Shear Strengthening of Reinforced Concrete Beams with Different Glass Fiber Fabric Strip Width and Adhesive Thickness

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***Abstract*—This paper presents the results of experimental research to examine the contribution of Glass Fiber Fabric in improving the shear resistance of simply supported reinforced concrete beams. A total of fifteen beams of five sets with dimensions of 100 x 150 x 1100 mm, 2Φ10mm tension reinforcement, 2Φ8mm hanger bars, and Φ6mm shear reinforcement placed at 200mm, were produced and tested. The five sets of beams are namely G1, G2, G3, G4, G5. The sets of beams named G1 is referred to as the control beams or reference beams, they are without external Glass Fiber Fabric as shear reinforcement. The 'G2' sets of beams were strengthened externally with Glass Fiber Fabric as shear reinforcement. The 'G2' had a Glass Fiber Fabric of 1mm thickness, a glue thickness of 6mm (Epoxy resin of Sikadur(R)-31), a Glass fiber fabric strip width of 120mm, and a spacing strip interval of 200mm. The 'G3' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G3' had a Glass Fiber Fabric of 1mm thickness, a glue thickness of 3mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 120mm, and a spacing strip interval of 200mm. The 'G4' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G4' had a Glass Fiber Fabric of 1.5mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm. The 'G5' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G5' had a Glass fiber fabric of 1mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm. The configuration schemes used were U-shaped wrapping of the section using Glass Fiber Fabric. The purpose was to establish a better understanding of the shear contribution of Glass Fiber Fabric. The results confirmed that the bonded Glass Fiber Fabric considerably improved the shear resistance of the reinforced concrete beams, and also indicate that the externally adhered Glass Fiber Fabric can change the mode of failure from brittle shear failure to flexural failure.**

Keywords— Glass Fiber Fabric; Adhesive Thickness; Strip Width; U-Shaped Wrapping; Shear Contribution

I. Introduction

The failures experienced by an existing reinforced. The concrete member may be due to carbonation and chloride-induced corrosion of internal reinforcements, poor design, or excessive loading, however referring to the [1], a structure of any form or size must meet the design requirements, all through the course of construction and its entire existence. Therefore, in an attempt to increase the shear performance and to control cracking, several parts of a structure may have to be rehabilitated. Correspondingly it is both economically and environmentally preferable to be strengthened externally rather than to demolish and reconstruct. There are numerous means obtainable for strengthening structural elements. The most commonly used methods employed in strengthening reinforced concrete structure subjected to flexure, for example, beam element, are those conventional methods like the bonding of steel plates externally, external prestressing, and additional concreting with longitudinal steel bars at the tensile face; and recently using structural epoxy resin to bond carbon fiber reinforced polymers (CFRP) to structural elements externally. The CFRP composites have been used since the 1940s to carry out functions in various disciplines such as engineering,

Juvandes et al.,[2]. The combination of polymers with carbon fibers has proven to be a reliable alternative in the strengthening of structures and has occupied an outstanding position in the building industry because of its satisfactory performance. And the most recognized technique for strengthening, is the practice of external bonding of fiber-reinforced polymer sheets or laminates and fiber fabrics in engineering

application. Most research results published is based on the bending moment capacity of concrete beams strengthened with
FRP composites ([3]; [4]). Due to the sudden nature of shear failure in concrete beams, understanding the complex mechanism of this failure is a necessity. (e.g. [5]; [6]) The primary concentration of previous studies has been on the shear strengthening of simply supported beam elements using carbon-fiber-reinforced polymer (CFRP) sheets or laminates. Very few investigations had centered on FRP strip width, spacing of strips as links, and adhesive thickness on U-wrap configuration. The configuration schemes commonly used are full wrapping, complete side wrap, or U-wrap of the section using CFRP sheet.
Chen and Teng, [7]; Khalifa and Nanni, [8] have publicized that FRP laminates or sheets effectively increases the shear strength of concrete beam elements. but, despite the various experiments, the shear performance of reinforced concrete beams strengthened externally with FRP hasn't been carefully examined, and the database of such research [9] is insufficient for detail design guidance.
Saeed et.,al [10] present the results of an experimental study to examine the contribution of carbon-fibre reinforced polymer sheets in improving the shear capacity of continuous, two-span reinforced concrete beam elements. A total of five, continuous reinforced concrete beams with rectangular cross-section were investigated. One beam was without shear strengthening as the reference and the remaining four beams were strengthened with a different configuration of polymer sheets. They aimed to develop a better understanding of the shear contribution of polymer and to study the cost-effectiveness by reducing the area of bonded polymer sheets externally. Study results were validated with four shear prediction models existing in the literature. The results show that the polymer sheet significantly improved the shear capacity of the beams and that the area of polymer sheet can be reduced with minimal compromise on the shear carrying strength of strengthened concrete beams.
American Concrete Institute [9] design procedures or guidelines for shear strengthening of reinforced concrete beam elements externally with CFRP are established on empirical design expressions established by Khalifa et al. [11] and Triantafillou and Antonopoulos [12], respectively. The simple addition of the individual contributions of the concrete, Vc, internal steel stirrups, Vs, and the external FRP composites, Vf, resulting in a simple expression to give the nominal shear strength, V_n

$$V_n = V_C + V_S + V_f \quad (1)$$

The Concrete Society published reviewed design guidelines in 2004 for shear strengthening of beams with FRP in the second edition of TR55 [13]. The design guidelines were based on [14] work and take the place of the initial recommendations in TR55, which were formulated from the publication of [13]. The required FRP's is computed as the least of three different equations. Based on TR55 recommendations, the first strain limit is taken as the average FRP strain once fracture occurs. The second strain limit is taken at the point of debonding of FRP and the third limit is to limit the loss of aggregate interlock based on experience as a result of excessive crack widths. The value of the design stress in the FRP is calculated by multiplying the required strain by the design elastic modulus, which is the same as the characteristic value divided by the safety factor governed by the FRP type and mode of application and is usually about 1.2.
Bukhari et al. [15] reexamined existing shear strengthening design guidelines with CFRP sheets and recommended a modification to TR55. The results of an experimental study that examined the contribution of CFRP sheets to the shear capacity of continuous reinforced concrete beams were depicted. A total of seven, continuous concrete beams with two-span having rectangular cross-sections were investigated. Bukhari et al. [15] recommended a procedure for shear strengthening with FRP that is in line with EN1992.
Triantafillou [16] method for computing effective strain was modified by Khalifa et al. (1998). The experimental study samples used by Khalifa et al. [11] were two different FRP materials (carbon and aramid) and three different wrapping schemes (sides wrapping only, U-shaped wrapping, and complete wrapping), with both continuous strips and sheets of FRP. Khalifa et al. [11] developed expressions from a regression analysis of experimental test results and recommended that the design shear capacity of shear strengthening should be calculated by multiplying each component in equation (1.0) given above by reduction factors equal to 0.85 for V_c and V_s and 0.70 for V_f.
Anand and Kavitha [17] present the results of an experimental study intended to evaluate the shear behavior of reinforced concrete beams strengthened externally with a steel plate. A total of four concrete beams were tested in this research. The study beams were designed to fail in shear. Consequently, they were strengthened in shear using various patterns of steel plates and angles which was connected by the weld and glued to the beams by epoxy adhesive. Research outcome confirmed an improvement in the shear capacity of the strengthened beams, mostly in the post-yield range of loading as a result of the partial composite effect. The configuration of steel plate strips played an important role in the performance of the strengthened beams. The failure of the strengthened beam due to the peeling of steel plates has been avoided.
The purpose of this experimental investigation is to establish a better understanding of the shear contribution of Glass Fiber Fabric and to look into the

possibility of reducing the bonded Glass Fiber Fabric area and the adhesive thickness.

II. MATERIAL AND METHODS

A total of fifteen beams of five sets with dimensions of 100 x 150 x 1100 mm, 2Φ10mm tension reinforcement, 2Φ8mm hanger bars, and Φ6mm shear reinforcement placed at 200mm, were produced for this research. The five sets of beams are namely G1, G2, G3, G4, G5. The sets of beams named G1 is referred to as the control beams or reference beams, they are without external Glass Fiber Fabric as shear reinforcement. The 'G2' sets of beams were strengthened externally with Glass Fiber Fabric as shear reinforcement.

The 'G2' had a Glass Fiber Fabric of 1mm thickness, a glue thickness of 6mm (Epoxy resin of Sikadur(R)-31), a Glass fiber fabric strip width of 120mm, and a spacing strip interval of 200mm center to center.

The 'G3' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G3' had a Glass Fiber Fabric of 1mm thickness, a glue thickness of 3mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 120mm, and a spacing strip interval of 200mm.

The 'G4' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G4' had a Glass Fiber Fabric of 1.5mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm.

The 'G5' sets of beams were strengthened externally with Glass fiber fabrics as shear reinforcement. The 'G5' had a Glass fiber fabric of 1mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm. See Table 1.0 and Fig. 1.0 for sample description.

TABLE 1: BEAM TYPES

Set of Beams	Adhesive Thickness (mm)	Glass fibre thickness (mm)	External Reinforcement Strip width	Number of Tests specimen
G1	-	-	-	**# 3**
G2	**6**	**1**	**120**	**# 3**
G3	**3**	**1**	**120**	**# 3**
G4	**5**	**1.5**	**90**	**# 3**
G5	**5**	**1**	**90**	**# 3**

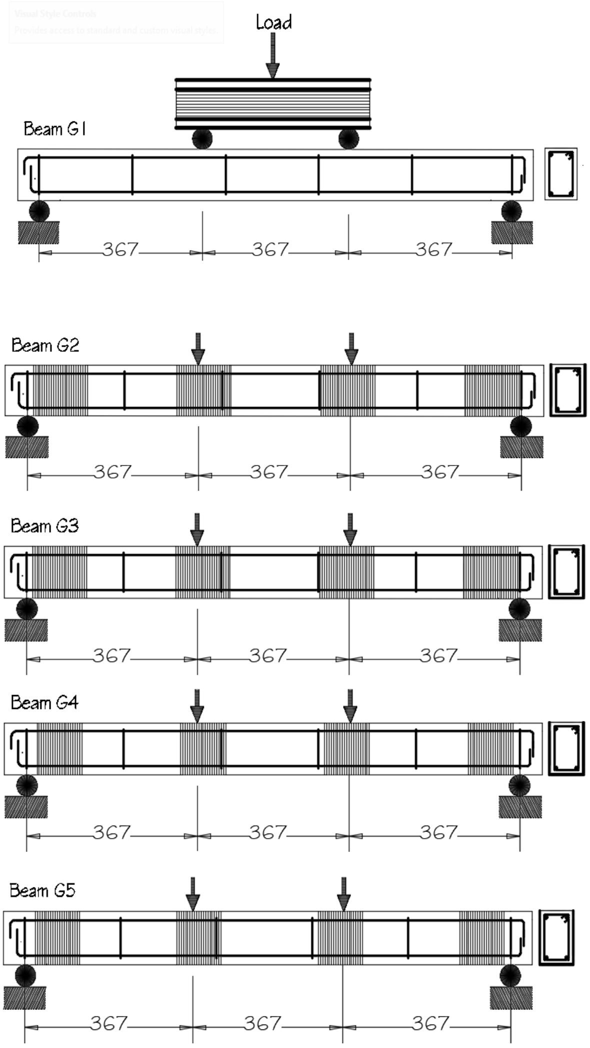

Fig.1. *Reinforced concrete beam showing strengthening configuration (in mm)*

A. Test Setup

The five sets of beams were subjected to two-point loads at the one-third of the span as depicted in Fig. 2. The load was applied with a hydraulic jack and was controlled manually. The beams were loaded gradually, and readings were recorded manually. Dial gauge was used to measure vertical deflections at the midspan. The dial gauge was positioned at the mid-depth of all the beams. Initial cracks and crack patterns were observed at each increment in load. Cracks were traced with a permanent marker on each side of the test beams throughout loading.

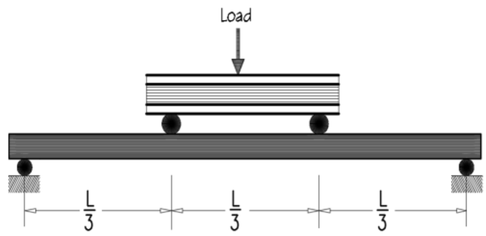

Fig. 2. Test Setup

III. RESULT

The study results of the Shear strengthening of the reinforced concrete beam with different Glass Fiber Fabric strip width and adhesive thickness is presented here in this section. First crack loads, deflections at first crack loads, ultimate failure loads, and deflections at ultimate failure loads of all the test beams are tabulated in Table 2.0, and their mode of failures can be understood in Fig. 5. Fig. 4 shows the load-carrying capacity of each beam type. Out of the five set of beams tested.

TABLE 2: Experimental results

Sets of beams	First crack load, Pc (kN)	Deflection at first crack load (mm)	Ultimate failure load, Pu (kN)	Deflection at ultimate failure load (mm)	Failure mode
G1	28.70	2.85	35.4	3.87	Flexure/ Splitting
G2	32.61	4.84	42.5	6.55	Flexural/de-bonding
G3	28.95	3.76	41.3	6.70	Flexural/de-bonding
G4	31.69	4.60	39.2	5.93	Flexural/de-bonding
G5	27.48	2.92	40.3	5.19	Flexural/de-bonding

TABLE 3. Glass Fibre Fabric shear contribution

Sets of beams	Ultimate failure load, Pu (kN)	Experimental shear force (kN)	Glass fibre reinforced polymers contribution to shear(kN)
G1	35.4	17.71	-
G2	42.5	21.25	3.55
G3	41.3	20.65	2.95
G4	39.2	19.6	1.9
G5	40.3	20.15	2.45

IV. DISCUSSION

A. Failure loads

The G1 beams were not strengthened and were used as a control beam. The first crack appeared at a load of 28.70 kN, the first crack appeared directly at the mid-span due to flexural stresses. As the load increases, the crack becomes visible. The G1 set of beams failed by flexure at an average load of 35.4 kN

G2 beams were strengthened U-shaped wrapping configuration with a Glass fiber fabric of 1mm thickness, a glue thickness of 6mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 120mm, and a spacing strip interval of 200mm. The first crack was flexural and was noticed at a load of 32.61 kN. As loading increased, shear cracks also appeared and became noticeable. The G2 beams failed at an averaged load of 42.5 kN which is 20% higher than the failure of G1 as a result of the Glass fiber fabric. Also, the deflection at ultimate failure was 1.7 times higher than that attained in G1. The G2 beams were able to contribute 3.55kN shear strength before Glass fiber fabric de-bond from the system.

G3 beams were strengthened U-shaped wrapping configuration with a Glass fiber fabric of 1mm thickness, a glue thickness of 3mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 120mm, and a spacing strip interval of 200mm. The first crack was seen at a load of 28.95 kN. G3 beams exhibited shear cracks also with an increase in load application. The presence of the Glass Fiber Fabric intercepts the crack from spreading further. The ultimate failure occurred at a load of 41.3 kN. The G3 beams contributed 2.95kN shear strength after that, the Glass Fiber Fabric de-bond. A comparison of G3 with control beam G1 revealed that the load-carrying capacity was 17% higher than that of G1. Deflection at ultimate failure was 1.73 times greater than that G1 beam. The deflection and the failure load of the G3 beam were smaller than those in the G2 beam.

Beam G4 was strengthened U-shaped wrapping configuration with a Glass fiber fabric of 1.5mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm. Cracking occurred due to flexural stresses at a load of 31.69 kN. The crack location was again at the mid-span. The beam failed at 39.2 kN, 11% higher than the control beam G1. The deflection at failure was 1.5 times the control beam G1. Comparing beam G4 with beams G2 and G3 reveals that the load-carrying capacity and deflection decreased in the case of G4. This could be a result of the reduction of the strip area.

Beam G5 was strengthened U-shaped wrapping configuration with a Glass fiber fabric of 1mm thickness, a glue thickness of 5mm (Epoxy resin of Sikadur(R)-31), a Glass Fiber Fabric strip width of 90mm, and a spacing strip interval of 200mm. First cracking crop up due to flexural stresses at a load of 27.48kN. The beam failed at 40.3 kN, 14% higher than the control beam G1. The deflection at failure was 1.34 times the control beam G1. The comparison also with beams G2 and G3 reveal that the load-carrying capacity and deflection decreased in the case of G5. This could be also due to the reduction of the strip area.

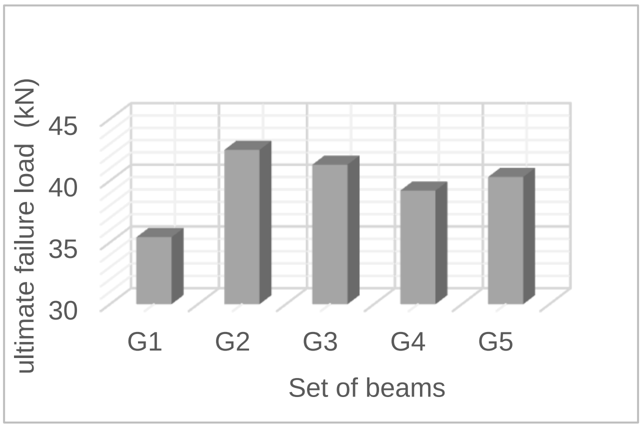

Fig. 3. Failure load of the beams sample

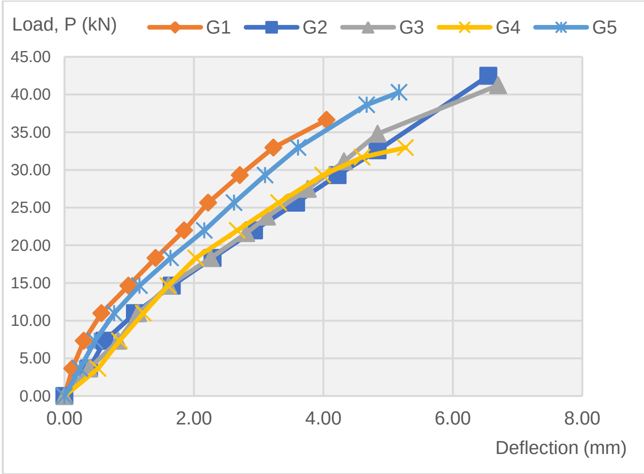

Fig. 4. Load against deflection experimental results

B. Shear Strength

Table 3 shows that the shear resistance of simply supported reinforced concrete beams can be significantly improved by strengthening with Glass Fiber Fabric externally using Epoxy resin of Sikadur(R)-31) as adhesive. Considering the drawing depicted in Fig.2 confirms that there is a significant reduction of 33% in the surface area of Glass Fiber Fabric used in beam G4 and G5 compared with that in beam G2 and G3. Yet, the shear contribution of the Glass Fiber Fabric of beam G4 and G5 was only 5.4% less than G2 and G3. Satisfactory results can also be attained with less surface area of Glass fiber fabric dependent on woven configuration of the fabrics. The shear strength contributed by G2, G3, G4, and G5, is 3.55kN, 2.95kN, 1.9kN, and 2.45kN respectively.

C. Load–Deflection Behaviour

The study results depicted in Fig. 3 of the load against the deflection plot showed that the reference beam, G1, was significantly stiffer than all the Glass Fiber Fabric strengthened beams. The deformations of all the strengthened reinforced concrete beams at failure were higher than that of the reference beam. The highest deflection was monitored in beam G3. Increased deflection in all strengthened beams could be caused by significant post-yield elongation of the existence of internal reinforcing steel and exhibited a comparatively reduced crack width and spacing,

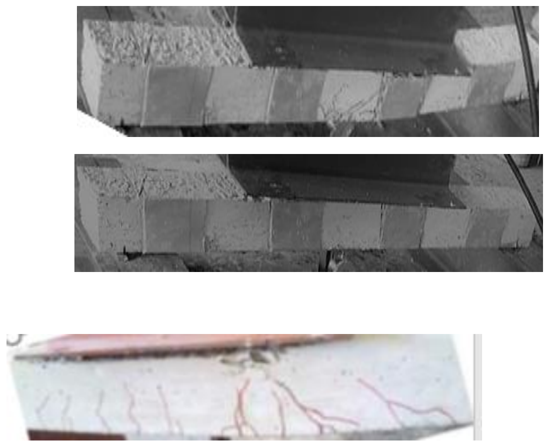

Fig. 5. Crack pattern

V. CONCLUSION

From the experimental investigation, intended at improving the shear strength reinforced concrete beam elements by strengthening with Glass Fiber Fabric externally using Epoxy resin of Sikadur(R)-31) as adhesive which study outcome was examined and the following conclusions were drawn:

I. Study results showed an improvement in the shear strength of the beams strengthened externally, especially in the post-yield range of loading as a result of the composite effect.
II. With a reduced Glass Fiber Fabric surface area, Satisfactory results can be attained depends on the adhesive thickness.
III. The mid-span deformation at the ultimate failure load of Glass fiber fabric strengthened beams was higher than the control beam.
IV. Test results established that the externally adhered Glass Fiber Fabric can change the mode of failure from brittle shear failure to flexural failure.
V. The bonded Glass Fiber Fabric present in the beam element changes the cracking pattern.

REFERENCES

[1] ABNT (2003) Associação Brasileira de Normas Técnicas. NBR6118: Projeto de estruturas de concreto – procedimento. Rio de Janeiro.

[2] Juvandes, L. F. P.; Marques, A. T.; Figueiras, J. A. (1996.) Materiais compósitos no reforço de estruturas de betão. Porto: Faculdade de Engenharia da Universidade do Porto, (Technical Report, p. 112).

[3] Duthinh D and Starnes M (2004) Strength and ductility prediction of concrete beams reinforced with carbon fiber-reinforced polymers plates and steel. ASCE Journal of Composites for Construction 8(1): 59–69.

[4] Hassan T and Rizkalla S (2004) Bond mechanism of near-surface mounted fiber-reinforced polymer bars for flexural strengthening of concrete structures. ACI Structural Journal 101(6): 830–839.

[5] Al-Amerya R and Al-Mahaidi R (2006) Coupled flexural-shear retrofitting of RC beams using CFRP straps. Composite Structures 75(1): 475–464.

[6] Chajes MJ, Januska TF, Mertz DR, Thomson TA and Finch WW (1995) Shear strengthening of reinforced concrete beams using externally applied composite fabrics. ACI Structural Journal 92(3): 295–303.

[7] Chen JF and Teng JG (2002) Shear capacity of FRP-strengthened RC beams: FRP rupture. Journal of Structural Engineering 129(5): 615–625.

[8] Khalifa A and Nanni A (2002) Rehabilitation of rectangular simply supported RC beams with shear deficiencies using CFRP composites. Construction and Building Materials 16(3): 135–146.

[9] ACI (2002) ACI Committee 440: Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures. ACI, Farmington Hills, MI, USA.

[10] Saeed Ahmad, Ayub Elahi, Salim Barbhuiya and Abdul Ghaffar (2011) Shear strengthening of reinforced concrete continuous beams. Proceedings of the Institution of Civil Engineers, publishing.

[11] Khalifa A, Gold W, Nanni A and Abdel-Aziz MI (1998) Contribution of externally bonded FRP to the shear capacity of RC flexural members. Journal of Composites for Construction 2(4): 195–202.

[12] Triantafillou TC and Antonopoulos CP (2000) Design of concrete flexural members strengthened in shear with FRP. Journal of Composites for Construction 4(4): 198–205.

[13] Concrete Society (2004) Design Guidance for Strengthening Concrete Structures using Fibre Composite Materials, 2nd edn. Concrete Society, Camberley, UK TR55.

[14] Denton SR, Shave JD and Porter AD (2004) Shear strengthening of reinforced concrete structures using FRP composites. In Advanced polymer composites for structural applications in construction (Holloway LC, Chrissanthopoulos MK and Moy SSJ (eds)). Woodhead, Cambridge, UK, pp. 134–143.

[15] Bukhari IA, Ahmad S, Vollum RL and Sagaseta J (2010) Shear strengthening of reinforced concrete beams with CFRP. Magazine of Concrete Research 62(1): 65–77.

[16] Triantafillou TC (1998) Shear strengthening of reinforced concrete beams using epoxy-bonded FRP composites. ACI Structural Journal 95(2): 107–115.

[17] Anand D and Kavitha A. (2015) Shear Strengthening of Reinforced Concrete Beams using Various Configurations of Steel Plates. IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 03, ISSN (online): 2321-0613, page 282-285.