Experimental Study on Shear Strengthening of RC Beam using Glass Fiber Reinforced Polymer Sheets

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Abstract— The strengthening is required to increase strength of the existing structures to meet current requirements of loadings and to restore the original strength of the structures that are damaged by accidents or earthquakes. A lot of strengthening work is carried out using FRP composites for flexure strengthening of beams and the confinement of the columns, but the studies on the use of the composite material for the strengthening shear deficient concrete structures are limited and mostly by using CFRP sheets. The shear failure of concrete is catastrophic because of the brittle nature and no advanced warning prior to the failure. Therefore it is often necessary to pay more attention to the shear strength of the concrete structure. The behavior of reinforced concrete structure in shear is itself quite complex that has not been completely resolved due to many influencing parameters such as amount of longitudinal reinforcement, shear span to depth ratio, grade of the concrete etc. If we add different varying parameters of fiber such as type of fiber, its orientation, thickness the problem becomes more complex. The shear strengthening by using FRP is still under investigation and the results obtained are scare and controversial. The experimental database available is also very less. The objective of this paper is to increase the shear capacity of the beams using externally bonded Glass Fiber Reinforced Polymer (GFRP) sheets, to provide an experimental database to study the effect of fiber orientation, wrapping pattern (side wrap and U jacketing) by keeping other parameters constant and most importantly to compare analytical models and check its suitability for the design members strengthened using GFRP sheets.

Key words: FRP, Glass Fiber Reinforced Polymer (GFRP) RC Beam, Shear Strength

I. INTRODUCTION

There are number of situation where the load-carrying capacity of a structure in service may need to be increased, such as change in load occupancy or damage of the structure. With the deterioration of the nation’s infrastructure comes the growing need for the effective means of the rehabilitation of the structures. Possibly this will be one of the most challenging tasks in the coming years.

In the past the strength was increased by, casting additional reinforced concrete or do welling in additional reinforcement. Few year back concrete structures have been strengthened by bonding steel plates to the surface of the tension zone with adhesive and bolts. Even more recently the use of fiber reinforced polymer plates, generally containing carbon fibers, has been developed using the same basic technique as for steel plate bonding. An appreciable number of structures have been strengthened using FRP materials and the rate at which the technique is being used is increasing rapidly. However there is a little data available on how to carried out design of shear strengthening work. The lack of independent guidance is leading to reluctance to adopt this technique.

The Shear failure is a brittle and catastrophic failure, this in reality occurs under the combined action of shear forces and bending moments. Therefore the behavior of the RC beam where the shear is predominant over the flexure is studied so as to understand possible modes of shear failure.

II. METHODOLOGY

To increase the shear strength of reinforced concrete member, FRP sheets can be used. It can be seen that wrapping a FRP sheets around the column member improving shear strength easily. However shear strengthening of beam is likely to be more problematic because of difficulty occurs on anchoring the FRP sheet at the beam-slab junction. But anchoring FRP sheets on the side faces and soffit will provide shear strengthening for such members.

The amount of additional strength that may be achieved is dependent on several factors including the wrapping scheme, the amount, orientation and type of FRP, the existing concrete strength, and the nature of the loads and support conditions. The Side wrapping and U-wrapping scheme with change in orientation of FRP has been studied to improve the shear strength of beams. The overall beam shear strength is significantly dependent on the aggregate interlock, interfacial bond between the FRP and concrete (especially in the case of partially wrapped beams) and strain at FRP at failure. These phenomenons will become evident in the design procedure. The design criteria for shear strength of RC beam, shear contribution of concrete ($V_{c)}$), stirrups ($V_{s)}$) and FRP ($V_{f)}$) presented in different codes and research papers.

Some of these codes to calculate the shear strength of the concrete ($V_{c)}$) are as follows:

1) IS 456:2000
2) ACI 318:1999 Code
3) BS 8110:1997
4) JSCE 1986 (Japanese Code)
5) Joint ACI-ASCE Committee (1973)
6) Rangan Equation (1971)

To calculate the shear capacity of the FRP reinforced beams ($V_{f)}$), different codes and equations are proposed by different researchers are as follows:

1) ACI 440.2R:2003 Code
2) Concrete Society Technical Report No. 55
3) Equation proposed by Khalipa
4) Equation proposed by Chajes

III. ANALYSIS AND DESIGN

The control beam is designed as under reinforced having its flexural capacity more than the shear capacity to ensure shear failure. The shear strength is expressed in terms of the total load under two- point loading. Four different wrapping configurations are considered and the shear contribution of GFRP sheet is calculated by the equations.

No.	Beam Configuration	Beam Notation
1	Unwrap Control Beam	CB
2	Wrapping in shear zone on both sides of the beam with 0° fiber orientation is in longitudinal axis.	GB-0
3	Wrapping in shear zone on both sides of the beam with 90° fiber orientation to the longitudinal axis.	GB-90
4	Wrapping in shear zone on both sides of the beam with 45° fiber orientation with longitudinal axis.	GB-45
5	Wrapping in shear zone on both sides and at bottom of the beam with 90° fiber orientation to the longitudinal axis.	GB-U

Table 1: Shear Strengthening Configuration

The beams are designed in such a way that even after shear strengthening, the beams should fail in shear so as to calculate the shear capacity of the beam. Thus the shear failure was the dominant mode of the failure. Therefore the control beam, under two point loading is designed as deficient in shear but strong in flexure by keeping sufficient margin between ultimate shear capacity and ultimate flexural capacity.

The beam is designed as per the IS456:2000 by neglecting the factor of safety to calculate the ultimate capacity of the section. The length breadth and depth of all concrete beams is considered as 1500 x 150 x 250mm.

Table 2 shows that the shear strength of the beam is expressed in terms of total load W than the shear resistance (VR) so that it would become more convenient and easy to compare theoretical and experimental results.

Beam	V_c (KN)	V_s (KN)	V_f (KN)	V_R (KN)	$W=2V_R$ (KN)	W_f (KN)
CB	32.34	15.54	—	47.88	95.76	—
GB-0	32.34	15.54	16.03	63.91	127.82	32.06
GB-90	32.34	15.54	16.03	63.91	127.82	32.06
GB-45	32.34	15.54	22.70	70.58	141.16	45.40
GB-U	32.34	15.54	28.44	76.32	152.64	56.88

Table 2: Analytical Shear Strength of FRP Strengthened Beam

Comparison of Shear capacity with different codes and equations are tabulated in table 3.

Beam	Theoretical total Load W (KN)				
	ACI	Concrete Society	Khalipa	Chajes	Proposed
CB	95.76	85.76	95.76	95.76	95.76
GB-0	121.74	108.84	142.14	124.62	127.82
GB-	121.74	108.84	142.14	124.62	127.82
GB-	132.50	118.40	161.34	136.56	141.16
GB-	124.70	108.84	142.14	124.62	152.64

Table 3: Comparison of Shear Capacity

IV. EXPERIMENTAL WORK

The testing of cement, fine aggregate, coarse aggregate and steel are carried out. The mix design was prepared for required mix and the casting of beams was done as per analytical model. The unidirectional glass fiber sheets of required thickness are specially weaved. The shear strengthening work is done by externally bonding single layer of unidirectional Glass fiber sheet having effective thickness 0.095mm. The testing of beams is carried out under two point flexural loading up to the failure.

The sequences of experimental work are as follows:

A. Testing of Materials

1) Testing of Cement
2) Testing of aggregates
3) Testing of Steel
4) Properties of Glass Fiber
5) Properties of Epoxy

B. Concrete Mix Design

C. Casting of Beam

D. Strengthening of the Beam

1) Surface Preparation
2) Application of Primer
3) Application of Putty
4) Mixing and Application of Adhesive
5) Application of Fiber Sheet to Concrete Surface

E. Testing of Beams

All the beams were tested under simply supported condition. The testing was done under two-point flexural loading as shown in the figure 1. The load was applied to the beam using universal testing machine of capacity 1000KN.

The deflection is measured at three different points,-under two point loads and at the center of the beam. The measurement of deflection is done with the help of dial gauges (least count 0.01mm). The diagonal strains are calculated by measuring the deformation between the strain points and dividing it by the distance between the strain points (200mm). All beams are tested statically up to the failure of beam in a single load cycle.

Fig. 1: Testing of the Beam

V. TESTING RESULTS

For different intervals of load values, deflections at three different points and strains at four positions in the shear zone are measured. Comparative graphs of load-midpoint deflection and load-strain on failure side are plotted. The ultimate failure load is considered as the maximum load prior to the load shedding.

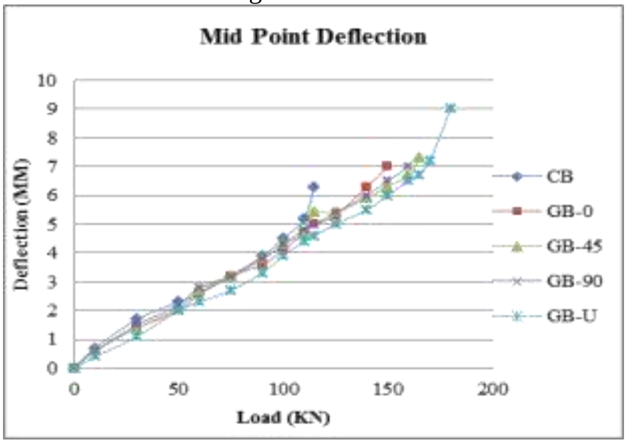

Fig. 2: Comparison of Mid-Point Deflection

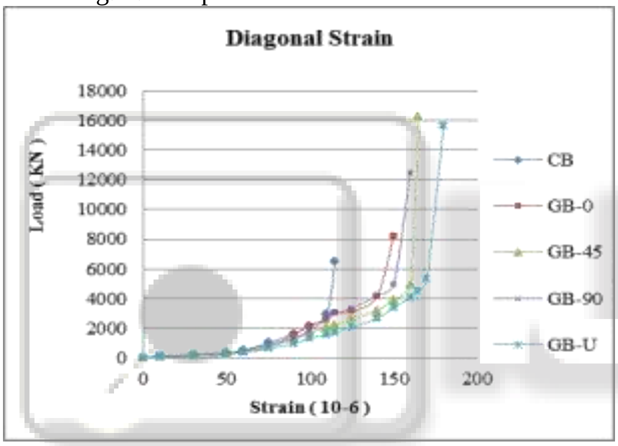

Fig. 3: Comparison of Strain

VI. DISCUSSION

A. *Behavior of Beams*

All the beams failed in the shear between the strain points by developing diagonal shear crack in the shear span zone. The strengthened beams wrapped with externally bonded GFRP sheets failed at higher ultimate load than the control beam. The GFRP fabric did not debond prior to the failure. The behavior of various beams under two point loading is given below.

1) *Control Beam (CB)*

In the control beam, at a load of 75KN the first shear crack appeared at neutral axis and on the tension side (below the neutral axis) in the shear zone of the beam.

The crack inclination was about 45° to the axis of the beam and the crack propagated in the compression zone with further increase in the load. With the propagation of crack in the compression zone (above the neutral axis), the inclination of crack reduced and additional shear crack was appeared in the shear span zone about an inclination of 45° to the axis of the beam. The beam finally failed in shear at ultimate load of 112-115KN. The diagonal strain measured in the shear zone of the beam increased slowly up to the appearance of the first shear crack and thereafter increased at faster rate up to the failure. The diagonal strain just before failure was 0.003 to 0.0031.

2) *Side Wrap-0 Beam (GB-0)*

For the beams, wrapped with GFRP sheet on sides of the beam with primary fiber orientation 0° to the axis of the beam, diagonal shear stretch was observed in the FRP at a load of about 80KN. The position of this stretch was same as that of the shear crack appeared in the control beam. Then the beam continued to carry more loads and at load of 142-146KN the beam suddenly failed in the shear. Just before the failure, very large increases in the diagonal strains were observed. The FRP did not debond prior to the failure. The GFRP fractured in the zigzag form with the development of diagonal crack in concrete tension zone.

3) *Side Wrap-90 Beam (GB-90)*

For the beams, wrapped with GFRP sheet on the sides of beam with fiber inclination perpendicular to the axis of the beam, the first shear stretch was appeared in FRP at a load of 80KN as that of the beam wrapped with 0° side inclinations. The inclination of shear stretch was diagonal to the axis of the beam. With further increased in the load, along with major shear stretch few minor stretches were appeared on the tension side and propagated towards load on compression side in the shear span zone of the beam.

4) *Side Wrap-45 Beam (GB-45)*

The beams wrapped on sides with primary fiber orientation 45° to the axis of the beam, the appearance of diagonal shear stretch in FRP was observed in the shear zone at a load of 90KN. The inclination of the stretch was about 45° to the axis of the beam. With further increase in the load, the stretch become wide and it propagated in the backward direction on the tension side of the beam. The propagation of diagonal shear crack in the compression zone was not observed. The beam finally failed in shear on the tension side of the beam at an ultimate load of 164-167KN. The failure was takes place suddenly by bursting of FRP sheet.

5) *U Wrap Beam (GB-U)*

In case of U wrapped beam, the diagonal shear stretch was observed in the FRP on the tension side of the beam at a load of 85KN. With further increased in the load, the shear stretch propagated in the compression side with reduced inclination. The beam finally failed in shear with fracture of FRP sheet observed in place of shear stretch at a load of 180-181KN. The width of crack was more on tension side and it goes on reducing towards compression side. The diagonal strain value just before the failure was 0.0051-0.0053.

B. *Comparison of the Results*

The experimental results shows that increase in shear strength of FRP strengthened beams in the ascending order as observed from the experimental investigation as shown in Table 4.

Beam	Average Ultimate Shear Strength (KN)	% Increase in Shear Strength over Control Beam	Average Midpoint Deflection at failure Load of control beam (mm)	% Reduction over control specimen
Control	113.5	—	5.25	—
Side-0	144.0	26.87	4.65	11.42

Side-90	154.0	35.68	4.75	09.52
Side-45	165.5	45.37	4.55	13.33
U-wrap	180.5	59.03	4.3	18.09

Table 4: Effect of Strengthening on Shear Strength and Deflection

VII. CONCLUSION

1) A prediction of shear contribution of GFRP sheet is comparatively more accurate than the shear strength of RC beam.
2) The prediction of shear strength of RC beam by IS456:2000 code is more conservative while the prediction by ACI318:1999 code detailed equation gives more realistic value.
3) The shear crack inclination in tension zone is nearly 45° with the axis of the beam and goes on reducing as the crack propagates in the compression zone. This verifies that the contribution of concrete in carrying tensile load is very less.
4) The major contribution of GFRP sheet in resisting the shear starts after the RC beam reaches its shear capacity due to the fact that the GFRP sheet is bonded externally to the concrete surface.
5) The U wrapped beam is more effective (59%) in increasing the shear strength of the beam as compared to other shear strengthening configurations due to the confinement effect to the concrete and due to more effective length of GFRP.
6) The shear strength of side wrap-0 beam and side wrap-90 beam should be same (assuming crack inclination 45°), but the experimental results shows that shear strength of side wrap-0 beam is less than side wrap-90 beam.
7) The performance of the side wrap-45 beam is as good as U wrapped beam at the early stage but the ultimate strength of side wrap-45 beam is less than the U-wrapped beam due to stress concentration.
8) The GFRP fabric did not debond prior to the failure. The strain measurement just prior to failure of beam, indicates that the fabric had not reached their ultimate tensile capacity. The strengthened beams fail at higher strain value (0.0053) than the control beams (0.003) due to the confinement effect to the concrete, which increases and maintains the aggregate interlock at higher value of strain.
9) The shear strengthening reduces the midpoint deflection of the beam. The reduction in deflection is more for U wrapped beams (18%).

REFERENCES

[1] Adhikary Bimal Babu, Mutsuyoshi Hiroshi, "Behavior of Concrete Beams Strengthened in Shear with Carhon-Fiber Sheets", Journal of Composites for Construction, Vol. 8, No. 3, May/June 2004, pp. 258-264.
[2] Adhikary Bimal Babu, Mutsuyoshi Hiroshi, and Muhammad Ashraf, "Shear Strengthening of Reinforced Concrete Beams Using Fiber-Reinforced Polymer Sheets with Bonded Anchorage", ACI Structural Journal Vol. 101, No.5, September 2004,pp 660-668.
[3] Alagusundarmoorthy P., Harik I.E., Choo C.C., "Shear Strength of R.C. Beams Wrapped with CFRP Fabrics", Research Report Kentucky Transporation Center, University of Kentucky, August 2002.
[4] Al-Sulaimani G.J., Sharif A., Basunbul I.A., "Shear Repair for Reinforced Concrete by Fiberglass Plate Bonding", ACI Structural Journal, Vol.91, No.3, July-August 1994. pp 466-472.
[5] American Concrete Institute, "ACI Committee Report 440.2R-02: Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures'", ACI Technical Documents, 2002.
[6] American Concrete Institute, "Report on Fiber Reinforced Plastic Reinforcement for concrete Structures", ACI Committee Report 440, January 1996.
[7] Bousselham A., Chaallal Omar, "Shear Strengthening Reinforced Concrete Beams With Fiber Reinforced Polymer: Assessment of Influencing Parameters And Required Research", ACI Structural Journal, Vol. 101, No.2, March-April 2004.pp 219-227.
[8] Chaallal O., Nollet M.J., Perraton D., "Shear Strengthening of RC Beams by Externally Bonded Side CFRP Strips", Journal of Composites for Construction, Vol. 2, No. 2, May 1998, pp. 111-113.
[9] Chajes M.J., Januszka T.F., Mertz D.R., "Shear Strengthening Reinforced Concrete Beams Using External Applied Composite Fabrics", ACI Structural Journal, Vol.92, No.3, May-June 1995. pp 295-303.

