Shear Strengthening of Reinforced Concrete Beams using Various Configurations of Steel Plates

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Abstract— This project presents the outcome of an experimental program aimed to investigate the shear behaviour of externally plated reinforced concrete beams. A total of four beams were tested in this program. The beams were designed to fail in shear. Then, they were strengthened using various configurations of steel plates and angles which have been connected by the weld and bonded to the beams by epoxy adhesive. Test results revealed an enhancement in the shear resistance of the strengthened beams, particularly in the post-yield range of loading due to partial composite effect. The pattern of steel strips played a significant role in the behavior of the strengthened beams. The failure of beam due to peeling of steel plates has been avoided. The load carrying capacity of the strengthened beams has been increased as compared to the control beam.

Key words: Shear strengthening, steel strips, Epoxy adhesive, Post-yield, Peeling

I. INTRODUCTION

Existing reinforced concrete structural elements may be damaged by chemical processes due to aggressive environment, excessive loading and poor initial design. The existing reinforced concrete beams may require stiffening or strengthening in order to increase their shear resistance, to control deflections and cracking. It is becoming both environmentally and economically preferable to repair or strength rather than rebuilt them. The choice between repair, strength and rebuilt is based on specific factors of each individual case, but certain issues are considered in every case. The strengthening of these beams would be desirable if rapid, economic, effective and simple strengthening techniques are available.

Different methods are available for strengthening of existing RC elements. These are bonding with steel plates, glass fiber reinforced plastic (GFRP), fibre reinforced polymer (FRP) sheets, external pre-stressing, external post tensioning and additional concreting. The plate bonding technique is becoming preferable for strengthening due to several advantages such as easy construction work, and minimum change in the overall size of the structure after plate bonding. The plate bonding technique has proved to be an effective and low-cost worldwide technique in many engineering applications. The plate bonding technique is becoming preferable for strengthening due to several advantages such as easy construction work, and minimum change in the overall size of the structure after plate bonding. The structural characteristics of the R/C member like strength, stiffness and ductility are significantly upgraded by application of steel jackets.

External plate bonding techniques aims at both increasing or restoring the load carrying capacity of a beam and decreasing its service-load deflections. Many studies in the literature focused on the mechanism of the premature plate peeling failure mode and parameters affecting this mode. Bimal Babu A et al. (2005) carried out a study on shear strengthening of reinforced concrete beams using epoxy-bonded continuous horizontal steel plates. R.A. Barnes et al. (2005) investigated the two methods of plate attachment, namely adhesive bonding and bolting were examined and compared. S.K. Sharma et al. (2007) studied the reinforced concrete beams were bonded with different forms of steel plates to determine the critical diagonal crack (CDC) debonding strength.

The objective of this paper is to find the effective configuration of steel plates to increase the shear strength of reinforced concrete beam.

II. EXPERIMENTAL INVESTIGATION

A. *Details of Test Beams:*

A total of 4 beams were tested. All the beams had the same dimensions and reinforcement details as shown in Fig. 1. The beam size used was 150mm(b) x 180mm(h) x 1200mm(l). The beams were reinforced with two 8mm diameter bars in compression zone and two 10mm diameter bars in tension zone. The control beam was expected to fail in shear while strengthened beams to fail in flexure and not in shear. No internal stirrups were provided in shear failure region. However, stirrups were provided outside the shear spans to mount the longitudinal reinforcement and to prevent the anchorage failure.

The average compressive strength of concrete used was in the range of 25-28 MPa at the time of testing. The average yield strength and elastic modulus of reinforcement were 413MPa and 200GPa respectively. The properties of plates and epoxy adhesive were shown in Table 1 &Table 2.

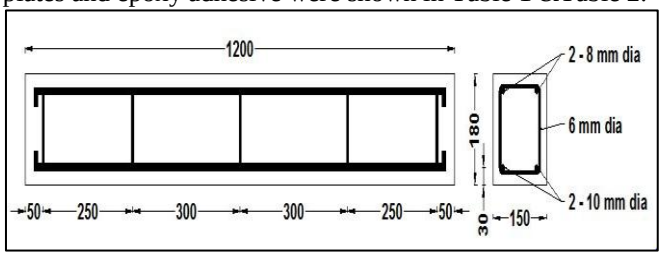

Fig. 1: Reinforcement Details of Beams
(All Dimensions are in mm)

Plates	Size	Yield strength (MPa)	Elastic modulus (GPa)
Steel strips	20mm width x 3mm thick	253	200
Steel angles	20mm x 20mm x 3mm thick	255	200

Table 1: Mechanical Properties of Mild Steel Plate Used For Strengthening

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Property	Value
Pot life (mm)	50
Tensile strength (MPa)	48
Compressive strength (MPa)	73
Tensile shear strength (MPa)	16.8
Elastic modulus (GPa)	2.14

Table 2: Properties of Epoxy Adhesive Used For Steel Plate Bonding

B. Strengthening of Beams:

Beam CB was kept as control beam. Other beams were strengthened using different configurations of external steel plate systems as shown in Fig. 2. Beam CS bonded with inclined continuous strips(60^o) for full length of the beam on both sides. Beam VS was bonded with vertical strips at 100mm spacing on both sides of shear spans. Beam IS was bonded with inclined strips(45^o) at 100mm spacing on both sides of shear spans. For all the beams steel angles were bonded on the corners using adhesive and connected to the strips by means of weld.

Bonding of plates on beams was done using an epoxy adhesive after grinding the concrete surface and cleaning thoroughly with acetone. Bonding faces of steel plates were sandblasted and cleaned thoroughly with acetone before bonding. The thickness of epoxy layer was kept about 2mm using steel spacers.

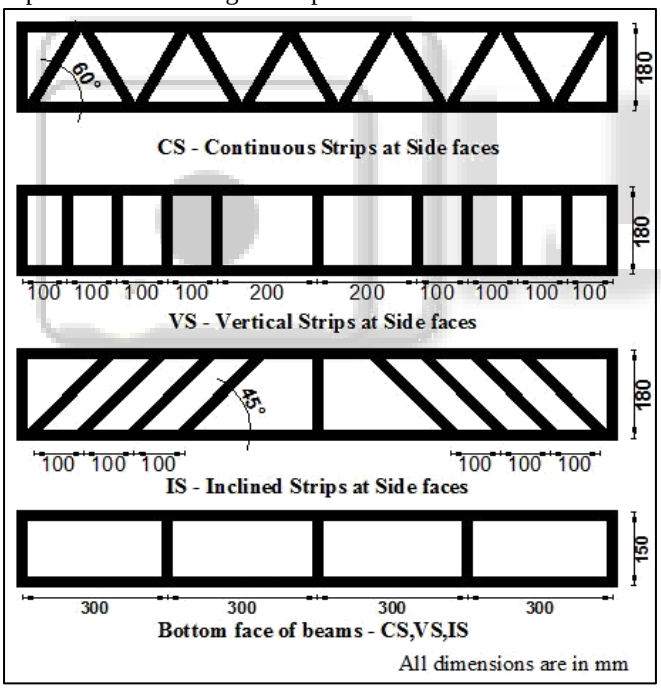

Fig. 2: Different Configurations for Shear Strengthening of Beams

C. Testing and Instrumentation:

Strain gauges were attached to measure strains in steel plates bonded on the beam at shear zone. Mid-span deflections of the beams were measured by the Linear Variable Differential Transducers (LVDTs). All the beams were tested under four-point loading keeping a shear span to effective depth ratio of 1.30. Test set up is shown in Fig. 3. Load was applied monotonically to the test beams till failure. Crack initiation and propagation were monitored by visual inspection during testing.

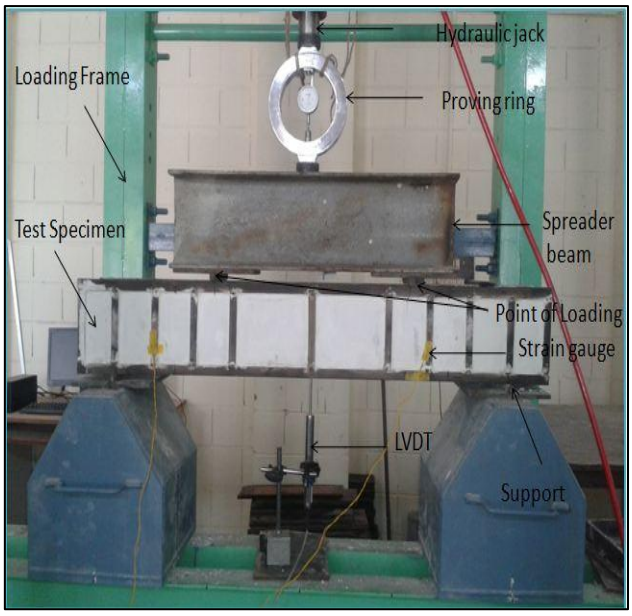

Fig. 3: Test Set Up

III. TEST RESULTS AND DISCUSSION

A. Failure Mode and Ultimate Load:

Table 3 shows the deflections for the corresponding load at various stages. Also failure mode and increase in strength have been mentioned. Fig. 4 shows the failure mode and crack pattern of all the beams.

The control beam failed in shear. Failure of the beam occurred due to formation of critical diagonal shear cracks. But in strengthened beams, shear cracks were considerably reduced and failure of the beams were delayed due to the partial confinement effect provided by the external plates as well as the sufficient adhesive layer between the steel plate and concrete.

Failure mode of the beams was changed from shear to flexure. Debonding of the plate due to critical diagonal cracks was not observed in any cases. The average increase in shear strength of the strengthened beams was 2.2 times of control beam.

(a) Control Beam – CB

(b) Continuous Strips – CS

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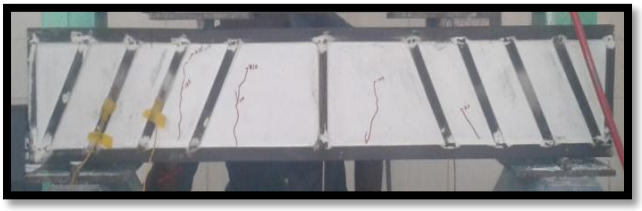
(c) Vertical Strips – VS



(d) Inclined Strips – IS

Fig. 4: Failure Mode and Cracking Pattern of the Beams

B. Load-Deflection Behavior:

Fig. 5 shows the relationship between load and mid-span deflection of control and shear strengthened beams. The strengthened beams showed greater stiffness throughout loading than the control beams. Beams with bonded steel plates also exhibited more ductile behaviour than the control beam, which results in smaller deflection at higher load. Particularly in the IS beam, deflection was reduced more when compared to the other beams.

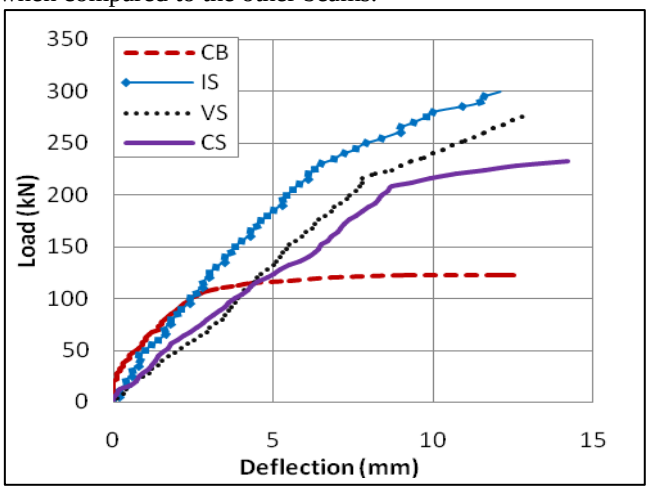


Fig. 5: Load Versus Mid-Span Deflection Curve

Specimen	1st Crack Load P_C kN)	Deflection D_c (mm)	Yield Load P_y (kN)	Deflection D_y (mm)	Ultimate Load P_u (kN)	Deflection D_u (mm)	Failure mode	Relative strength
CB (Control Beam)	37.5	0.3	107.5	2.9	120	6.8	Shear	1.00
CS (Continuous Strip)	68	3.3	212.5	9.3	232	14.2	Flexure	1.93
VS (Vertical Strip)	80	2.9	220	8.2	276	12.9	Flexure	2.30
IS (Inclined Strip)	100	2.4	230	6.5	300	12.1	Flexure	2.50

Table 3: Experimental Results

C. Load-Strain Behavior:

Fig. 6 shows maximum plate strain recorded in steel strips in beam -VS. It is observed that the strain values were rather low and all curves show a reverse trend after certain load. The reverse trend indicates the initiation of slip and local debonding due to which plates did not develop yielding stress.

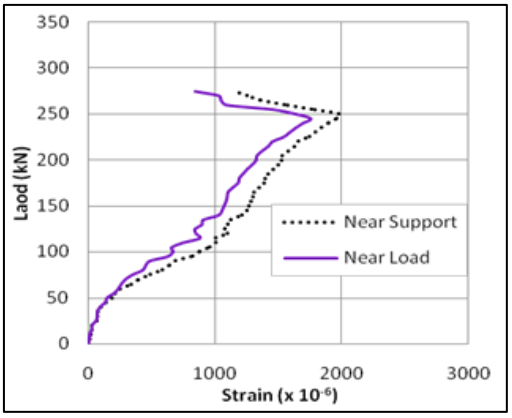


Fig. 6: Strain in Steel Strip in Beam VS

Beam -CS failed in flexure. Fig. 7 shows the load versus strain curve in the strips in beam-CS. The curves show that the strain was not linear. The reverse curve indicates that the slip between the steel strips and the beam at the regular interval.

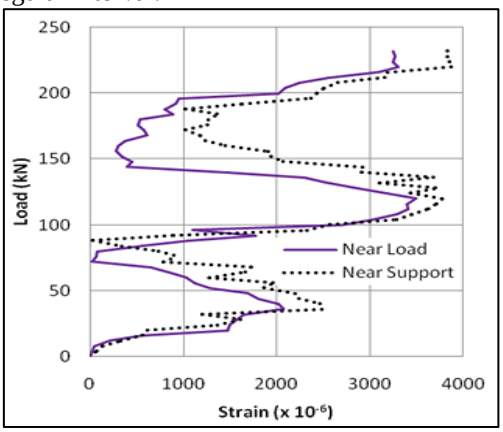


Fig. 7: Strain in Steel Strip in Beam CS

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Beam IS failed in flexure and crushing of concrete occurred finally in the compression zone. This indicates a higher or at least the same shear strength of this beam as defined by observed flexural failure load. The increase in ultimate shear strength was at least 150% for this beam compared to control beam. Fig. 8 shows the load versus strain curve in the strips that developed the maximum strain. In pre-cracking stage, strain development was almost constant, but after concrete cracked in shear span, strain increased rapidly showing steel strip's greater contribution to shear capacity of the beam.

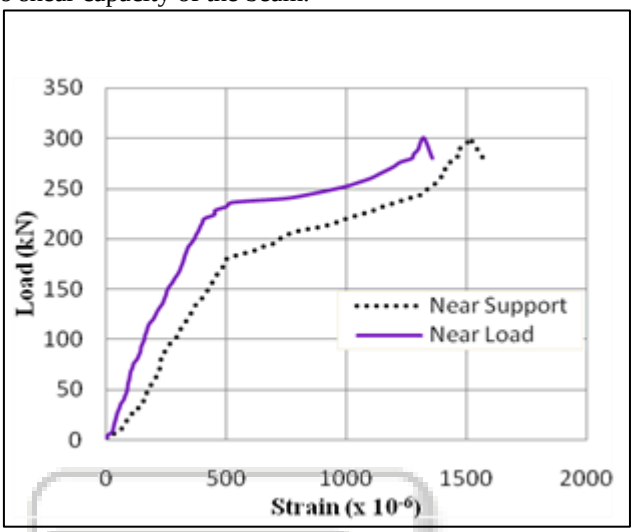

Fig. 8: Strain in Steel Strip in Beam IS

Thus, it was confirmed that though all the configurations were effective, the Inclined Strips configuration (Beam-IS) was the best among the method studied in this investigation for shear strengthening of reinforced concrete beams.

IV. CONCLUSION

Experiments have been performed to study the effectiveness of different configurations of steel plate for shear enhancement of reinforced concrete beam. From the test results, the following conclusions can be drawn.

1) It has been confirmed that the externally bonded steel plates can improve the ultimate shear strength of reinforced concrete beams and change the failure mode from brittle shear to flexural one.
2) Test results revealed an enhancement in the shear resistance of the strengthened beam, particularly in the post-yield range of loading due to composite effect.
3) The pattern of steel strips played a significant role in the behavior of the strengthened beam. Inclined steel strips were found to be very effective configuration. Beam-IS failed at a load 150% of the failure load of Control Beam - CB.
4) Inclined strips delayed the debonding of the plates from the beam. Formation of Critical Diagonal Crack has been reduced.
5) The external steel plates did not fracture in any of the tests conducted.
6) The externally bonded steel plate method is easy for construction and requires less anchorage work and can be used effectively to strengthen RC beams requiring shear upgrading.

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