FIBER RAINFORCED POLYMER SHEAR STRENGTHENING OF RC BEAMS USING GFRP SHEETS

C.Praveen Kumar[1]& P.Shifana[2] & Dr.P.Paramaguru[3]
[1] PG Scholar, Department of Environmental Engineering (FT), Ponnaiyah Ramajayam Institute of Science and Technology, Tamilnadu, India
(e-mail: sespraveen95@gmail.com)
[2] Assistant Professor, Department of Civil Engineering, Ponnaiyah Ramajayam Institute of Science and Technology, ECR-Chennai, Tamilnadu, India

ABSTRACT

An experimental investigation on the shear behavior of RC beams strengthened with externally bonded glass fiber reinforced polymer (GFRP) sheets. The externally applied GFRP technique is significantly effective to enhance the ultimate load carrying capacity of RC beams. Two beams without GFRP and nine beams wrapped in different lay-up patterns with one/two layers of GFRP sheets have been tested for shear under two-point loading. Loads at first crack of beam/delaminating of GFRP, tearing point of GFRP and ultimate failure of the beam has been noted and types of failure have also been observed. Thereafter, a critical discussion is made with respect to increase in the strength of retrofitted beams with respect to the beam without GFRP in order to explore the optimal use of GFRP for strengthening the RC beams. The comparison is also made between the shear strength obtained from experimental results and that predicted from different design proposals available in the literature.

Keywords: Failure mode; GFRP fabrics; RC beam; shear; strengthening

INTRODUCTION

Rehabilitation of deteriorated civil engineering infrastructure such as buildings, bridge decks, beams, girders, parking structures, marine structures, roads, etc. has been a major issue in the last decades. The deterioration of these structures is mostly owing to ageing, poor preservation, corrosion, aggressive environmental circumstances, poor early intend or construction errors and accidental situation like earthquakes. The up gradation of the deteriorated civil engineering infrastructure is greatly influenced by the demand of the nation. Consequently rehabilitation of the accessible civil engineering communications has been acknowledged as an important issue nowadays. Fiber reinforced polymer (FRP) is the popular retrofitting material as used in rehabilitation of the existing structure and strengthening of the new civil engineering structures. There are two major types of failure that takes place in the reinforced concrete (RC) beams. The two main failure modes of RC beams are governed by flexure and shear. Flexural failure of an RC beam is ductile in nature, whereas shear failure has a catastrophic effect. When an RC beam is deficient in shear strength and is over loaded, shear failure may occur suddenly without any advance warning of distress, because it is brittle in nature. Shear deficiency of the beam might happen due to numerous reasons such as inadequate shear reinforcement or lessening in steel district due to corrosion, augmented design service load, and building errors.

The use of fiber-reinforced polymer (FRP) composite materials has gained its popularity in the strengthening of RC structures applications during the last three decades. This is due to its numerous advantages over the conventional retrofitting methods such as enlarging beam’s sections or using steel plates. These compensation comprise high strength-to-weight ratio, effortlessness of installation, deterioration resistance, versatility, and sturdiness of the FRP composites. Many studies that have been conducted to investigate strengthening of RC structures by the EBR technique proved that bonding FRP sheets to concrete substrate improved the flexural and shear capacity of the structural elements. However, the main drawback of this method is debonding of the FRP laminates from the concrete substrate before utilizing the FRP tensile strength. To increase the effectiveness of the utilization of FRP tensile strength, complete and partial wrapping were introduced. Ideally, completely wrapped RC beams have proven to be effective in terms of delaying FRP debonding failure. In addition, it utilizes the effective strain in the CFRP sheets. However, this wrapping scheme cannot always be implemented due to the presence of geometrical obstructions, since in most of the cases RC beams are connected to the slabs. Accordingly, U-Wrapped scheme is the most commonly used in the shear strengthening of RC structures

Shear failures are usually sudden and brittle, since the internal forces do not get redistributed. Therefore, it is vital that RC beams have sufficient shear capacity to prevent such sudden failures. In general, the three ways in which the FRP laminates can be bonded to RC beams to strengthen them in shear includes side-bonded, where the laminates are bonded to the vertical sides of the beam; U-wrapped, where the laminates are bonded to the sides of the beam as well as the tension face in a U-shaped manner; and completely wrapped, where the laminates are bonded around the beam. Studies proved that completely wrapped beams perform the best in terms of enhancing the shear capacity and ductility of RC beams. This is due to the higher attained effective strain along the fibers' vertical direction than that with side-bonded and U-wrap strengthening schemes. However, practically it cannot be implemented in many cases, where the beams are connected to the slabs. Hence, U-wrapped scheme is the most commonly used method to strengthen RC beams in shear

RELATED WORKS

In [1] Jinan L. Abbas, Suhad M. Abd et al presents analytical investigations of reinforced concrete beams strengthened in shear with U-shaped carbon fiber reinforced polymer warps and strips .Six beams are used in this study which are separated into two collection regarding to loading span and strengthening scheme. One beam for each group was kept as a organize beam while the additional two beams for each group were strengthened with U-shaped CFRP wraps in the shear span and U-shaped CFRP wraps in trim span every beside with CFRP strip on the soffit of the beam. A three dimensional finite constituent exploration ANSYS computer curriculum is conduct to revise the presentation of the strengthened beams in shear with outwardly bonded U-shaped CFRP in terms of functional load-deflection and applied load- strain in the main bottom flexural reinforcement at the location of maximum instant. The finite element reproduction are residential using a tarnished rupture advance for material, three dimensional solid elements for concrete, three dimensional solid elements for steel plate, and three dimensional covered elements for carbon -fiber reinforced polymers wrap. The consequences acquire from finite element investigation are compared with available experimental results. The analytical results showed that carbon fiber-reinforced polymer acts as anchorage and can improve the capacity of the strengthened beams and the strengthened beams having small values of shear distance to depth ratio not succeed in a diagonal compression shear malfunction method. The assessment gives good correctness.

In [2] G. M. Chen, J. F. Chen, J. G. Teng, et al presents RC beams shear strengthen with externally bond fiber-reinforced polymer U strips or side strips usually fail owing to debonding of the bonded FRP shear reinforcement. Because such debonding typically happen in a brittle manner at moderately small shear crack widths, some of the internal steel stirrups intersected by the serious shear crack could not have reached yielding at beam shear breakdown. As a result, capitulate stress of inside steel stirrups in such a strengthened RC beam cannot be fully utilized. This difficult shear interaction connecting the internal steel shear reinforcement and the outside FRP shear reinforcement might significantly reduce the benefit of the shear increase FRP but has not been considered explicitly by numerous of the shear strength models in the existing intend guidelines. This paper presents an innovative shear strength model considering this adverse shear interaction through the introduction of a shear interaction factor. A wide-ranging evaluation of the projected representation as well as three other shear strength models is conduct using a large test database. It is exposed that the proposed shear strength model performs the most excellent amongst the models compared, and the performance of the other shear strength models can be appreciably improved by including the proposed shave interaction factor. Finally, a devise recommendation is presented.

In [3] Ahmed B. Shuraim et al presents the results of an investigation on shear strengthening of RC beams externally reinforced with CFRP composite. A totality of six full-scale beams of four CFRP strengthened and two unstrengthened were experienced in the absence of internal stirrups in the shear span. The strengthening configurations contained two styles: discrete consistently spaced strips and customized extensive strips over B-regions. The composite systems provided an augment in ultimate strength as compared to the unstrengthened beams. Among the three layouts that had the same area of CFRP, the highest contribution was providing by the customized layout that besieged the B-regions. A comparative learning of the experimental results with published empirical equations was conduct in order to appraise the unspecified effective strains. The empirical equations were found to be unconservative. Nonlinear finite element models were urbanized for the beams. The reproduction agreed with test consequences that targeting the Bregion was more effectual than distributing the same CFRP area in a discrete strip style over shear spans. Moreover, the numerical models predicted the contribution of different configurations better than the empirical equations.

In [4] V. Colotti, R.N. Swamy et al presents a rational model to predict the ultimate load capacity of reinforced concrete (RC) beams strengthened by a combination of longitudinal and transverse fiber reinforced polymer (FRP) composite plates/sheets (flexure and shear strengthening system). The reproduction is based on the truss analogy and the supposition of plasticity and is opportunely sophisticated in order to integrate various dangerous aspects, such as variable angle crack, non-uniform FRP stress distribution more than the shear crack, shear span/depth ratio. It is an all-purpose and combined reproduction that allows deliberation of every the major probable failure mechanisms of strengthened RC beams, connected to flexural-shear interaction, shear web-crushing and unpolluted flexural mechanisms. The model is validated alongside a large number of beam tests report in the journalism, involving a wide range of geometrical and mechanical characteristics. The numerical investigation shows a very satisfactory correlation between predicted and experimental data. As a result, very large numbers of structures are in need of strengthening. Therefore, the development of effective, durable, inexpensive and unobtrusive rehabilitation techniques represents a formidable challenge facing the construction industry in the next years.

In [5] Tara Sen, Shubhalakshmi, H.N.Jagannatha Reddy, et al presents numerous of the existing reinforced concrete structures all during the earth are in urgent require of rehabilitation, renovate or reconstruction because of deterioration due to a assortment of factors resembling corrosion, lack of detailing, failure of bonding connecting beam-column joints, increase in service loads, etc., leading to cracking, spelling, loss of strength, deflection, etc. The topical developments in the application of the higher composite in the building production for concrete rehabilitation and strengthening are increasing on the basis of precise requirements, nationwide needs and industry contribution. The demand for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in examines and progress of composite strengthening systems. Fiber Reinforced Polymer compound has been established in the building industry as a capable substitute for repair and in incrementing the potency of RCC structures. FRP composites obtain various exceptional properties such as: confrontation to corrosion, good quality fatigue and damping resistance, high strength to weight ratio, and electromagnetic clearness. FRPs over the years have gained respect in terms of its greater performance and versatility and now are being used not only in housing manufacturing but its potentials are being continuously discover for its use in retro-fitting and strengthening of damaged structural members

Reinforced Concrete (RC)

Reinforced Concrete (RC) is one of the common and widespread building materials in the world. Many structures like bridges, buildings etc. uses reinforced concrete as their principal construction material. Due to various reasons, these structures face reduction in their strength. So that there is a possibility that the structure should not take its designed load. So these structures or parts of it are not fulfilling their structural functions due to defects on the concrete caused by corrosion, poor construction practices, accidental damage, fire damage or deterioration caused by environmental action. Whereas some reinforced concrete structures need to be upgraded due to design and construction faults and in cases of load increment or damage induced to the structural members by the earthquake or any other action. Also, there is construction of many structure in paste designed by older codes are became unsafe with introduction to newer codes. So replacing these deficient structures requires huge investments and is not a viable option, hence strengthening of structure is only appropriate way for increasing the load capacity and prolonging their service life.

FRP composites

FRP composites are useful in increasing strength and ductility without increasing stiffness. So in recent times using externally bonded FRP composites plates concrete members can be easily and effectively strengthened. By wrapping FRP sheets, strengthening of concrete structures provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low heaviness, corrosion confrontation, high fatigue resistance, effortless and speedy installation and negligible modify in structural geometry.

GFRP configuration for beams

To check the effect of strengthening, beams were wrapped by different types of GFRP configurations for all three categories of beams. For full strength beam category, one beam was control beam without GFRP sheet (CB1) where other two beams were wrapped by full side wrapping (S1) and full bottom wrapping (F1), respectively. For beam weak in shear category, one beam was control beam (CBS1), where other beams were wrapped by full side wrapping (BS2), middle 0.5 depth at sides (BS3), rectangular strips of 50 mm width @ 50 mm spacing at sides (BS4), rectangular 45° inclined sheets of 50 mm width @ 50 mm spacing (BS5) and U-wrapping (BS6), respectively. For beam weak in flexure category, one beam was control beam (CBF1), where other beams were wrapped by middle 0.5 width of bottom (BF2), full bottom (BF3), middle 0.5 length at bottom (BF4), rectangular strips of 50 mm width @ 50 mm spacing at bottom (BF5) and U-wrapping (BF6), respectively

Glass Fiber Reinforced Polymer (GFRP)

Glass Fiber Reinforced Polymers were among the oldest and least expensive of all composite materials. GFRP sheet having fiber oriented in both longitudinal and transverse directions was used. GFRP sheet and epoxy resin both were procured. The epoxy resin was used to attach the GFRP sheet to the beam surface which was mixer of Part A and Part B (2 : 1). Before bonding the composite fabric onto the concrete surface, the concrete surface was made rough using grinder. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with manufacturer’s instructions. Mixing was carried out in metal container (Part A: Part B :: 2:1) and was continued until the mixture was in uniform color. When this was completed and fabric had been cut to the size, the epoxy resin was applied to the concrete surface. The composite fabric then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with plastic laminating roller. This operation was carried out at room temperature.

Experimental investigation

The experimental investigation aims to study the structural performance of retrofitted RC beams with GFRP fabrics. A total of 11 beams of equal cross sectional dimensions were casted, out of which, two beams were taken as control beam (without GFRP) and the remaining nine beams were retrofitted with GFRP fabrics with various methods of strengthening scheme. All these beam specimens were tested under two point loading. Details of casting of beam specimens, testing of GFRP fabrics, wrapping of GFRP fabrics on beams, experimental setup, testing and observations are presented in the following sub-heads.

Casting of specimen

Rectangular concrete beams having cross-sectional dimensions of 120 mm × 150 mm and a total length of 1,000 mm were casted with M20 grade concrete and Fe 415 grade steel. Three concrete cubes of size 150 mm were casted along with the casting of each beam. The beams and cubes were allowed for 28 days curing in water.

GFRP fabrics

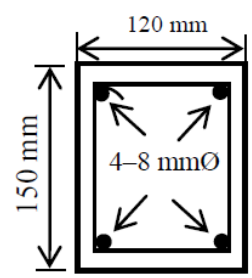


Fig Dimensions and reinforcement detailing of RC beam cross section

In this experiment, GFRP fabric was used as an external strengthening material made up of by stitching cross glass fibres of 0.275 mm thick. Four GFRP coupons of the specified dimensions as shown in Figure 2 were prepared and tested in INSTRON as per ASTM D7565 – 10(2017) up to failure. Thereafter, the mean of the various test parameters such as peak load, breaking load, % strain at 0.2% yield, strain at peak, % strain at break, stress at 0.2% yield, ultimate tensile strength and young's modulus was found to be 7.280 kN, 6.442 kN, 1.231, 4.069, 4.084, 101.4 Mpa, 236.5 MPa and 9,825 MPa respectively.

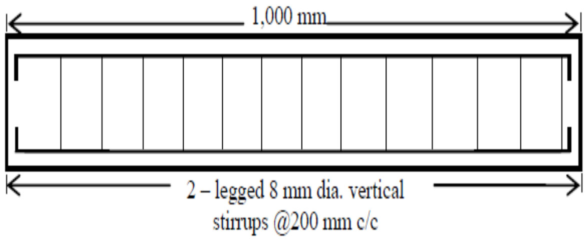


Fig Dimensions and reinforcement detailing of RC beam longitudinal section

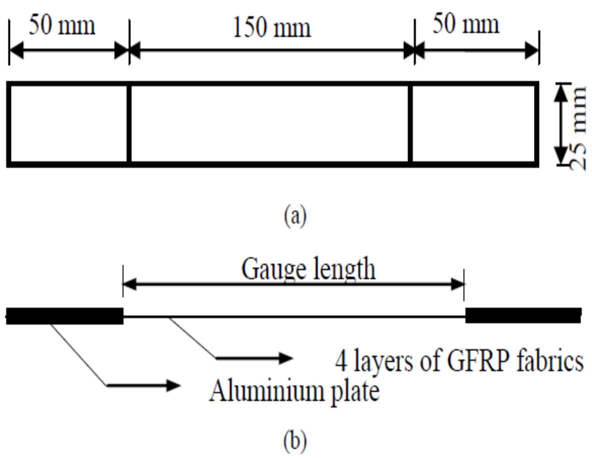
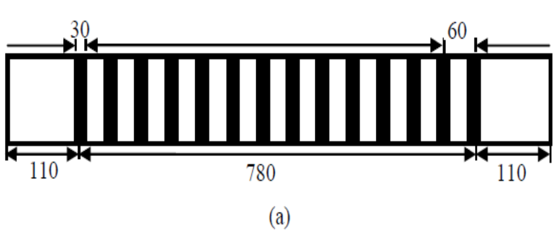


Fig Dimension of a typical GFRP coupon, (a) top view (b) side view

Wrapping of GFRP fabrics

In order to obtain the effectiveness of the retrofitted RC beams with GFRP fabrics, the beams were wrapped with different layers and lay-up schemes. Two beams were kept as control beam (without GFRP) and were designated as the beam type B1 and B2. Other two beams were wrapped with GFRP fabrics of one and two layers, respectively on two lateral sides of the beam and designated as BLS1 and BLS2.



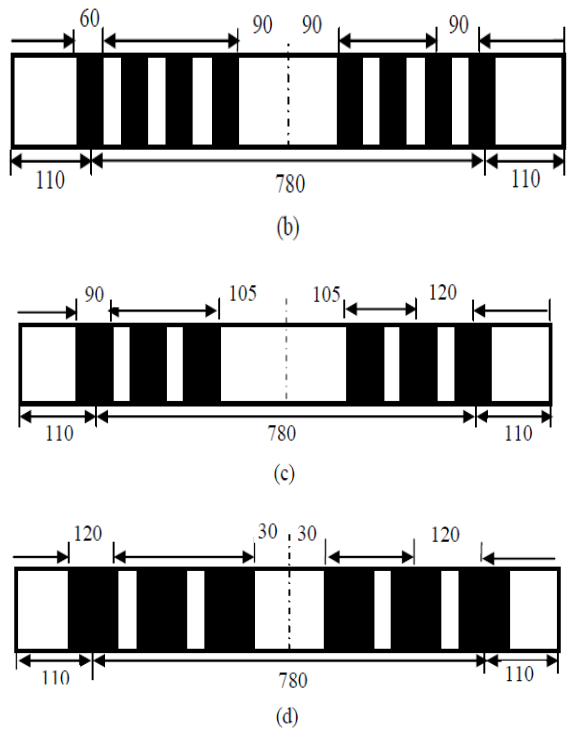


Fig Schematic diagrams of wrapping of beams with different layers and lay up schemes of GFRP, (a) BU1 and BU2 (b) BU3 and BU4 (c) BU6 (d) BU7 and BU8

Two beams designated as BU1 and BU2 were wrapped with U-jacketing single and double layer vertical GFRP strips, respectively of 30 mm with a spacing of 60 mm. Similarly, the beams BU3 and BU4 were wrapped with single and double layer U-jacketing vertical strips of 60 mm with a spacing of 90 mm, respectively and BU7 and BU8 were wrapped with the single and double layer with 120 mm vertical strips with a spacing of 150 mm, respectively. Only one beam BU6 was wrapped with double layer U-jacketing vertical strips of 90 mm width with a spacing of 120 mm. Before wrapping with GFRP in wet lay-up system, a standard procedure was followed to ensure a well-prepared surface of concrete for proper bonding between concrete and GFRP. Then, epoxy and hardener were mixed together in ratio 9:1 form a homogeneous binding paste. Thereafter, the paste was brushed on the prepared concrete surface. Then, wrapping of GFRP was made layer-wise and pressed with a roller to remove any air void. Finally, the specimens were kept for seven days air curing before the testing.

Testing and observation

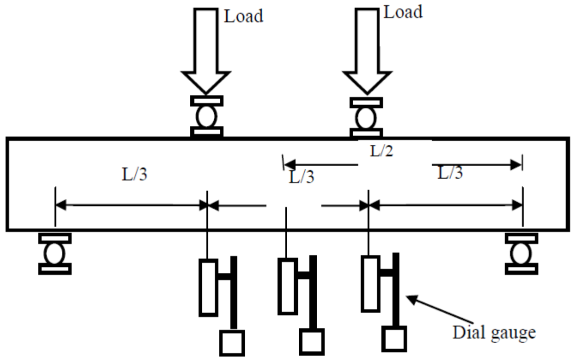


Fig schematic diagram

The beam specimens were tested in the universal testing machine (UTM-1,000 kN) under two-point loading. The load, at which the first visible crack/delamination was developed, was recorded as the cracking/delamination load. Then the load was applied up to the failure of the beam. The deflection at three salient points of the beams were recorded with respect to increase in the load by fixing three LVDT gauges at L/3, L/2 and 2L/3 locations from the left support where L is the centre to centre distance between both the supports. The experimental setup with its schematic diagram and the complete test setup in UTM is shown in Figures 5 and 6, respectively. During the testing, it was observed that all the 11 beams tested were almost similar behaviour in the initial stage of loading except one beam. It is because that the failure of all the beams except BU7 occurred in flexural failure whereas the failure of the beam BU7 was due to shear. In the case of beam B1, the first flexural crack appeared at the mid-span of the beam at a load of 37 kN. With the increase in load several flexural cracks were observed and finally, the beam failed due to wide cracks developed from the bottom fibre and crushing of concrete in top fibre of the beam at a load of 90 kN. Similarly, when the beam B2 was subjected to two point loading, 1st flexural crack appeared at a load of 70 kN. When the load increased, several flexural cracks appeared. The final failure of the beam was occurred at a load of 89.85 kN

In the beam BLS1 at a load of 90 kN, it was observed that the de-bonding started in the lower part of the front side towards right loading point with very mild sound. When the load increased, the de-bonding occurred on the lower side of the beam near the right loading point as shown in Figure and then lower part of the side GFRP sheet was separated. Thereafter, the flexural cracks developed near the right loading point which propagated vertically upwards and widened. Finally, flexural failure occurred at 91.2 kN with the tearing of side GFRP sheets near the right loading point and crushing of concrete at the top part of the beam at that location. Finally, the failure of beam BLS1 occurred after de-bonding of the lower part of side GFRP sheet at the mid-span.

CONCLUSION

The experimental study is carried out in order to study the shear behavior of RC beams retrofitted by GFRP fabrics. The shear strength capacity of RC beams retrofitted with continuous FRP fabrics of different layers on two lateral sides of the beams (BLS1 and BLS2) is higher than that of control beams (B1 and B2). Shear strength of the above beams increases with the increase in the number of layers (thickness). The enhancement of shear strength of beams retrofitted with isolated U-shape jacketing GFRP fabric strips is not encouraging, which contradicts the results available in the literature. All the beams except BU7 failed due to flexure. However, BU7 failed in shear only. It is due to fact that the beams considered in the present study are flexural deficient, but not shear deficient. Therefore, the full capacity of shear strength could not be achieved at the time of failure and hence, enhancement of shear strength of RC beams with isolated U-shape jacketing GFRP fabric strips could not be observed. In order to obtain the effectiveness of isolated U-shape jacketing GFRP fabric strips, RC beams may be a shear deficient one. Predictions of the ultimate shear capacity by different authors from the literature are in good agreement with that obtained from the experimental investigation. Above concluding remarks can be improved by carrying out the further investigation with retrofitting of a shear deficient beam using isolated U-shape vertical/inclined FRP fabric strips.

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