Strengthening/Retrofitting Strategy of Externally Bonded GFRP Composites

Anshul Sharma[1] and Vishnu Sharma[2]
[1]M. Tech. Scholar, Department of Civil Engineering, YIT, Jaipur (Rajasthan)
[2]Professor, Department of Civil Engineering, YIT, Jaipur (Rajasthan)
seethaanshul@gmail.com[1], vishnu2668@gmail.com[2]

ABSTRACT

The primary goal of the planned experimental inquiry is to determine if externally bonded GFRP composites may be used to refit slightly damaged R.C.C. frames and reinforce seismically weak R.C.C. frames. The efficacy of GFRP composites wrapped around R.C.C. columns and R.C.C. beams in flexure and shear zones will also be examined. To compare the flexure behavior of the beams wrapped in GFRP composites to the unwrapped beams, twenty-one flexure beams intended to fail in flexure were cast and tested in group II beams. The remaining three beams acted as reference beams for this category of beams, while nine of the twenty one flexure beams were strengthened and nine more were retrofitted utilizing GFRP composites in three distinct wrapping patterns. In order to compare the shear behavior of the beams with GFRP composites to that of the unwrapped beams, nine shear beams intended to fail in shear were cast and evaluated for group III beams. The remaining three beams acted as reference beams for this category of beams while three of the nine shear beams were strengthened and another three refitted utilizing GFRP composites. To compare the load carrying capability of these columns to that of the other nine, three of the nine columns were strengthened, while another three were retrofitted with GFRP composites. The remaining three columns acted as this category's control columns and were unwrapped columns. In order to evaluate the efficiency of GFRP composites in load carrying capacity, three of the nine frame specimens were strengthened, and another three were retrofitted using GFRP composites. The remaining three frames acted as control frames for this category. In order to model the behavior of R.C.C. beams and R.C.C. frames with and without GFRP composites wrapping, numerical analysis was also carried out using the finite element tool ABAQUS. The findings were then compared with experimental data.

Keywords: *GERP, RCC, Beam, Glass Fiber, ABAQUS*

1. INTRODUCTION

The constructions are currently exposed to a hostile environment. Older buildings that were built in a peaceful atmosphere without any additional precautions are vulnerable to damage during earthquakes.

Retrofitting of structural components is

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favored if the damage to buildings, bridges, and other significant structures is within the acceptable range and the rehabilitation work of the damaged elements is more cost-effective than that of new construction.

To make a beam stronger or more rigid, concrete is added. This conventional retrofit technique has significant drawbacks. First, adding concrete expands the beam's size and weight. Second, the existing concrete and the new concrete must be properly bonded. The bleed water from fresh concrete causes a thin cement paste to form at the contact in beam soffits. Thirdly, drying shrinkage's effects must be taken into account since it causes tensile tensions in the fresh concrete.

Fiber reinforced concrete may be used for retrofitting in place of ordinary concrete. The strength and energy absorption capacity of concrete are increased by the use of high performance fiber reinforced concrete, such as slurry infiltrated mat concrete.

To enhance the flexural and shear performances of beams, the method of gluing mild steel plates to beams is frequently utilized. Applying the addition of steel plate is easy and quick. It may be used when the building is in operation and does not considerably lower the story clear height. However, it has significant drawbacks including corrosion and increasing self-weight over a lengthy period of time.

Similar to how steel plates are mounted to beams to boost their flexural and shear capabilities, FRP laminates are attached to them (Arduini et al., 1997; Attari et al., 2008; Santhakumar et al). (1999). To maintain the ductility in the flexural failure mode, the quantity of FRP connected to the soffit should be kept to a minimum.

FRP has been employed as re-bars in addition to sheets (Arduini et al., 1997; Nanni, 1993). To reinforce a beam under shear, FRP bars can be fastened to the web. As tendons for external prestressing, FRP bars can be employed..

Using post-tensioned reinforcement, the flexural strength may be improved or broken pre-stressing strands can be replaced.

AIM OF THE INVESTIGATION

Enhancing the strength, stiffness, and/or ductility of the components or the entire structure is referred to as the strengthening/retrofitting strategy.

The main goal of this experimental inquiry will be to determine if externally bonded GFRP composites can be used to refit the slightly damaged R.C.C. frames and reinforce the seismically weak R.C.C. frames (in determining the lateral load carrying capacity). Additionally, a finite element model of the R.C.C. frame will be created using the ABAQUS software, and it will be compared to the analytical results to confirm the experimental findings.

This investigation's other objectives include examining the effects of various GFRP composite wrapping patterns on the behavior of flexural beams and shear beams as well as the efficiency of GFRP composite exterior wrapping on R.C.C. columns..

SCOPE OF THE INVESTIGATION

In this investigation an attempt will be made to compare the performance of undamaged and damaged R.C.C. beams, R.C.C. columns and R.C.C. frames

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wrapped by GFRP composites externally.

These experimental investigations will be made in two major phases. The first phase will be the strengthening study in which undamaged specimens will be considered for GFRP composites wrapping and the behaviour will be examined.

The second phase will be the retrofitting study in which slightly damaged specimens (i.e) specimens are initially loaded upto 75 percentage of ultimate load of reference specimens and then these specimens are considered for GFRP composites wrapping and the behaviour examined.

2. LITERATURE REVIEW

In recent years, fiber reinforced polymer retrofit technology has been developed in the field of civil engineering. Fiber reinforced polymer is primarily employed in two categories for structural purposes. In the first, fiber reinforced polymer bars are used in concrete constructions rather of pre-stressed strands or steel reinforcing bars. The alternative application, on which this work focuses, involves retrofitting structural parts with fiber reinforced polymer on the outside. There are several ways to bind fiber reinforced polymer to structural parts made of reinforced cement concrete, including external bonding, wrapping, and near surface mounting. To give flexural strength or shear strength, fiber reinforced polymer plates or sheets can be attached to the tension side of a structural member or to the web side of a beam. Fiber reinforced polymer sheets can also be wrapped around a column to create confinement and boost strength and ductility, as well as a beam to give shear strength. A fiber reinforced polymer bar or strip is inserted into a concrete component after it has been sawed longitudinally, then a bonding substance is applied in the groove.

A numerical investigation on the adhesion behavior of fiber reinforced polymer enhanced R.C.C beams was conducted by Perera et al. in 2004. They talked about how using epoxy glue affected the bonding between composite plates and reinforced concrete. The examination was based on beam test, which is comparable to the adherence test for concrete with steel reinforcement. To simulate the behavior of R.C.C. components reinforced with FRP plates, they also created a numerical model based on finite elements. The enhanced members' nonlinear reaction was identified. They came to the conclusion that the shear bond stresses are crucial to the reinforcement of R.C.C. beams using FRP plates.

In their study of reinforced concrete rectangular beams strengthened in shear with externally bonded U-wrapped carbon fiber-reinforced polymer, Pellegrinocarlo & Modenaclaudio (2006) published their findings. These findings provide some fresh perspectives on the intricate failure mechanisms that define the maximum shear strength of R.C.C. members with transverse steel reinforcement and FRP sheets. These findings revealed a few processes by which the externally applied FRP sheets and the interior steel reinforcement with various static schemes interacted.

In an experimental examination, Ayman et al. (2007) examined how to increase the shear strength of reinforced concrete beams externally strengthened using fiber-reinforced polymer composites.

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Nine full-scale beam specimens of three different classes—as-built (unstrengthened), repaired, and retrofitted—were evaluated in total. For the evaluation of retrofit and repair, they employed three composite systems: carbom/epoxy wet lay up, e-glass/epoxy wet lay up, and carbon/epoxy purchased strips. In comparison to pre-cracked and as-built beam specimens, the testing results showed that the composite systems significantly increased the ultimate strength of mended and reinforced beams.

Different failure mechanisms of the FRP-strengthened R.C.C. were investigated by Bogao et al. in 2007. They create a failure diagram, and using it, they demonstrate the relationship and transfer propensity between various failure modes for R.C.C. beams reinforced with FRP strips, as well as how failure modes alter with FRP thickness and the length of the FRP strips before they reach the support. They discovered that the ultimate flexural strength and stiffness of reinforced concrete beams may be greatly increased by epoxy-bonding fiber reinforced polymer to the tension soffit. A reinforced R.C.C. beam's failure mechanism might be predicted using this technology, they added. This failure diagram offers recommendations for practical.

This approach helps build a process for choosing the kind and size of FRP for the exterior reinforcement of R.C.C. beams.

An experimental-analytical examination was conducted by Guidocamata et al. (2007) to examine the brittle failure mechanisms of R.C.C. components that were flexure-strengthened by FRP plates. Both plate end and mid span failure mechanisms were investigated. In this experimental piece, two slabs and two beams were cast as four R.C.C. members. One slab and one beam out of these four members were tested as unreinforced members, and the other slab and beam were tested as reinforced members. Additionally, they created an analytical model of this R.C.C. component and used the finite element method to analyze it. The R.C.C. beams were strengthened using both CFRP and GFRP. This study demonstrated how the failure processes are influenced by concrete cracking, adhesive behavior, plate length, breadth, and stiffness. The findings of the computational and experimental studies demonstrated that the failure mechanisms for debonding and concrete cover splitting invariably include internal crack propagation. Failure occurs near the end of shorter FRP plates whereas it occurs in the middle of longer FRP plates. Comparing strengthening techniques using CFRP and GFRP that had varied contact areas but the same axial stiffness revealed that increasing plate width significantly raised the peak load and deformation level of the reinforced beam.

A research on the behavior of reinforced concrete beams with externally attached fiber reinforcing polymer was conducted by Pannirselvam et al. in 2008. In this work, three distinct steel to polymer ratios were combined with two different kinds of glass fiber reinforced polymers. There were two distinct thicknesses for each type of GFRP. They cast fifteen beams, three of which served as control beams, while the remaining ten were fastened to the soffit using GFRP laminate. They used a basic beam with two points of stress for the flexural test,

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and they looked at how well FRP-plated beams performed in terms of flexural strength, deflection, and ductility. They came to the conclusion that GFRP laminate-strengthened beams performed better. As GFRP plate thickness grew, so did its flexural strength and ductility. They discovered that for 3 mm thick Woven Rovings Glass Fiber Reinforced Polymer (WRGFRP) plates and 100.00 percent for mm WRGFRP plated beams, the increase in first crack loads was up to 88.89 percent and the increase in ductility and deflection was found to be 56.01 percent and 64.69 percent, respectively.

The flexural behavior of carbon fiber reinforced polymer strengthened reinforced concrete beams was investigated by Balamuralikrishnan & Antony Jeyashar (2009). They cast 10 beams for flexural strengthening of R.C.C. beams and tested them under monotonic and cyclic loads across an effective span of 3000 mm till failure. The beams were intended to be made of under-reinforced concrete. The remaining two beams served as control specimens. Eight beams were reinforced with bonded CFRP fabric in a single layer and two layers that were parallel to the beam axis at the bottom and tested to failure. The outcome revealed that the reinforced beams had composite action till failure as well as higher flexural strength and stiffness.

Obaidat et al. (2010) conducted an analytical examination of the finite element analysis, which was further verified by testing of eight beams in a lab. All beams were loaded under four point ends and had the identical rectangular cross-section geometry, but the length of the carbon fiber reinforced polymer plate varied between them. They assessed the various material models using ABAQUS, a commercial numerical analysis program. For the concrete, a plastic damage model was utilized. Regarding load-displacement response, fracture pattern, and debonding failure mode, the analysis's findings were in good accord with the experimental results.

A simple concrete block was wrapped in bamboo fiber reinforced polymer by Tarasen & Jagannathareddy (2011) in order to examine the efficacy of bamboo fibers in structural retrofitting. In comparison to controlled specimens, they discovered that the strengthened specimens showed a significant increase in strength, stiffness, and stability.

The performance of intact and damaged reinforced concrete beams enhanced with near-surface mounted CFRP and GFRP bars was experimentally examined by Urmil et al. in 2012. Damaged beams were exposed to an extra load of 80% of their pre-strengthened failure load. By lowering the proportion of tensile reinforcement, the beams were rendered flexure-deficient. By keeping the overall area of the bars for beams essentially constant, they defined variable as changes in the diameter and quantity of fiber-reinforced polymer bars. They discovered that, as compared to control beams, FRP reinforced beams showed an increase in failure load that ranged from 49.78 to 120.26 percent. For beams, an increase in failure load and a decrease in displacement were seen as the number of FRP bars was increased. In comparison to beams strengthened with GFRP bars, a load increase of 10.13 to 14.71 percent was seen for beams strengthened with

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CFRP bars.

For the numerical modeling of FRP-concrete delamination, Ferracuti et al. (2006). For the delamination phenomena, a non-linear bond-slip model was applied. This analytical study demonstrated how a FRP retrofit could significantly improve the way a reinforced concrete structure behaves under both short- and long-term service loadings. A non linear interface law was used to simulate the bonding between the FRP plate and the concrete. The finite difference approach was then used to generate a non-linear system of equations. Different control parameters can be used in the various phases of the delamination process according to the Newton-Raphson analogy (alternatively, force or displacements variables). They provided a few numerical stimulations relating to various bond lengths and delamination test setups. The study's numerical findings and the outcomes of the experiment were in good agreement.

Sandeep et al. (2008) explored several uses of fiber reinforced polymer composites for R.C.C. components' exterior strengthening. Their evaluation concentrated on experimental, analytical, and numerical research contributions. The primary structural elements, including beams, columns, and beam-column junctions, were examined, and a brief discussion of each element's structural behavior was made.

In order to ensure the preservation of these structures, Natarajan et al. (2010) presented a case study report on the rehabilitation of the historic St. Lourdes Church in Tiruchirappalli, India. This report also demonstrated the significance of rehabilitation of historic structures using appropriate construction techniques, as well as potential alternative rehabilitation approaches.

Experimental research on the behavior of reinforced concrete beam columns joints under cyclic loads was conducted in 2012 by Antonyjeyasehar & Ravichandran. At the beam column junction, joints with sufficient and insufficient shear capacity and bonds of reinforcements were cast. Slurry-infiltrated mat concrete and other fiber-reinforced composites were applied to the joints in a variety of volume fractions and aspect ratios. Axial force was applied to the column, and controlled displacement cyclic load was applied to the beams. The displacement was raised monotonically using a hydraulic push and pull jack. For each specimen, they plotted the hysteretic curves. The ability of retrofitting beam column joints to dissipate energy was compared to several slurry-infiltrated mat concrete arrangements. Additionally, they contrasted the experimental and analytical findings of the control specimen with the retrofitted slurry penetrated mat concrete specimen. They came to the conclusion that the enhanced beam column junction had improved stiffness, strength, and composite action up until failure.

According to a study of the literature, research have mostly looked at using FRP to strengthen R.C.C. beams, whereas just a few authors have looked at using FRP to strengthen R.C.C. beams with deficiencies such flexure and shear.

The amount of research done for the retrofitting of damaged R.C.C. beams, as well as damaged flexure deficient and shear deficient R.C.C. beams, is determined to be minimal. Studies on all R.C.C. components have demonstrated

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that adding FRP to reinforce them will boost their capacity to hold more weight.

R.C.C. components There is no literature that compares FRP-enhanced R.C.C. elements with FRP-retrofitted R.C.C. elements.Few attempts have been made to examine the behavior of a FRP-strengthened R.C.C. beam-column junction under static and cyclic loads, but it has been determined that this would strengthen the joint. There is no literature that compares the behavior of retrofitted and reinforced R.C.C. frames. There are relatively few studies that compare the behavior of strengthened and retrofitted R.C.C. elements, R.C.C. frames with CFRP/GFRP. The literature we gathered, presented, and analyzed here concentrated on the topic of strengthening or retrofitting of R.C.C. elements with CFRP/GFRP individually. In comparison to carbon fiber, the glass fiber reinforced polymer has good ductile behavior. It can mold complicated forms, has a very high strength to weight ratio, is lightweight, resistant to sea water, chemicals, and the environment, requires little maintenance, is long-lasting, and is also very inexpensive. This research gives a comparison of both strengthening and retrofitting of reinforced concrete elements, including R.C.C. frames with GFRP, according to the IS code 13920-1993's significant insistence on the ductile behavior of reinforced concrete buildings in earthquake resistant design

3. METHODOLOGY

The R.C.C. frames taken into consideration in this study are seismically unsound R.C.C. frames from a two-story building built before Indian standards IS 13920-1993, the code of practice for ductile detailing of R.C.C. buildings in India, were introduced. The laboratory model of R.C.C. frames was shrunk to a fifth of its original size by adopting a scale factor of 1.5 while maintaining the smallest possible dimension. To investigate the load deflection behavior, these specimens were tested for lateral load both with and without GFRP covering. To explore the strength behavior, scaled-down models of beams and columns created in accordance with Indian Standard code I.S. 456-2000 were cast and tested both with and without GFRP wrapping. The variables in various test specimen series are displayed in Table 3.1.

Nine regular R.C.C. beams (Reference beams) were cast, and three of them were tested in UTM as a simply supported beam for two point loads both with and without GFRP wrapping as well as using retrofitting techniques.

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Table 3.1 Description of Variables in Different Series of Test Specimens

Description	**R.C.C. Beam**			**R.C.C. Column NC,SC,RC**	**R.C.C. Frame NF, SF,RF**
	Group (I) Normal beam NB, NSB,NRB	Group (II) Flexure beam FB,FS1,FS2,FS3 FB,FR1,FR2,FR3	Group (III) Shear beam SB,SSB,SRB		
Design Concept	Designed as per Indian Standard- I.S 456	Designed as flexure deficient beam i.e reducing percentage of Tensile Reinforcement and made them to fail by flexure	Designed as Shear Deficient beam i.e reducing percentage of Shear reinforcement and made them to fail by shear	Designed as per I.S. 456	Designed as per I.S. 456
Study Purpose	Study the effectiveness of GFRP composites wrapping in load carrying capacity, i.e study the increment in ultimate load carrying capacity of strengthened retrofitted beam specimens over the normal beam specimens.	Study the influence of different patterns of GFRP Composites wrapping(like full portion, bottom half portion, bottom half portion, middle one third portion) in flexure zone only and conclude the effective patterns of wrapping for flexure, i.e study the increment in ultimate load carrying capacity of strengthened, retrofitted flexure specimens over the unwrapped flexure beam specimens.	Study the influence of GFRP composites wrapping in shear zone only, i.e study the increment in ultimate load carrying capacity of strengthened, retrofitted Shear specimens over the unwrapped shear beam specimens.	Study the effectiveness of GFRP composites wrapping in load carrying capacity, i.e study the increment in ultimate load carrying capacity of strengthened, retrofitted column specimens over the normal column specimens	Study the effectiveness of GFRP composites wrapping in load carrying capacity, i.e study the increment in ultimate load carrying capacity of strengthened, retrofitted frame specimens over the normal frame specimens

EXPERIMENTAL SET UP

Test Set up for Beam Specimens

Two point loads were applied to beam specimens during testing using a universal testing machine (UTM) with a 1000kN capability. To measure the deflection, a deflectometer was mounted at the beam's center. Every 5 kN increase of loading

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resulted in a measurement of the deflection at the center of the beam.

Test Set up for Column Specimens

In a universal testing equipment with a 1000kN load capacity, column specimens were tested while being kept upright (since columns behaved like short columns there was no buckling effects and crushing failure have occurred). The specimens were fully loaded till they broke. It was noted the load at failure.

Test Set up for Frame specimens

Single bay, two-story R.C.C. frame examples were examined in a testing frame, and the steel box that housed the frame specimens' base was lined with sand and equipped with a testing floor. The situation of this support fixity is nearly fixed. As a result, it has been treated as a fixed condition when modeling in ABAQUS. On one end, the top storey level was used to apply the lateral load, and on the other, each storey level was used to measure the lateral deflection. The samples were loaded until they broke.

4. INVESTIGATION ON REINFORCED CEMENT CONCRETE COLUMNS

The behavior of GFRP-strengthened reinforced cement concrete columns was the subject of a two-part experimental research. The experiment's first section dealt with reinforced R.C.C. columns, while its second section dealt with R.C.C. beams that had been modified. Study and comparison of the load-bearing capacities of enhanced R.C.C. beam specimens and retrofitted beam specimens. This chapter presents the findings..

Behavior of R.C.C. Columns

Nine 100 mm x 120 mm and 600 mm long R.C.C. columns were cast, and three of each type were tested in a UTM under axial load, with and without GFRP wrapping, and with a retrofitting technique.

Normal columns

To determine their load carrying capability, three R.C.C. column specimens were evaluated as unwrapped column specimens. These results were used as a standard for column investigation. Concentric compression on columns was tested.

At 115 kN, the unwrapped specimens began to give way. Since these columns were intended to be short, their failure mode was crushing failure, as illustrated in Figure 4.1, and their individual ultimate loads were recorded as 217 kN, 217.50 kN, and 217 kN.

Figure 4.1 Failure pattern of normal column

Strengthened columns

To determine the increase in load carrying capability brought on by the strengthening via GFRP wrapping, three reinforced column specimens were examined. The efficiency of the GFRP wrapping was evaluated by comparing the load bearing capability of these

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specimens to the reference value. It was indicated that the maximum load was 250 kN, 250.50 kN, and 250 kN. Strengthened column specimens had an overall improvement in load bearing capacity of 15.19 percent.

Retrofitted columns

To determine the increase in load bearing capability brought on by GFRP wrapping, tests were performed on three initially produced and retrofitted column specimens. The efficiency of the GFRP wrapping was evaluated by comparing the load bearing capability of these specimens to the reference value. A total load of 240 kN, 240.25 kN, and 240 kN were recorded. Retrofitted column specimens' maximum load bearing capability rose by 10.55 percent. Table 4. compares the load-bearing capacities of regular columns, reinforced columns, and retrofitted columns, and Figures 4.2, 4.3, and 4.4 illustrate this comparison.

Table 4.14 Comparison of Load Carrying Capacity 0f NC, SC And RC

Load Carrying Capacity of Columns (kN)			
	Specimen(A)	Specimen(B)	Specimen(C)
Normal Column (NC)	217	217.50	217
Strengthened Column (SC)	250	250.50	250
Retrofitted Column (RC)	240	240.25	240

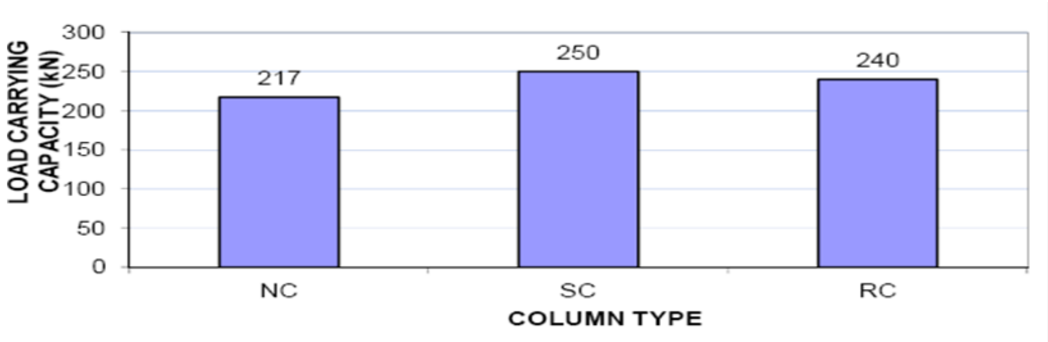

Figure 4.2 Comparison of load carrying capacity of NC, SC and RC (Specimen 'A')

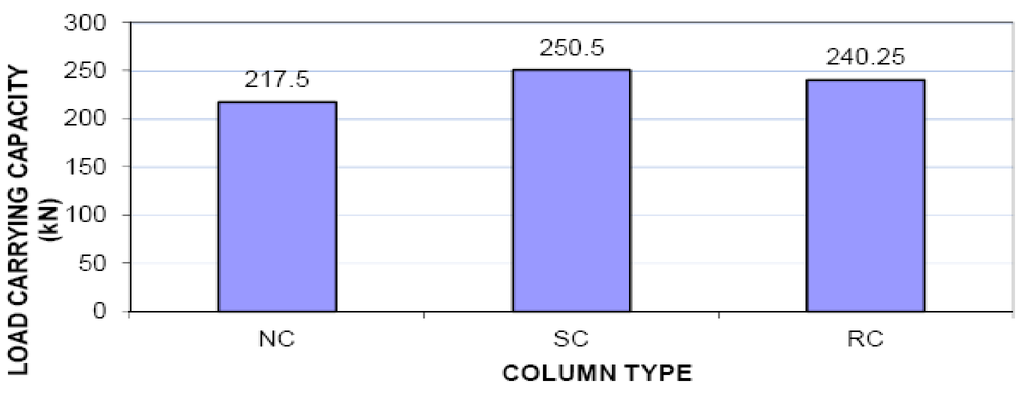

Figure 4.3 Comparison of load carrying capacity of NC, SC and RC (Specimen 'B')

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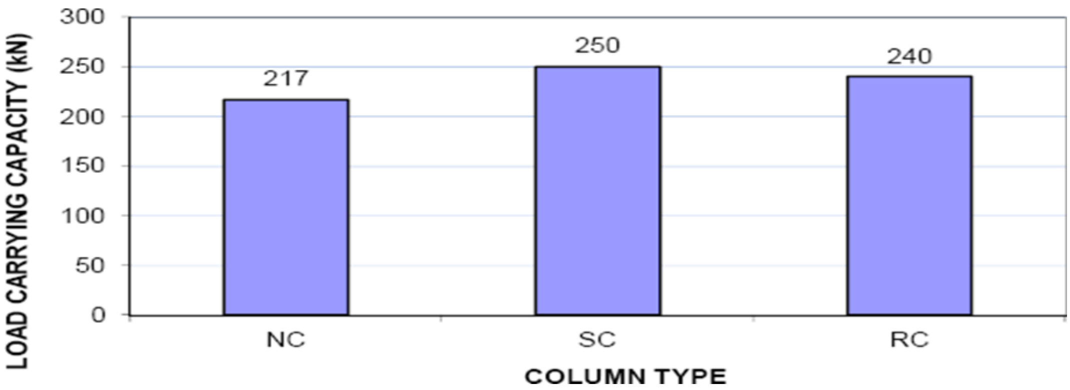

Figure 4.4 Comparison of load carrying capacity of NC, SC and RC (Specimen 'C')

5. RESULT ANALYSIS

One of the goals of this examination is to foster a limited component model addressing the R.C.C. bars and casings to concentrate on the heap avoidance conduct of wrapped and opened up examples. Mathematical examinations were performed utilizing the ABAQUS 6.10.1 limited component program to foresee a definitive stacking limit of rectangular built up cement footers reinforced by GFRP composites. Direct material way of behaving, as it connects with steel building up bars, plain concrete and fiber-built up polymer were mimicked utilizing suitable constitutive models. The impacts of examples of wrapping with GFRP on a definitive strength of the pillars were explored.

These iso-parametric elements are generally preferred for most cases because they are usually the more cost-effective of the elements that are provided in ABAQUS. They are offered with first- and second-order interpolation and are described in detail in "Solid iso-parametric quadrilaterals and hexahedra". For practical reasons it is sometimes not possible to use iso-parametric elements throughout a model; for example, some commercial mesh generators use automatic meshing techniques that rely on triangulation to fill arbitrarily shaped regions. Because of these needs, ABAQUS includes triangular, tetrahedron, and wedge elements. For concrete model, 3D solid element C3D8R shown in Figure 5.1 was considered and for the reinforcing steel modelling it was considered as 2D truss element and which was called as T3D2. Ultimate strength failure criteria analysis were considered.

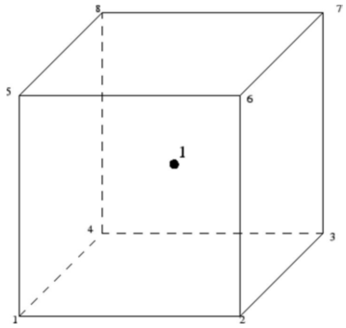

Figure 5.1 'C3D8R'- 8 Nodes linear hexagonal brick element

Glass Fibre Reinforced Polymer (GFRP)

As the FRP material has been assumed to behave as a linearly elastic and orthotropic material, a "lamina" option for the elastic behaviour of the material was chosen. For this type of material, ABAQUS requires the longitudinal, transverse and shear modulus of elasticity. The manufacturer provided the longitudinal and transverse modulus of elasticity. For the near surface mounted system, the strips were modelled in the same way as the reinforcing steel was. Meanwhile the reinforcing steel was

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modelled with surface elements and the FRP strips were modelled using membrane elements. Membrane elements represent thin surfaces in space that offer strength in the plane of the surface, but have no bending stiffness. An ABAQUS tool called "Skin Reinforcement" was used to model the FRP strips externally bonded to the beams. This tool defines a skin that is perfectly bonded to the surface of an existing part and specifies its engineering properties.

The results obtained from the ABAQUS finite element analysis were compared with the experimental data and plotted in Figures 5.2 and 5.3. The validity of the experimental results were assessed by comparison with the FEM results, which were found to be in good agreement.

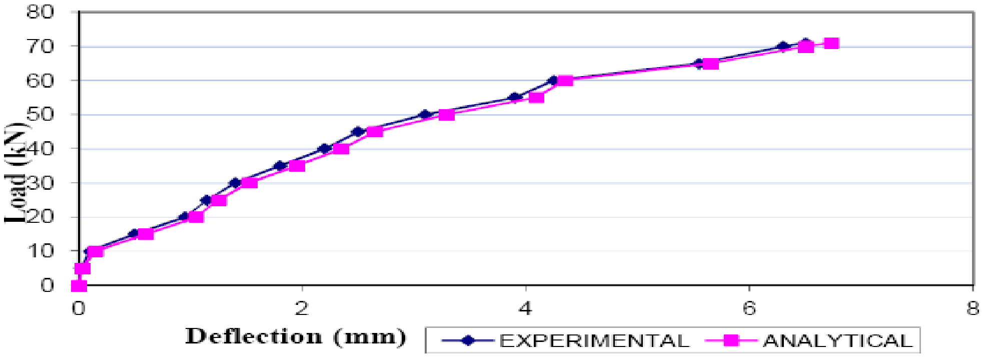

Figure 5.1 Comparison of analytical and experimental load deflection curve of normal beam

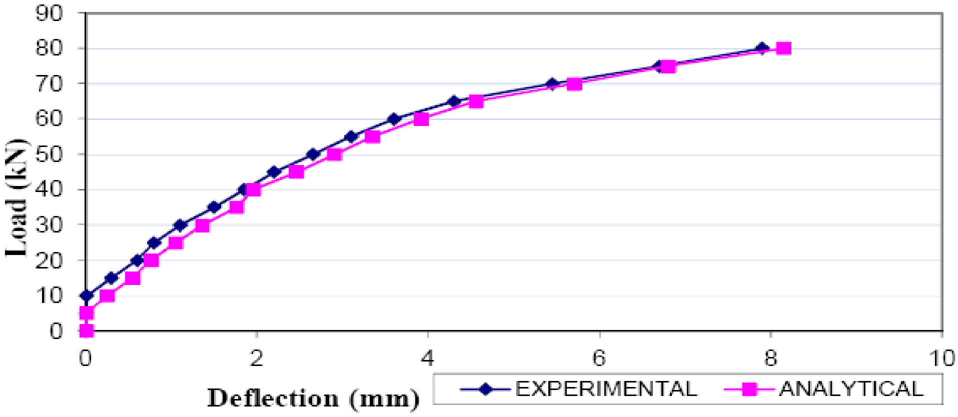

Figure 5.2 Comparison of analytical and experimental load deflection curve of normal strengthened beam

The influences of pattern of wrapping with GFRP on the ultimate strength of the beams were investigated. It was found that the fully wrapped beam model could carry more load than the other patterns of wrapping and it has been shown that the use of GFRP can significantly increase the ductility as well as the ultimate strengths of reinforced concrete beams.

The comparisons are made for three different wrapping patterns.

The results from finite element analysis were obtained at the same location as that of the experimental test of the beams. The validity of the experimental results was assessed by comparing with the analytical results, which are found to be in good agreement. Figures 5.3, 5.4, 5.5 and 5.6 show the analytical and experimental load deflection curves of flexure beam and strengthened flexure beam with three different pattern of wrapping respectively.

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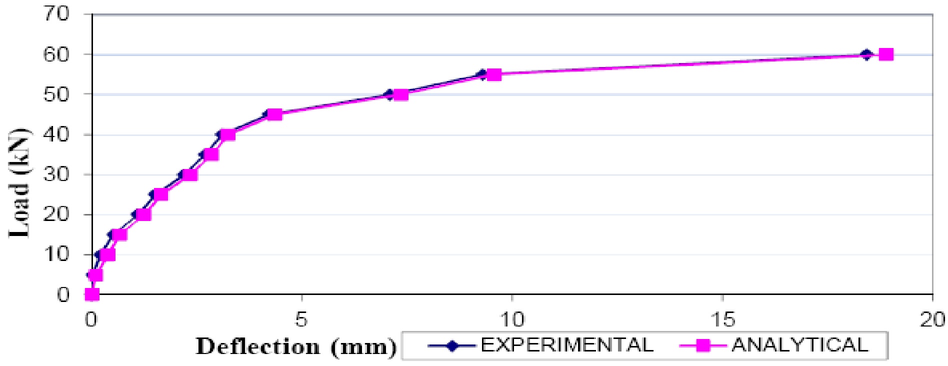

Figure 5.3 Comparison of analytical and experimental load deflection curve of flexure beam

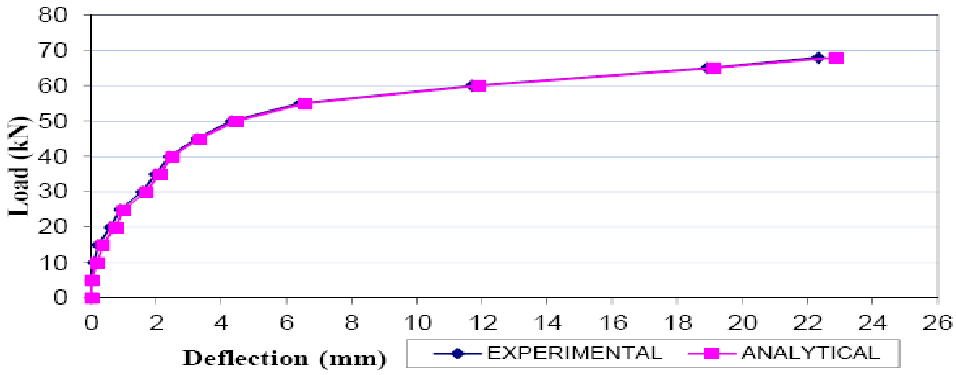

Figure 5.4 Comparison of analytical and experimental load deflection curve of full portion wrapped flexure strengthened beam

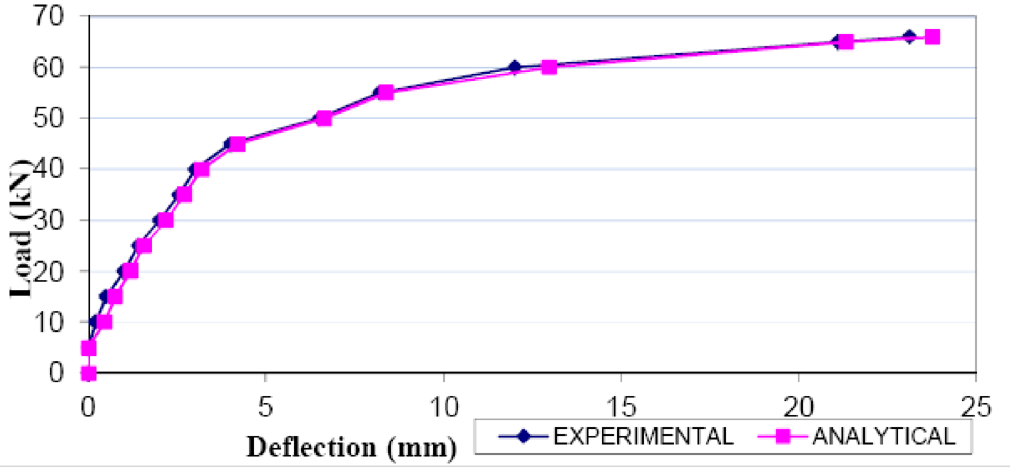

Figure 5.5 Comparison of analytical and experimental load deflection curve of bottom half portion wrapped flexure strengthened beam

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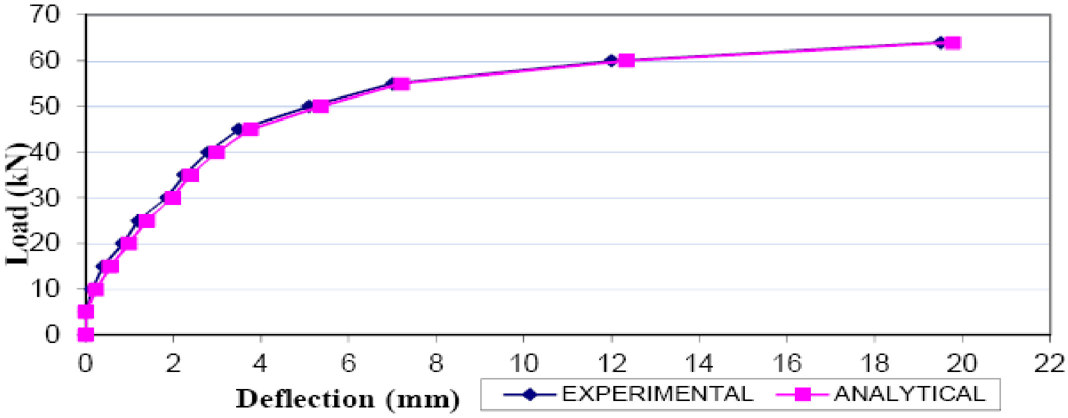

Figure 5.6 Comparison of analytical and experimental load deflection curve of middle one third portion wrapped flexure strengthened beam

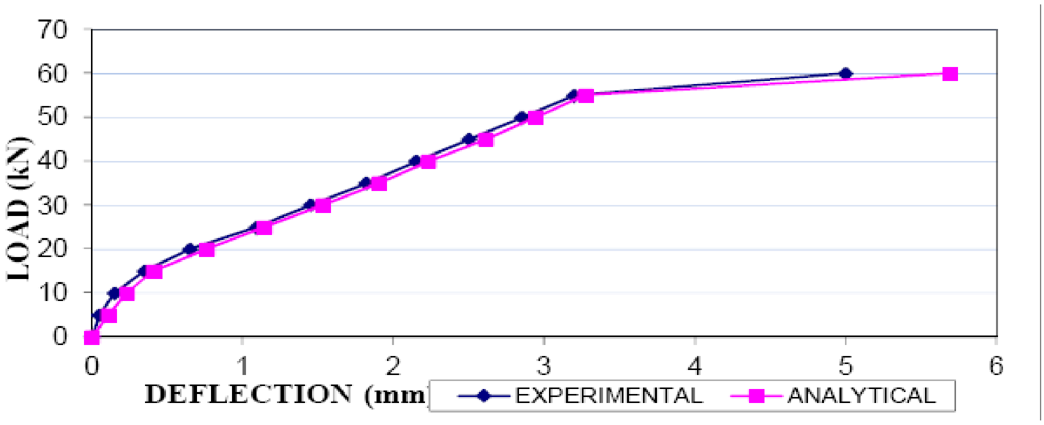

Figure 5.7 Comparison of analytical and experimental load deflection curve of shear beam

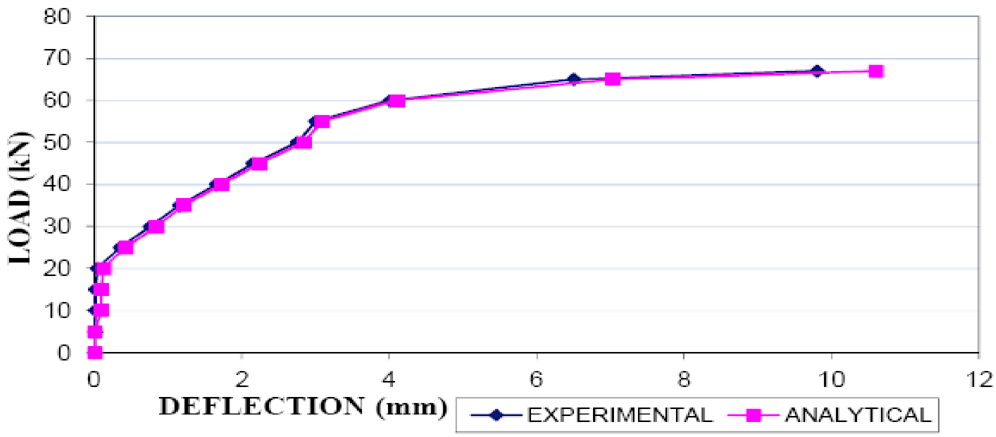

Figure 5.8 Comparison of analytical and experimental load deflection curve of shear strengthened beam

The ultimate load of shear beam was found to be 60 kN and the corresponding deflection was 5.689 mm. The shear strengthened specimen failed at ultimate load of 67 kN and the corresponding maximum deflection at mid span was 10.6 mm as shown in Figure 5.6. Comparison between analytical and experimental load

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deflection values obtained and which are found to be in good agreement. Figures 5.7 and 5.8 show the analytical and experimental load deflection curves of shear beam and shear strengthened beam.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

SUMMARY

Nine normal beam specimens, twenty one flexure beam specimens, nine shear beam specimens, nine column specimens and nine frame specimens were cast and tested.

In group I beams, three of the nine normal beams were strengthened, and another three retrofitted using GFRP composites while the remaining three beams served as reference beams for this category of beams.

In group II beams, twenty one flexure beams designed to fail in flexure were cast and tested to compare the flexure behavior of the beams wrapped with GFRP composites to that of the unwrapped beams. Nine of the twenty one flexure beams were strengthened and another nine of them were retrofitted using GFRP composites in three different wrapping patterns while the remaining three beams served as reference beams for this category of beams.

In group III beams, nine shear beams designed to fail in shear were cast and tested to compare the shear behavior of the beams with GFRP composites to that of the unwrapped beams. Three of the nine shear beams were strengthened and another three retrofitted using GFRP composites while the remaining three beams served as reference beams for this category of beams.

Three of the nine columns were strengthened and another three retrofitted with GFRP composites to study the load carrying capacity of these columns to that of the unwrapped columns while the remaining three columns served as control columns for this category.

Three of the nine frame specimens were strengthened and another three retrofitted using GFRP composites to study the effectiveness of GFRP composites in load carrying capacity while the remaining three frames served as control frames for this category.

Numerical analysis were also performed using finite element package ABAQUS to simulate the behavior of R.C.C. beams and R.C.C. frames with and without GFRP composites wrapping and the results obtained were compared with experimental results.

Based on the experimental and analytical study and the analysis of test results the following conclusions were arrived at:

CONCLUSIONS

The revised design codes consist of stringent requirements for seismic resistance. The structures built in India before code revisions were seismically deficient. The performance of these structural elements may be very poor under lateral loads due to earthquake. If such elements are strengthened with GFRP composites, their life span can be extended, and due to mild earthquake, the whole structure sometimes may not collapse but some of the structural elements might be slightly damaged. If such elements are retrofitted with GFRP composites, their life span can be extended as they can perform well by the increase in

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load carrying capacity. The ductile behavior and stiffness characteristic of the specimens were also improved.

- Load carrying capacity of normal strengthened beam and normal retrofitted beam increased by 12.58 % and 5.64 % respectively than the unwrapped normal beam.
- Load carrying capacity of strengthened flexure beam and retrofitted flexure beam with full portion wrapping increased by 13.35 % and 8.34 % respectively than the unwrapped flexure beam.
- Load carrying capacity of strengthened flexure beam and retrofitted flexure beam with bottom half portion wrapping increased by 10.01 % and 6.68 % respectively than the unwrapped flexure beam.
- Load carrying capacity of strengthened flexure beam and retrofitted flexure beam with middle one third portion wrapping increased by 6.68 % and 4.17 % respectively than the unwrapped flexure beam.
- Load carrying capacity of shear beam strengthened and retrofitted with GFRP in shear zone increased by 11.69 % and 6.54 % respectively than the unwrapped shear beam.
- Load carrying capacity of strengthened column and retrofitted column wrapped with GFRP increased by 15.19 % and 10.55 % respectively than the unwrapped column.
- Load carrying capacity of frame strengthened and retrofitted with GFRP increased by 16.07 % and 10.02 % respectively than the unwrapped normal frame.
- Ductility factor of normal strengthened beam and normal retrofitted beam increased by 46.90 % and 73.10 % than the unwrapped normal beam.
- Ductility factor of flexure strengthened beam with different wrapping patterns increased by 57.57 % for full portion wrapping, 32.34 % for bottom half portion wrapping and 27.75 % for middle one third portion wrapping than the unwrapped flexure beam.
- Ductility factor of flexure retrofitted beam with full portion wrapping pattern increased by 58.03 % and other two types wrapping did not show any ductility increment.
- Ductility factor of shear strengthened beam and shear retrofitted beam increased by 103.43 % and 60.00 % respectively than the unwrapped shear beam.
- Ductility factor of strengthened frame and retrofitted frame increased by 62.53 % and 56.14 % respectively than the unwrapped normal frame.
- Energy absorption capacity of normal strengthened beam and normal retrofitted beam increased by 49.15 % and 42.37 % respectively than the unwrapped normal beam.
- Energy absorption capacity of flexure strengthened beams with three different wrapping patterns increased by 42.51 % for full portion wrapping, 42.08 % for bottom half portion wrapping and

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17.68 % for middle one third portion wrapping than the unwrapped flexure beam.

Based on the experimental results, it was concluded that the R.C.C. elements and R.C.C. frames which were externally wrapped in full portion with GFRP composites produced higher load carrying capacity, ductility factor, energy dissipation capacity and stiffness. Hence, external wrapping of GFRP composites could be effectively utilized in seismic strengthening and also in seismic retrofitting of R.C.C. elements and R.C.C. frames.

RECOMMENDATIONS FOR FUTURE WORK

Based on the research work presented the following recommendations for future research are proposed.

- Present research work concentrated only on single layer GFRP wrapping. It can be extended to two or more layers.
- Alternate fibers with single and multiple layers of wrapping can be studied.
- This research work was limited to static load only, the research can be extended for dynamic loads also.

REFERENCES

[1]. Adhikary, BB & Mutsuyoshi, H 2004, ‘Behaviour of concrete beams strengthened in shear with carbon-fibre sheets’, Journal of Composites for Construction, vol. 8, no. 1, pp. 258-264.

[2]. Alam, MJ, Ali, H, Ahmed, E & Paul, A 2001, ‘Repair and strengthening of existing R.C.C. structural elements for future earthquake’, Proceedings of first International conference and annual paper meet on civil engineering, pp. 130-134.

[3]. Alfarabisharif, Al, Sulaimani, GJ, Basunbul, IA, Baluch, MH & Ghaleb, BN 1994, ‘Strengthening of initially loaded reinforced concrete beams using FRP plates’, ACI Structural Journal, ACI, vol. 91, no. 2, pp. 160-169.

[4]. Amer, M & Mohammed, SH 2009, ‘Finite element modelling of reinforced concrete beams strengthened with FRP laminates’, European Journal of Scientific Research, vol. 30, no. 4, pp. 526-541.

[5]. Antonyjeyasehar, C & Ravichandran, K 2012, ‘Cyclic behaviour of beam column joint retrofitted with SIMCON laminates’, Asian Journal of Civil Engineering, vol. 14, no. 2, pp. 269-288.

[6]. Arduini, M & Nanni, A 1997, ‘Behaviour of precracked R.C. beams strengthened with carbon FRP sheets’, ASCE Journal of Composite Construction, vol. 1, no. 2, pp. 63–70.

[7]. Arduini, M & Nanni, A 1997, ‘Parametric study of beams with externally bonded FRP reinforcement’, ACI Structural Journal, vol. 94, no. 5, pp. 493–501.

[8]. Attari, N, Amziane, S & Chemrock, M 2008, ‘Strengthening reinforced concrete beams using hybrid FRP laminates’, Fourth international conference on FRP composites in civil engineering, pp. 1-6.

[9]. Ayman, S, Mosallam & Swagata Banerjee 2007, ‘Shear enhancement of reinforced concrete beams strengthened with FRP composite laminates’, Journal of Composites, vol. 38, no. 2, pp. 781-793.

[10]. Balamuralikrishnan, R & Antony Jeyasehar 2009, ‘Flexural behaviour of R.C.C. beams strengthened with

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

carbon fiber reinforced polymer (CFRP) fabrics', Bentham, The Open Civil Engineering Journal, vol. 3, no. 1, pp. 102-109.

[11]. Barbato, M 2009, 'Efficient finite element modelling of reinforced concrete beams retrofitted with fibre reinforced polymers', Journal of Computers and Structures, vol. 87, no. 1, pp. 167-176.

[12]. Bazaa, IM, Missihoun, M & Labossiere, P 1996, 'Strengthening of reinforced concrete beams with CFRP sheets', Proceedings of the first international conference on composites in infrastructures, pp. 746-759.

[13]. Bhutta, S 1993, Analytical modelling of hybrid composite beams, M.S thesis, Virginia Polytechnic Institute and State University, Blacksburg.

[14]. Bogao, Leung Chritopher KV & Kim Jang Kyo 2007, 'Failure diagrams of FRP strengthened R.C.C. beams', Composite Structures', vol. 77, no. 4, pp. 493-508.

[15]. Brena, SF & Schlick, BM 2007, 'Hysteretic behaviour of bridge columns with FRP-Jacketed lap splices designed for moderate ductility enhancement', Journal of Composites for onstruction, ASCE, vol. 11, no. 6, pp. 565-574.

[16]. Brena, SF, Bramblett, RM, Wood, SL & Kreger, ME 2003, 'Increasing flexural capacity of reinforced concrete beams using carbon fibre-reinforced polymer composites', ACI Structural Journal, vol. 100, no. 1, pp. 36–46.

[17]. Chaalla, O, Nollet, MJ & Perraton, D 1998, 'Shear strengthening of R.C. beams by externally bonded side CFRP strips', Journal of Composites for Construction, vol. 2, no. 2, pp. 111- 113.

[18]. Chajes, MJ, Januszka, TF, Mertz, DR., Thomson, TA & Finch, WW 1995, 'Shear strengthening of reinforced concrete beams using externally applied composite fabrics', ACI Structural Journal, vol. 92, no. 3, pp. 295–303.

[19]. Chajes, MJ, Thomson, TA, Januszka, TF & Finch, W 1994, 'Flexural strengthening of concrete beams using externally bonded composite materials', Construction and Building Materials, vol. 8, no. 3, pp. 191-201.

[20]. Chandrasekaran, P & Malathy R, ' Strength study of Concrete with colour adsorbed flyash', Journal of Technology World, Malaysia, vol.5, no. 1, pp. 421-426

[21]. Datduthinh & Monicastarnes 2004, 'Strength and ductility of concrete beams reinforced with carbon fibre-reinforced polymer plates and steel', Journal of Composites for Construction, vol. 8, no. 1, pp. 59-69.

[22]. Engindeniz, M, Kahn, LF & Zureick, AH 2005, 'Repair and strengthening of reinforced concrete beam-column joints – State of the art', ACI Structural Journal, vol. 102, no. 2, pp. 187–97.

[23]. Faza, SS & GangaRao, HVS 1994, 'Fibre composite wrap for rehabilitation of concrete structures', Proceedings of materials engineering conference, pp. 1135–1139.

[24]. Ferracuti, B, Savoia, M & Mazzotti, C 2006, 'A numerical model for FRP-concrete delamination', Journal of Composites, vol. 37, no.2, pp. 356-364.

[25]. Grace, NF, Sayed, GA, Soliman, AK, & Saleh, KR 1999, 'Strengthening of reinforced concrete beams using fibre reinforced polymer (FRP) laminates', ACI Structural Journal, vol. 96, no. 5, pp. 865-875.

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

[26]. Guidocamata, enrico spacone & roko zarnic 2007, 'Experimental and non linear finite element studies of R.C.C. beams strengthened with FRP plates', Journal of Composites, vol. 38, no. 2, pp. 277-288.

[27]. Hamidsaadatmanesh, Mohammed, R, Eshsani & Limin Jin 1997, 'Repair of earthquake damaged R.C.C. columns with FRP wraps', ACI Structural Journal, vol. 94, no. 2, pp. 206-215.

[28]. Hibbitt, Karlsson & Sorensen 2000, ABAQUS Theory Manual, User Manual and Example Manual, Version 5.8, Providence, RI.

[29]. Ilki, A & Kumbasar, N 2002, 'Behaviour of damaged and undamaged concrete strengthened by carbon fibre composite sheets', Structural Engineering Mechanics, vol. 13, no. 1, pp. 75–90.

[30]. IS 10262-1982, Recommended Guidelines for Concrete Mix Design, Indian standard code of practice, BIS, India.

[31]. IS 13920-1993, Ductile Detailing of Reinforced Concrete Structures subjected to seismic forces, Indian standard code of practice, BIS, India.

[32]. IS 13935-1993, Repair and Seismic Strengthening of Buildings-Guidelines, Indian standard code of practice, BIS, India.

[33]. IS 1893-2002, Criteria for Earthquake Resistant Design of Structures, Indian standard code of practice, BIS, India.

[34]. IS 383-1970, Specification for Coarse and Fine Aggregate from Natural Sources for Concrete, Indian standard code of practice, BIS, India.

[35]. IS 516- 1959, Method of Test for Strength of Concrete, Indian standard code of practice, BIS, India.

[36]. Karabinis, AI, & Rousakis, TC 2006, 'FRP confining effects on steel reinforced concrete square sections subjected to axial load', Proceedings of the second FIB International Congress, pp. 88-95.

[37]. Karam, G & Tabbara, M 2005, 'Confinement effectiveness in rectangular concrete columns with fibre reinforced polymer wraps', Journal of Composites for Construction, vol. 9, no. 5, pp. 388–396.

[38]. Limam, O, Foret, G & Ehrlacher, A 2003, 'RC beams strengthened with composite material: a limit analysis approach and experimental study', Composite Structures, vol. 59, no. 4, pp. 467- 472.

[39]. Malek, AM & Patel, K 2002, 'Flexural strengthening of reinforced concrete flanged beams with composite laminates', ASCE Journal Composites Construction, vol. 6, no. 2, pp. 97–103.

[40]. Meier, U & Kaiser, H 1991 'Strengthening of structures with CFRP laminates', Advanced Composite Materials, vol.10, no.1, pp. 224-232.

[41]. Mostofinejad, D & Talaeitaba, SB 2006, 'Finite element modelling of R.C. connections strengthened with FRP laminates', Iranian Journal of Science and Technology, Transaction , Engineering, vol. 30, no.1, pp. 21-30.

[42]. Muratengindeniz, Lawrence, F, Kahn & Abdul Hamid Zureick 2005, 'Repair and strengthening of reinforced concrete beam column joints: State of the art', ACI Structural Journal, vol.102, no. 2, pp. 1-14.

[43]. Mutsuyoshi, H 2004, ' Behaviour of concrete beams strengthened in shear with carbon fibre sheets', Journal of Composites for Construction, vol. 8, no. 3, pp. 258-264.

[44]. Nanni, A 1993, 'Flexural behaviour and design of R.C. members using FRP reinforcement', Journal of

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

Structural Engineering, vol. 119, no.11, pp. 3344–3359.
[45]. Natarajan, C, Shen-En Chen & Mohiuddin Syed 2010, 'Rehabilitation and preservation of the St. Lourdes Church, Thiruchirapalli', ASCE Journal of Performance of Constructed Facilities, vol. 24, no. 3, pp. 281-288.
[46]. Niemitz, CW, James, R & Brena, SF 2010, ' Experimental behaviour of carbon fibre- reinforced polymer (CFRP) sheets attached to concrete surfaces using CFRP anchors', Journal of Composites for Construction, vol. 14, no.2, pp. 185-194.
[47]. Obaidat, YT, Heyden, S & Dahlblom, O 2010, 'The effect of CFRP/ CFRP and concrete interface models when modelling retrofitted RC beams with FEM', Composite Structures, vol. 92, no.1, pp. 1391–1398.
[48]. Pannirselvam, N, Raghunath, PN & Suguna, K 2008, 'Strength modelling of reinforced concrete beam with externally bonded fibre reinforcement polymer reinforcement', American Journal of Engineering and Applied Sciences, vol. 1, no. 3, pp. 192-199.
[49]. Pellegrinocarlo & Modenaclaudio 2006, 'Fibre-reinforced polymer shear strengthening of reinforced concrete beams: Experimental study and analytical modelling', ACI Structural Journal, vol. 103, no. 5, pp. 720-728.
[50]. Perera, R, Recuero, A, De Diego, A & Lopez, C 2004, 'Adherence analysis of fibre reinforced polymer strengthened R.C. beams', Journal of Computers and Structures, vol. 82, no. 1, pp. 1865-1873.
[51]. Ramana, VPV, Kant, T, Morton, SE, Dutta, PK, Mukherjee, A & Desai, YM 2000, 'Behaviour of CFRP strengthened reinforced concrete beams with varying degrees of strengthening', Composites: Part B, vol. 31, no. 1, pp. 461–70.
[52]. Ritchie, PA, Thomas, DA, Lu, LW & Connelly, GM 1991, 'External reinforcement of concrete beams using fibre reinforced plastics', ACI Structural Journal, vol. 88, no. 3, pp. 490–500.
[53]. Robertravi, S & Princearulraj, G 2010, 'Experimental investigation on the behaviour of R.C.C. beam column joint retrofitted with GFRPCFRP hybrid wrapping subjected to load reversal', International Journal of Mechanics and Solids, vol. 5, no. 1, pp. 61-69.
[54]. Saadatmanesh, H & Ehsani, MR 1990, 'Fibre composite plates can strengthen beams', American Concrete Institute, Concrete International, Design and Construction, vol. 12, no. 3, pp. 65-71. 55. Sadjadi, R, Ziari, A & Kianoush, MR 2010, 'Experimental study of R.C. rectangular liquid containing structures retrofitted with GFRP composites', Applied Composite Materials, vol. 17, no. 2, pp. 195-207.
[55]. Sandeep, S, Pendhari, Tarun kant & Yogesh, M, Desai 2008, 'Application of polymer composites in civil construction, a general review', Composite Structures, vol. 84, no. 2, pp. 114-124.
[56]. Santhakumar, R, Chandrasekaran, E & Dhanaraj, R 2004, 'Analysis of retrofitted reinforced concrete shear beams using carbon fibre composites', Electronic Journal of Structural Engineering, vol. 4, no. 1, pp. 66-74.
[57]. Santhakumar, R, Kannabiran, S & Dhanaraj, R 1999, 'Strengthening of reinforced concrete beams using glass fibre reinforced plastic laminates', The Indian Concrete Journal, vol. 15, no. 3, pp. 737–740.
[58]. Sergio, F, Brena & Geoffrey, N, Mcguirk 2013, 'Advances on the behaviour characterization of FRP-anchored carbon fiber-reinforced

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

polymer (CFRP) sheets used to strengthen concrete elements', International Journal of Concrete Structures and Materials, vol. 7, no. 1, pp. 3-16.

[59]. Shahawy, MA, Arockiasamy, M, Beitelman, T & Sowrirajan, R 1996, 'Reinforced concrete rectangular beams strengthened with CFRP laminates', Composites Engineering, vol. 27, no.2, pp. 225-233.

[60]. Shamshersingh 2013, 'Shear response and design of R.C. beams strengthened using GFRP laminates', International Journal of Advanced Structural Engineering', vol. 15, no. 16, pp. 1-16.

[61]. Sharif, Alfarabi, Al-sulaimani, GJ, Basunbul, IA, Baluch, MH & Ghaleb, BN 1994, 'Strengthening of initially loaded reinforced concrete beams using plates', ACI Structural Journal, vol. 91, no. 2, pp. 160-168.

[62]. Srikalyanarama, J & Pandurangarao, B 2013, 'Strengthening of plain and reinforced concrete plate using fibre reinforced polymer- Computational approach', International Journal of Civil and Structural Engineering, vol. 4, no. 1, pp. 47-55.

[63]. Tarasen & Jagannatha Reddy, HN 2011, 'A numerical study of strengthening of R.C.C. beam using natural bamboo fibre', International Journal of Computer Theory and Engineering', vol. 3, no. 5, pp.707-713.

[64]. Teng, TG, Cheng, JF, Smith, ST & Lam, L 2002, FRP Strengthened R.C. Structures, John Wiley and Sons.

[65]. Urmil, V, Dave & Patel Hardik, B 2012, 'Flexure strengthening of reinforced concrete beams using near surface mounted FRP reinforcements', The IUP Journal of Structural Engineering, vol. 5, no. 2, pp. 28-50.

[66]. Vijay, PV & GangaRao, HVS 2001, 'Bending behaviour and deformability of glass fibre reinforced polymer reinforced concrete members', ACI Structural Journal, vol. 98, no. 6, pp. 834–842.

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731