given in Equation (5-a) and (5-b).

$$\epsilon_{fe} = 0.0119 - 0.0205 (\rho_f E_f) + 0.0104 (\rho_f E_f)^2 \dots\dots\dots (5-a)$$

For $0 \leq \rho_f E_f \leq 1$ Gpa

$$\epsilon_{fe} = 0.00245 - 0.00065 (\rho_f E_f) \dots\dots\dots (5-b)$$



for $\rho_f E_f \leq 1 \text{ Gpa}$

➤ **Modifications to the Effective Strain Model**

As originally suggested, the effective strain is determined by equating the experimentally determined shear strength to Equation (3) and back calculating ϵ_{fe} . To eliminate the effects of various types of FRP sheet, the ratio of effective strain to ultimate strain, $R = \epsilon_{fe} / \epsilon_{fu}$, is plotted versus axial rigidity. This plot is shown in Figure 3. A polynomial is used as a best fit to the data in the case of $\rho_f E_f < 1.1 \text{ GPa}$. This polynomial is given in Equation (6).

$$R = 0.5662 (\rho_f E_f)^2 - 1.2188 (\rho_f E_f) + 0.778 \leq 0.50 \dots\dots\dots(6)$$

The upper limit on R of 0.50 has the effect of limiting the strain in the FRP sheet to an order of 400 $\mu\epsilon$ to 500 $\mu\epsilon$. This limit is suggested to maintain the shear integrity of the concrete. At higher levels of strain the shear crack widths would be such that aggregate interlock would be lost and the shear capacity of the concrete dramatically reduced.

The ratio of effective strain to ultimate strain, R, may be used as a reduction factor on the ultimate strain. Thus, the effective strain for use in Equation (3) may be computed from Equation (7).

$$\epsilon_{fe} = R \epsilon_{fu} \dots\dots\dots(7)$$

Where,

ϵ_{fu} = Ultimate tensile elongation of the fiber material in the FRP composite

ϵ_{fe} = The effective FRP strain

R = Ratio of effective stress or strain in the FRP sheet to its ultimate strength or elongation

Thus the computational procedure for design would involve finding the reduction factor, R, from Equation (6); finding the effective stress, f_{fe} , by Equation (8); and determining the shear contribution of the CFRP, V_f , from Equation (4).

➤ **Limitations of the Effective Stress Method**

The experimental data used in Figure 3 includes two different types of fiber material (CFRP and AFRP), three bonded surface configurations (completely wrapped, U-jacket, and bonded on two sides), continuous reinforcement as well as strips, 45° and 90° fiber orientations, and single as well as double plies. Although all the data follow nearly the same trend (and only a single curve fit was proposed), a modification for each group may be required in the future when more experimental data becomes available. For example, there are only four available experiments with AFRP. This is not sufficient to warrant the use of this equation for AFRP reinforcement; the authors suggest this approach for CFRP only. The fiber orientation angle in the experimental data is limited to 45° and 90°, whereas Equations (3) and (4) suggest application to all angles including 0°. More experimental data is required to validate the use of these equations for other fiber orientations. Another observation is that the proposed equations do not take into consideration either the strength of the concrete or the bonded surface configuration. However, the bond between the FRP and concrete depends on, among other things, the concrete strength and the bonded area. Therefore, these equations are only applicable when failure is governed by FRP sheet rupture not by FRP sheet delamination.

2) Durability: Performance and Design

FRP durability in concrete has predominantly been measured by accelerated test methods that expose specimens to environments harsher than they would normally encounter in service. These data are then used to extrapolate estimates of the likely long-term performance. Mechanical changes in tensile strength, interlaminar shear and bond strength and elastic modulus, are the best indirect indicators of durability of FRP composite reinforcement.

➤ **Durability of FRP as Internal Reinforcement**

There are three components within a composite material that influence its long term properties, as follows:

- The matrix
- The fibres
- The fibre/matrix interface

Each of these elements can be susceptible to attack by various aggressive environments, yet all three should continue to function fully throughout the design life of the composite. The matrix is inherently resistant to the

aggressive medium (in this instance - strong alkalis), therefore, it prevents deterioration of the fibres and the interface region by providing a barrier against the concrete and the external environment. External factors which may influence the effectiveness of this protection include:

- Nature of the environment (ph and presence of aggressive ionic species),
- Stress in the composite,
- Temperature,
- Condition of composite (cut ends, damage etc.), and
- Quality of composite (surface finish, voids, resin homogeneity).

The effectiveness of the resin will depend upon the continuity of its surface. This is why cut ends of short FRP reinforcement bars and exposed fibres can be problematic from a durability point of view. Such regions generally provide a transport network throughout the composite by a wicking mechanism. Here the media can attack the fibre/matrix bond and continue to progress along the fibre length very rapidly, which then exposes both fibres, matrix and the resin/fibre interface to direct attack by the surrounding environment. Cut surfaces of short bars, may need to be sealed to avoid penetration of chemical agents. The quality of a composite in terms of its durability performance can be expressed by a number of factors.

- Resin wet out (how well the fibres are covered by resin).
- Absence of cracks (either surface or throughout the cross section).
- Absence of voids (generally smaller and well distributed is better).
- Degree of cure of resin (if the production process is not well controlled the resin may be insufficiently cross-linked to provide the designed protection).
- Strong fibre/matrix interface (incorrect selection of fibre or matrix type or incorrect processing can lead to a poor interface prone to environmental attack).

3) Combination

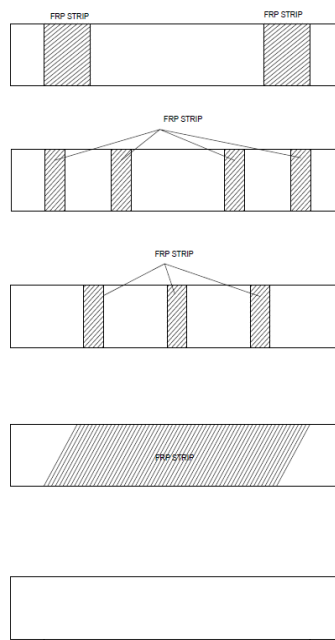


Fig.3: Combinations of Study

IV. RESULT AND DISCUSSION

1. Analytical Load Carrying Capacity Concrete Beam

Table No 1: Load Carrying Capacity Of Section

Sr. No	Description	Overall Depth Of Beam	Width Of Beam	Width Of FRP Strip	Thickness Of FRP Strip	Effective Span Of Beam	ABAQUS Load Carrying Capacity	Load/ Area Ratio
		mm	mm	mm	mm	mm	KN	
1	Application of End Plate Type of FRP Strip At Both End Of Beam	150	150	Nil	Nil	700	20.096	0.893
		150	150	25	2	700	21.52	0.956
		150	150	30	2	700	23.41	1.040
		150	150	35	2	700	26.1	1.160
		150	150	40	2	700	24.3	1.080
		150	150	45	2	700	25.8	1.147
		150	150	50	2	700	28.41	1.263
		150	150	55	2	700	29.45	1.309
		150	150	60	2	700	30.2	1.342
		150	150	65	2	700	31.56	1.403
2	Application of Vertical Type of FRP Strip At Both Sides Of Beam	150	150	25	2	700	25.78	1.146
		150	150	30	2	700	27.85	1.238
		150	150	35	2	700	29.45	1.309
		150	150	40	2	700	30.45	1.353
		150	150	45	2	700	32.74	1.455
		150	150	50	2	700	35.4	1.573
		150	150	55	2	700	39.45	1.753
		150	150	60	2	700	40.12	1.783
3	Application of Debonding Type of FRP Strip At Bottom Of Beam	150	150	600	2	700	22.387	0.995
		150	150	600	3	700	22.117	0.983
		150	150	600	4	700	22.66	1.007
		150	150	600	5	700	25.56	1.136
		150	150	600	6	700	26.5	1.178
		150	150	600	7	700	26.45	1.176
		150	150	600	8	700	27.2	1.209
		150	150	600	9	700	25.236	1.122
150	150	600	10	700	23.905	1.062		

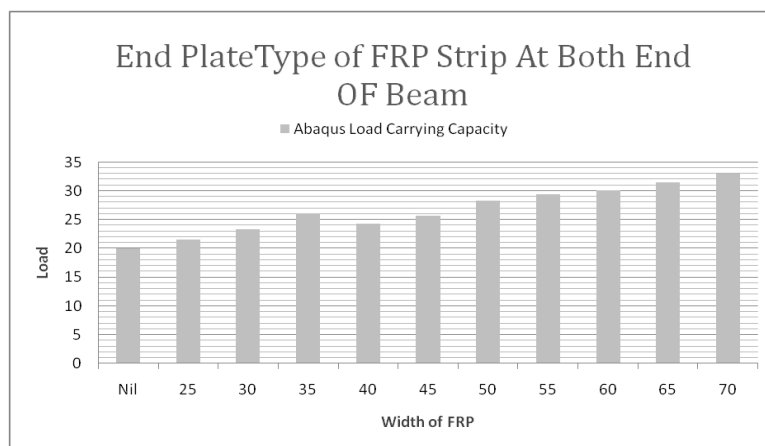


Fig.4: Load Carrying Capacity of Application of End Plate Type FRP Strip at Beam

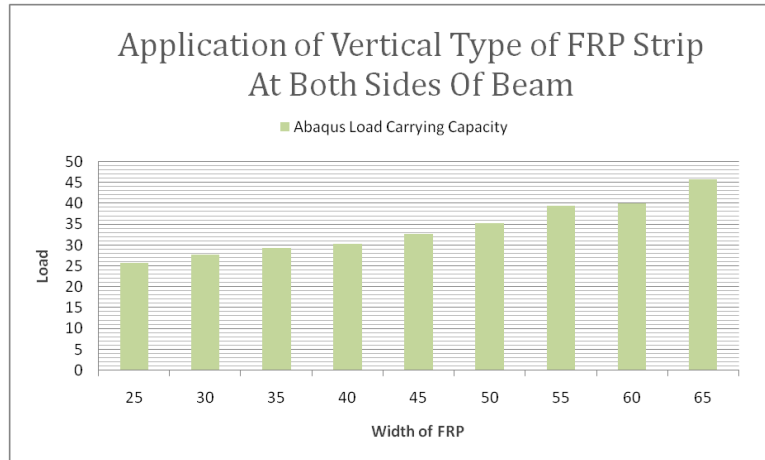


Fig.5: Load Carrying Capacity of Application of Vertical Type Of FRP Strip at Beam

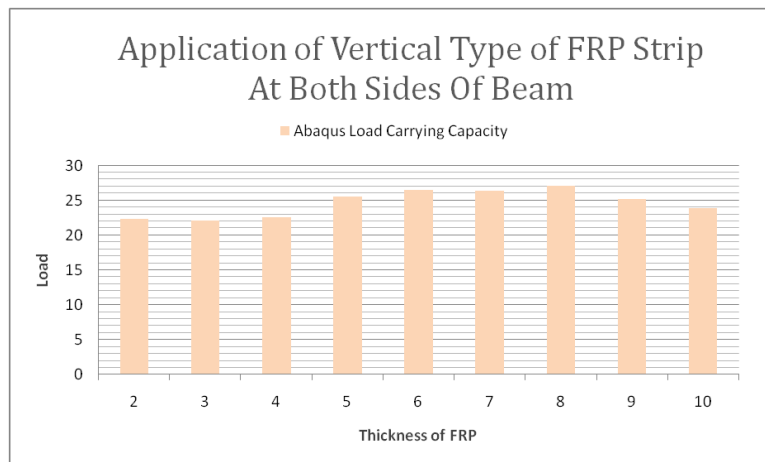


Fig.6: Load Carrying Capacity of Application of Debonding Type Of FRP Strip at Beam

2. Comparison For Concrete Beam With CERP Strip and Without Strip

Table No 2: Comparison Of Analytical Load Carrying Capacity Of Concrete Beam

Sr. No	Description	Overall Depth Of Beam	Width Of Beam	Width Of FRP Strip	Thickness Of FRP Strip	Effective Span Of Beam	Abaqus Load Carrying Capacity	Increase in Load Carrying Capacity	Actual increase in Term OF Ratio
		mm	mm	mm	mm	mm	KN	KN	
1	Application of End Plate Type of FRP Strip At Both End Of Beam	150	150	Nil	Nil	700	20.096	-	-
		150	150	25	2	700	21.52	1.4	0.07
		150	150	30	2	700	23.41	3.3	0.14
		150	150	35	2	700	26.1	6.0	0.23
		150	150	40	2	700	24.3	4.2	0.17
		150	150	45	2	700	25.8	5.7	0.22
		150	150	50	2	700	28.41	8.3	0.29
		150	150	55	2	700	29.45	9.4	0.32
		150	150	60	2	700	30.2	10.1	0.33
		150	150	65	2	700	31.56	11.5	0.36

		150	150	70	2	700	33	12.9	0.39
2	Application of Vertical Type of FRP Strip At Both Sides Of Beam	150	150	25	2	700	25.78	5.7	0.22
		150	150	30	2	700	27.85	7.8	0.28
		150	150	35	2	700	29.45	9.4	0.32
		150	150	40	2	700	30.45	10.4	0.34
		150	150	45	2	700	32.74	12.6	0.39
		150	150	50	2	700	35.4	15.3	0.43
		150	150	55	2	700	39.45	19.4	0.49
		150	150	60	2	700	40.12	20.0	0.50
		150	150	65	2	700	45.74	25.6	0.56
		3	Application of Debonding Type of FRP Strip At Bottom Of Beam	150	150	600	2	700	22.387
150	150			600	3	700	22.117	2.0	0.09
150	150			600	4	700	22.66	2.6	0.11
150	150			600	5	700	25.56	5.5	0.21
150	150			600	6	700	26.5	6.4	0.24
150	150			600	7	700	26.45	6.4	0.24
150	150			600	8	700	27.2	7.1	0.26
150	150			600	9	700	25.236	5.1	0.20
150	150			600	10	700	23.905	3.8	0.16

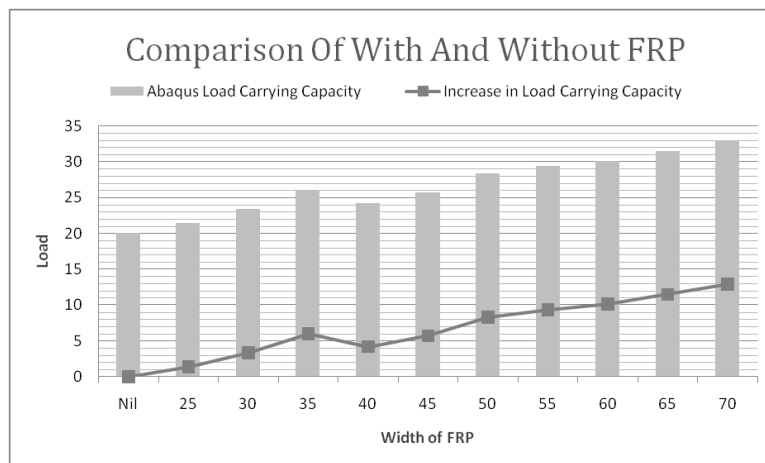


Fig.7: Comparison Of Load Carrying Capacity of Application of End Plate Type FRP Strip at Beam

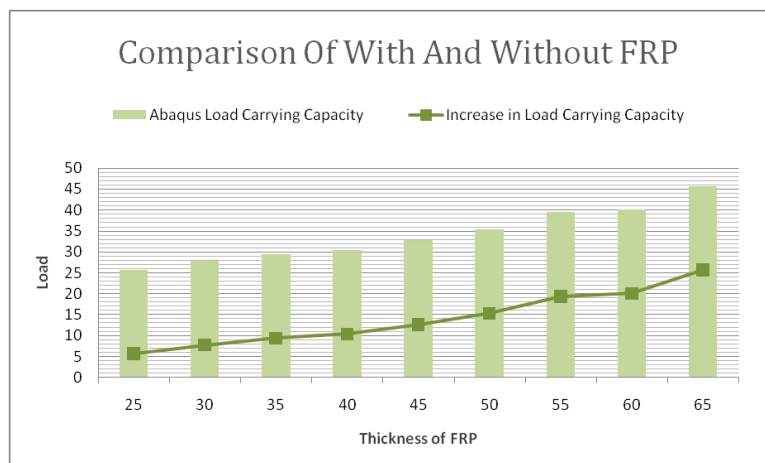


Fig.8: Comparison Of Load Carrying Capacity of Application of Vertical Type FRP Strip at Beam

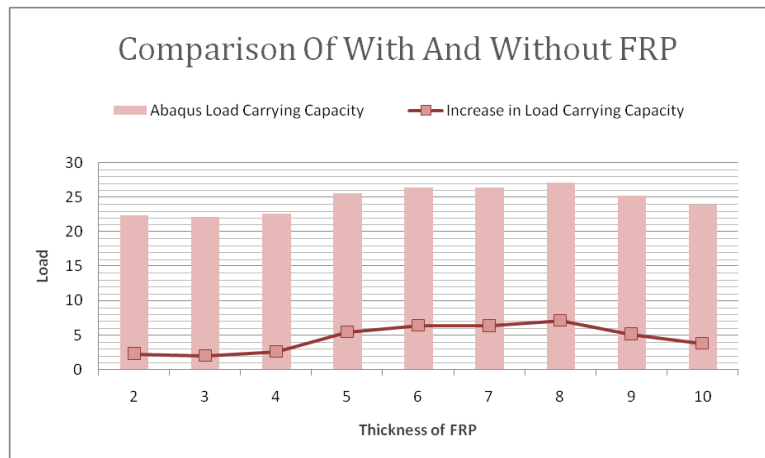


Fig.9: Comparison Of Load Carrying Capacity of Application of Debonding Type FRP Strip at Beam

V. CONCLUSION

This brief examination of FRP has summarized the very wide range of strange functionalities that these products bring (Polymers, Carbon, and Glass). While the chemistry plays an important role in defining the scope of applications for which these materials are suited, it is equally important that the final parts are designed to maximize the value of the inherent properties of these materials. The ability of a polymer material to deform is determined by the mobility of its molecules, characterized by specific molecular motions and relaxation mechanisms, which are accelerated by temperature and stress. Since these recreation mechanisms are material specific and depend on the molecular structure, they are used here to establish the desired link with the intrinsic deformation behavior. The CFRP application led to an increase of the beam strength and stiffness. Although all specimens were reinforced with identical layers of CFRP, it was observed in literature that different resin and anchorage systems significantly influenced the resulting strength and stiffness of the specimens.

Based on the results presented herein, the following conclusions can be drawn:

- The CFRP application led to an increase of the beam strength and stiffness. Although all specimens were reinforced with identical layers of CFRP, it was observed that different resin and anchorage systems significantly influenced the resulting strength and stiffness of the specimens. The best results were achieved with connectors.
- All strengthened beams have higher properties than that of the CB, the improvement of flexural load, deflection of beam.
- In this end plate type of FRP strip at both end of beam carry 39% more load than normal beam and other FER attached beam.
- In this vertical type of FRP strip at both sides of beam carry 56% load than normal beam and other FER attached beam.
- In this debonding type of FRP strip at bottom of beam carry 26% load than normal beam and other FER attached beam.
- The analytical results giving load carrying capacities of strengthening of beam provided loading, is found to be almost similar to that of the result obtained in the research paper using software and a percentage variation in load carrying capacity is found to be below 10% approximately. Hence, it can be concluded that the results of ABACUS are validated with the results obtained by using software in research paper.

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