Strengthening of Reinforced Concrete Beam in Shear Zone by Compensation the Stirrups with Equivalent External Steel Plates

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Abstract

An experimental study on reinforced concrete beams strengthened with external steel plates instead of shear stirrups has been held in this paper. Eight samples of the same dimensions and properties were used. Two of them were tested up to failure and specified as references beams; one with shear reinforcement and the other without shear reinforcement. Another samples without shear reinforcement were tested until the first shear crack occurs, then the samples strengthened on both sides with external steel plates as equivalent area of removed stirrups. The strengthened beams were divided into three groups according to the thickness of plates (1, 1.5, 2) mm, each group involved two beams; one bonded using epoxy and the other bonded using epoxy with anchored bolts. Finally, the strengthened beams tested when using anchored bolts with epoxy glue to bond plates. Where the increasing in maximum load is higher than that in reference beam with no internal stirrups reach to (75.46 –106.13)% and has a good agreement with the control beam with shear reinforcement reach to (76.06 – 89.36)% of ultimate load.

Key words: strengthening, reinforced concrete beams, steel plates.

الخلاصة

في البحث الحالي تم دراسة استخدام الصفائح الحديدية من الخارج لتقوية العتبات الخرسانية المسلحة عند منطقة القص للتعويض عن الاتاري في حالة عدم وجودها. تم فحص ثمانية نماذج بنفس الابعاد والخواص. أثنان من هذه النماذج تم تحميلها الى حد الفشل واستخدمت كمراجع ، احداهما يحتوي على تسليح قص والاخر بدونه. بقية العتبات لا تحتوي على تسليح قص وقد تم تحميلها الى حين ظهور اول شق في العتب ليتم بعدها تقوية العتبات باستخدام الصفائح الحديدية من الخارج وبمساحة مكافئة للأتاري المفقود. أستخدمت صفائح حديدية بسمك ١ملم ، ١,٥ ملم ، و ٢ملم وتم ربط كل نوع من هذه الصفائح مع سطح العتبات مره باستخدام غراء الايبوكسي فقط ومرة اخرى باستخدام غراء الايبوكسي مع البراغي. بعد اكمال عملية تقوية العتبات تم اعادة تحميلها مرة اخرى وصولا الى الفشل. جميع العتبات المقواة اظهرت تحسنا ملحوظا في المقاومة وخصوصا عند استخدام البراغي مع الايبوكسي لتثبيت الصفائح. حيث وصلت الزيادة في التحمل الى %(75.46 –106.13)عن العتب المرجعي الذي بدون تسليح قص. واظهرت توافقا جيدا مع العتب الذي يحوي تسليح قص وصل الى %(76.06 – 89.36)من تحمله الاقصى.

الكلمات المفتاحية: التقوية، العتبات الخرسانية المسلحة، الصفائح الحديدية

1. Introduction

Strengthening of reinforced concrete structural elements has been increased during last decades. It is a very important practical matter especially in partially damaged members to avoid collapse. Several techniques can be used in strengthening and rehabilitation of R.C. beams i.e. (carbon fiber reinforced polymer composite, Glass fiber reinforced polymer, steel plates, cement based composite, etc.). It is well known that the use of plates for this aim has considerable success owing to their high capacity, easy construction, and deformability restraining.

Tankut and Arslan (1992), Jumaat and Alam (2008), and Onik et al. (2015) showed through an experimental study on the behavior of reinforced concrete beams strengthened by steel plates the efficiency of techniques on the ductility and load capacities of beams.

Raoof and Zhang (1997) suggested a guideline for the design of reinforced concrete beams with external plates, assuming that plate debonding occur when the tensile stress in concrete reaches to the tensile strength of concrete. Raoof et al. (2000)

specified through a theoretical and experimental study on externally plated reinforced concrete beams the effects of several factors like concrete strength, beam width, and number of layers of tension reinforcement on the plate peeling failure.

Kl and Zhu (2005) carried out an experimental study for strengthening of reinforced concrete coupling beams tested under reversed cyclic loadings. The results showed that external steel plate attachment by bolted connections could enhance the strength and shear capacity of beams.

Barnes and Mays (2006a) investigated the contribution of side plates to the shear strength of reinforced concrete beams subject to different shear failure modes, and Barnes and Mays (2006b) proposed a design method for reinforced concrete beams with continuous external steel side plates.

Tekin *et al.,* (2011), carried out an experimental study to repair damage reinforced concrete beams with steel plates. The experimental results showed that the capacity of damaged beams was increased. Bhagat and Bhusari (2013) presented an experimental study on strengthening of RC beams using epoxy bonded continuous steel plates. it is observed that the increase in depth is better is than the increase in thickness for plates with equal cross-sectional area.

In this study the steel plate used to strengthening reinforced concrete beam when the first crack appear.

2. Experimental Program

External steel plates were used to enhance the shear capacity of reinforced concrete beams by compensation the missed stirrups. The beams were strengthened with external steel plates on both sides when the first shear crack occurs at test. The strengthened beams were divided into three groups according to the thickness of plates; each group involved two samples one bonded with the concrete surfaces using epoxy and the other bonded using epoxy with anchored bolts.

2.1 Specimen Details

The experimental program involved testing of eight beams. All beams have same materials and geometry. The length of the beams is 1050 mm with 150 × 200 mm cross-sectional dimensions. The concrete compressive strength is 25.8 MPa. All beams reinforced with 2Ø16 mm in tension zone and without any shear reinforcement except one of them denoted as (B1) which has shear bars reinforcement and (1 Ø 6 mm) in compression zone just to support ties as shown in Figure 1.

2.2 Materials Properties

2.2.1 Concrete

Ordinary Portland cement, coarse aggregate have a 20 mm maximum size crushed gravel and the fine aggregate was natural river sand, zone 2 according to IQS:45 1984 with 2.81 fineness modulus. Volumetric mixing ratio of (1:1.5:3) was used, with water/cement ratio (w/c)= 0.45. Cylinders and prisms for control tests were cast and stored with each beam and then tested when the beam was tested. Average results of cylinder strength f'_c and modulus of rupture f_r are given in Table 1.

2.2.2 steel reinforcement (bars and plates)

Details of steel bar used in tested beams are indicted in Figure1. Steel plates with different thicknesses of 1.0, 1.5 and 2 mm were used as an external reinforcement to compensations the missed stirrups. The steel plates can be bonding to the concrete surfaces in the following ways:

- Epoxy adhesive
- Epoxy adhesive with anchor bolts

Sample of bars and plates was tested by tensile testing machine to product some properties of them, results of test were listed in Table 2.

Table 1: Test results of Concrete (MPa)

Table 2: Test results of steel bars and plates (MPa)

	fc	fr
1:1.5:3	25.8	3.55

Material type	f_y	f_u
bar Ø 16	٤٤٠	٧٢٤
bar Ø 10	٤٥٥	٧٣٨
bar Ø 6	٣٢١	٥٤٦
Plate(t=1 mm)	265	452
Plate(t=1.5 mm)	279	449
Plate(t=2 mm)	279	447

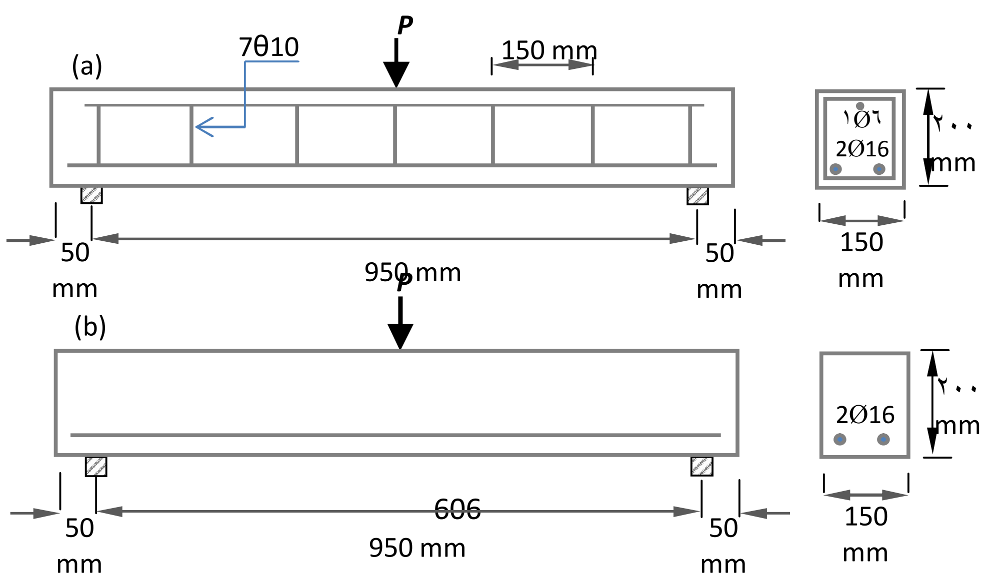


Figure 1: Loading arrangement, geometry and reinforcement detail for (a): Beam B1 , (b): All beams except beam B1

2.3 Steel Plate Dimensions

Some researchers adopted expressions to attain a desirable or rational design for externally bonded plates; these expressions are shown in Figure 2.

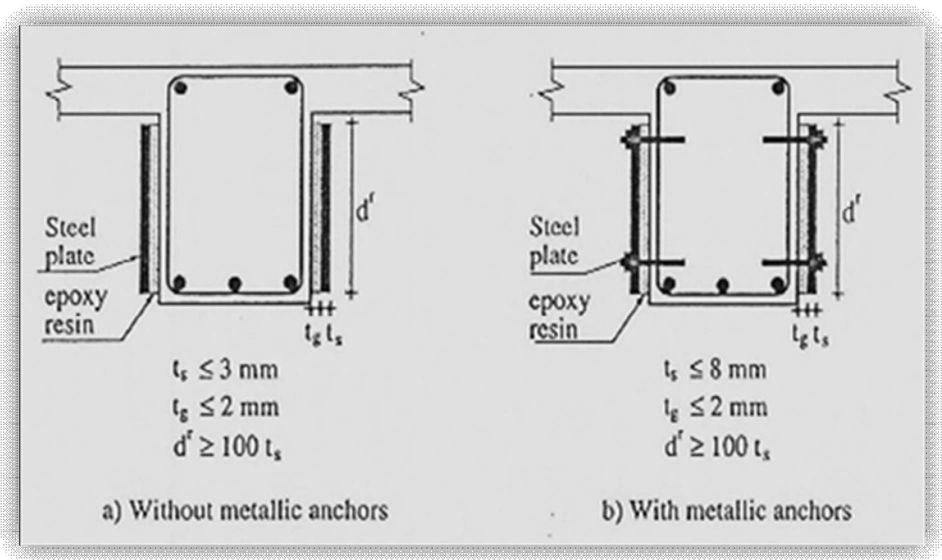


Figure 2: shear strengthening- recommended dimensions (Gomes and Appleton 2002)

Where
t_s = thickness of plate , t_g = thickness of glue, d^r = depth of plate.
According to this limitation and size of concrete section of beam, three thicknesses were use (1.0, 1.5, and 2) mm with 200 mm high. Width of steel plate (w_s) was taken from the equivalent area of removed stirrup of reference beam B1 as follow:

$$(\mathbf{A_s} \cdot \boldsymbol{f_y})_{\mathbf{stirrup}} = (\mathbf{A_{sp}} \cdot \boldsymbol{f_{yp}})_{\mathbf{plate}}$$

$$\mathbf{A_{sp}} = \mathbf{w_s} \times \mathbf{t_s}$$

So the width of plate with 1.0 mm, 1.5 mm, and 2mm was 134 mm, 85 mm, and 64 mm respectively. The number of plates used in the strengthening beam with no shear reinforcement was equal to the number of stirrup of reference beam that have shear reinforcement (B1) and with the same arrangement. The plates with 1.0 mm thickness are used as one continuous steel plate because of the small space between pieces of plate.

2.4 Bonding procedure

Special consideration is given for bonding the steel plates to the concrete surface of the reinforced concrete beam, as shown in Figure 3 and as it is shown below:

1- Fixing the position of plates on sides of beam.
2- The adhesive was two part epoxy glue. The two parts were mixed in accordance with the manufacturer's instructions. Mixing is continued until the mixture is a uniform color.
3- The epoxy spread uniformly on the beams and steel plates of about 2-mm thickness then the plates are bonded to the beams.

4- Before the anchorage bolts of 4 mm in diameter and 33 mm in depth were applied, the holes with a diameter about 8 mm and a depth about 35 mm were opened using a mechanical drill on the two side face of the beam. These holes were filled by hilti. Drilled holes with a diameter of 4 mm were also formed in the steel plates.
5- After completion of the bonding operations, the steel plates were fixed to the side faces of the beam by mechanical clamp. The testing was done after no less than three days of the gluing operation.

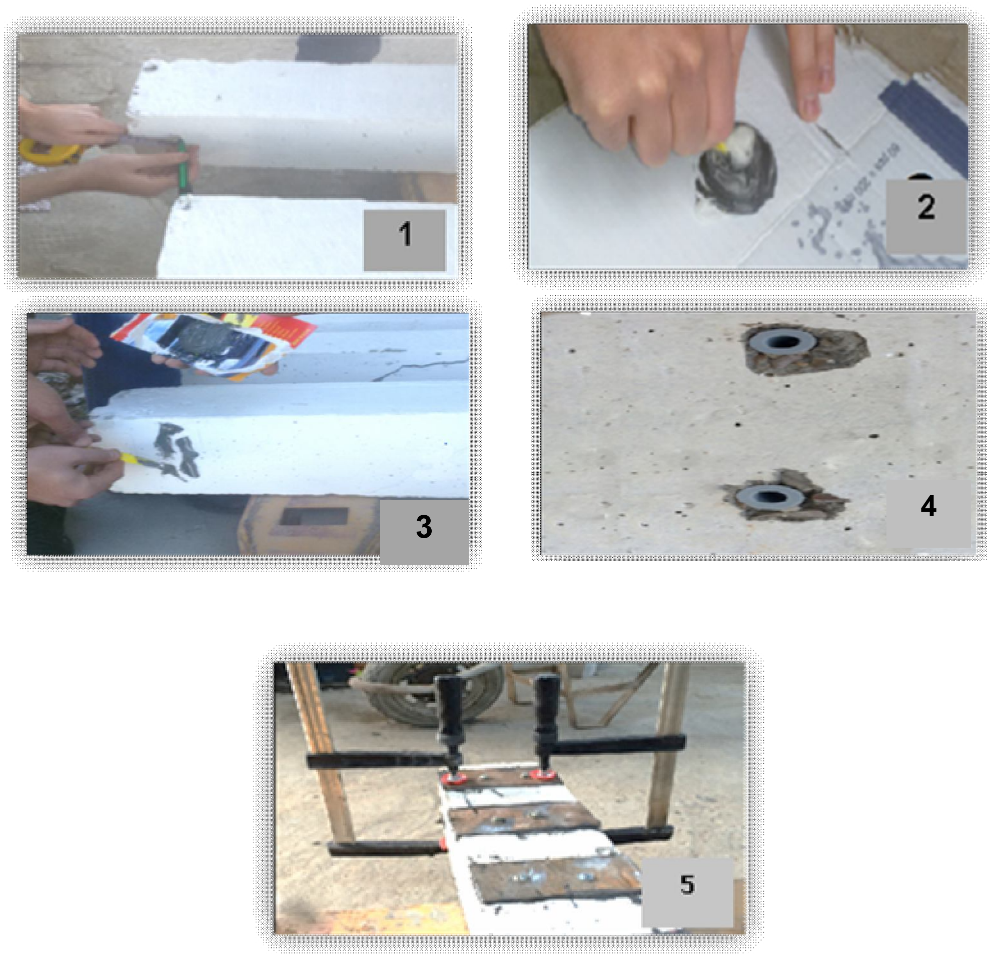


Figure 3: Steps of bonding procedure

3. Experimental setup

All the tested beams were simply supported under one point load at mid span which incrementally loaded by means of a hydraulic jack with maximum capacity of 200 kN as shown in Figure 4. For each increment of the load, the deflection was measured by dial–gage placed at mid span of beams.

Beam with shear reinforcement (B1) and beam with no shear reinforcement (B2) were incrementally loaded up to maximum load capacity and used as reference beams. For another six beams, two cycles of loading were done. The first cycle for cracking load, where the beams initially loaded up to first crack occur then the test was stopped. In the end of first cycle test, the residual deflection was recorded as the load removed. The second cycle represented the loading of the strengthening beams up to ultimate, where the beams strengthening by compensation the missed stirrup with bonded external steel plate. For all beams, the first crack was initiated as diagonal shear crack formed between the point of load application and near the support with an inclination ranges between 37° and 48° to the horizontal. Figure 5 showed the first crack on the beam B3. The epoxy or anchor bolts with epoxy were used to bond steel plates to the concrete surface at the both side of the beams. The arrangement of plate on strengthening beams was identical as arrangement of stirrups on reference beam B1 as indicted in Figure 6 and Table 3.

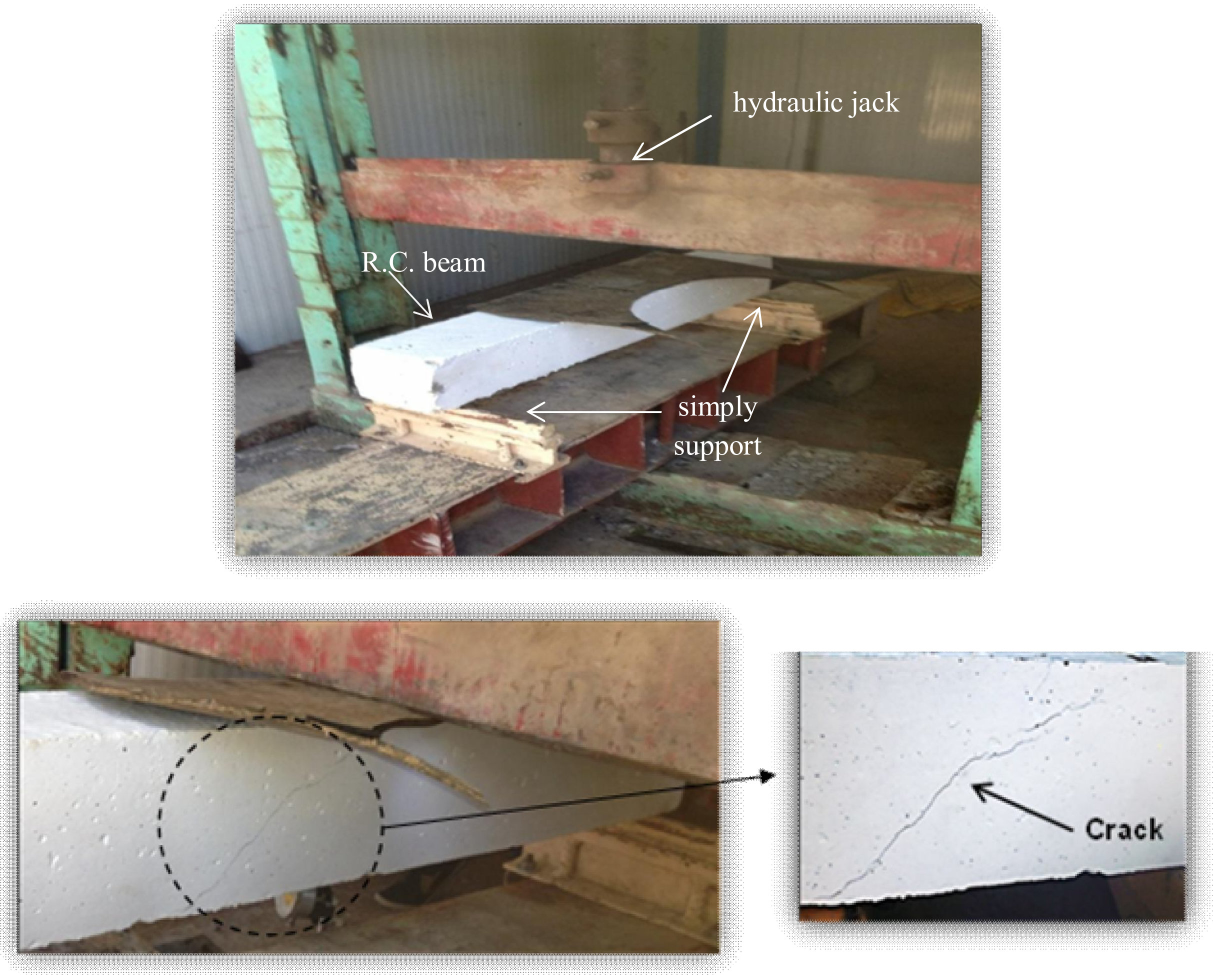
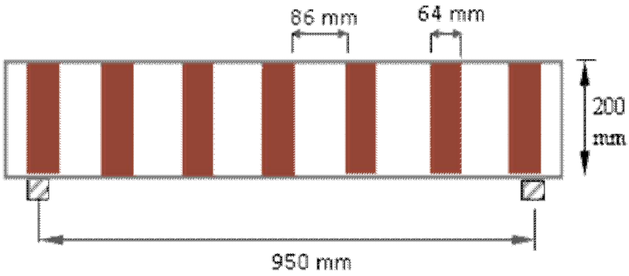
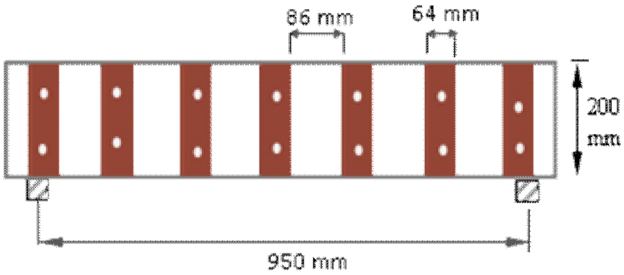


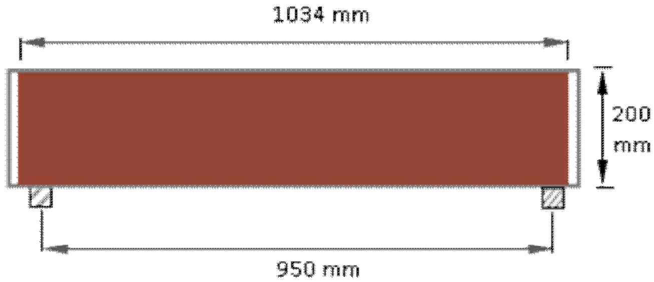
Figure 5: First crack on the tested beam B3 (at 27.5 kN)

Beam B7

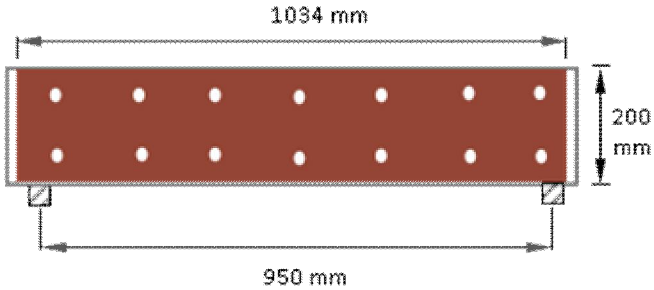


Beam B8



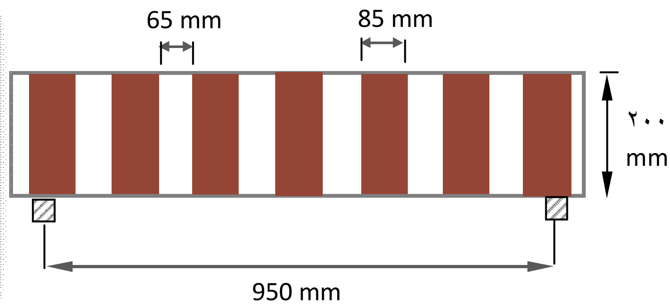


Beam B3

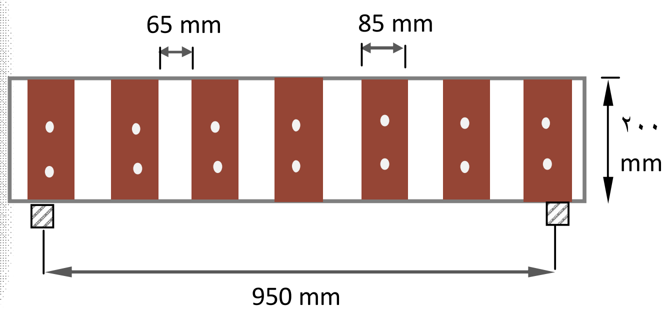


Beam B4

Figure 6: Continued



Beam B5



Beam B6

Table 3: Details of reinforced concrete beams

Beam No.	Internal Stirrups	Thickness of plate t_s mm	Dimension of plate $d^r \times w_s$ mm	No. of plate in each side of beam	Bonding method
B1	Ø10 mm @ 1٥0mm	-	-	-	-
B2	No stirrups	-	-	-	-
B3	No stirrups	1.0	200 × 1034	1 continuous plate	Epoxy
B4	No stirrups	1.0	200 ×1034	1 continuous plate	Epoxy & Anchor bolts
B5	No stirrups	1.5	200 ×85	7	Epoxy
B6	No stirrups	1.5	200 ×٨٥	7	Epoxy & Anchor bolts
B7	No stirrups	2	200 ×64	7	Epoxy
B8	No stirrups	2	200 ×64	7	Epoxy & Anchor bolts

Table 4: Test result of strengthening beams with steel plate

Beam No.	plate thick-ness t_s (mm)	Cracking load P_{cr} (kN)	Ultimate load without strength -ening P_u (kN)	Ultimate load after strength -ening (cycle 2) P_{su} (kN)	Increasing rate in ultimate load respect to B1 $\frac{P_{su}}{P_u}$ %	Increasing rate in ultimate load respect to B2 $\frac{P_{su}-P_u}{P_u}$ %	Failure mode
B1	-	60	94	-	-		Crushing of concrete
B2	-	26.5	40.75	-	-		Shear
B3	1.0	27.5	-	71.5	76.06	75.46	Plate split
B4	1.0	26	-	84	89.36	106.13	Plate-split & Shear
B5	1.5	28	-	73	77.65	79.14	Plate split
B6	1.5	27.5	-	80.5	85.64	97.55	Shear
B7	2	٢٩	-	74	78.72	81.60	Plate split
B8	2	26.5	-	82.25	87.5	101.84	Shear

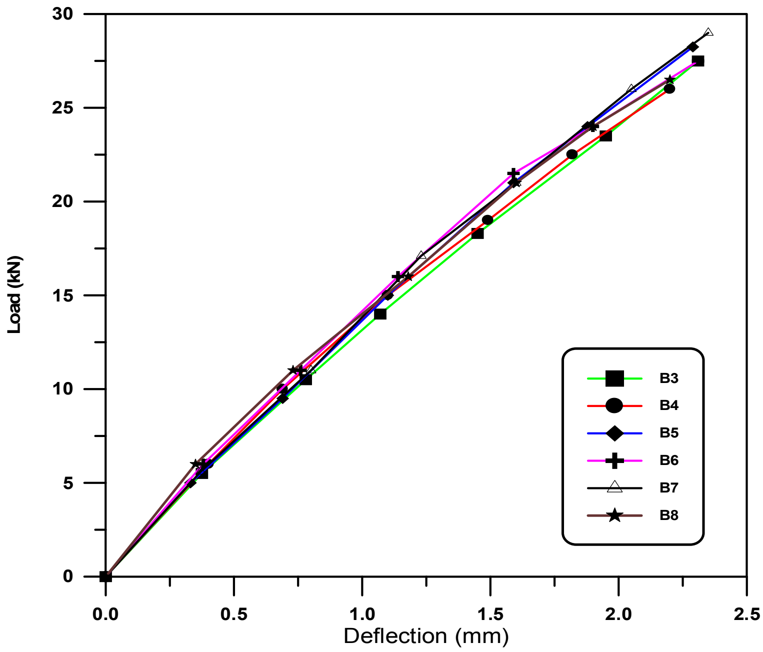
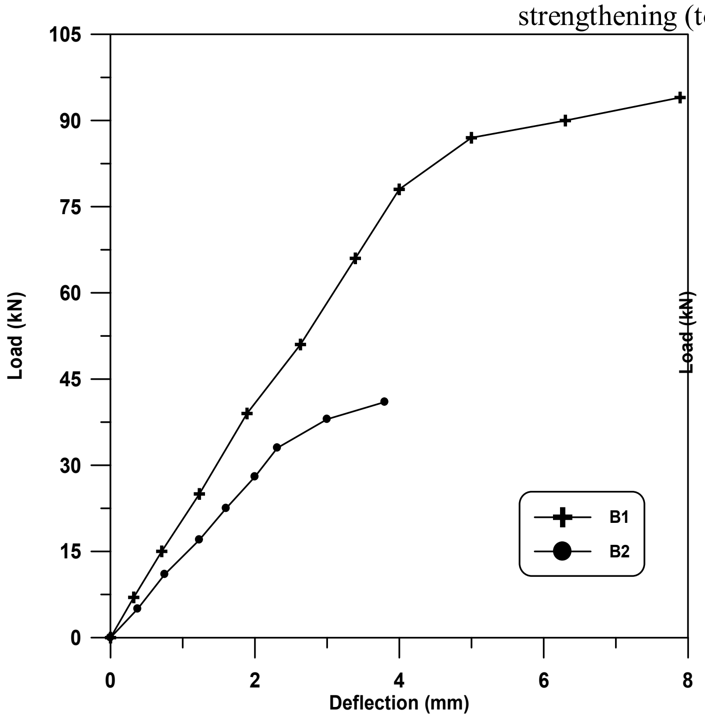


Figure 7: Load-deflection curve for beams B3,B4,B5,B6,B7 and B8 before strengthening (to cracking load)



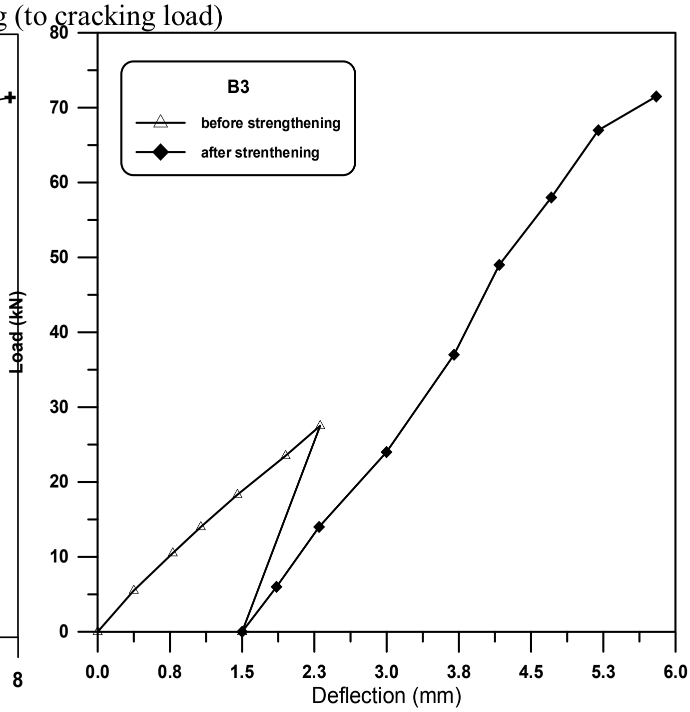


Figure 8: Load-deflection curve for refrences beams B1 and B2

Figure 9: Load-deflection curve for beam B3

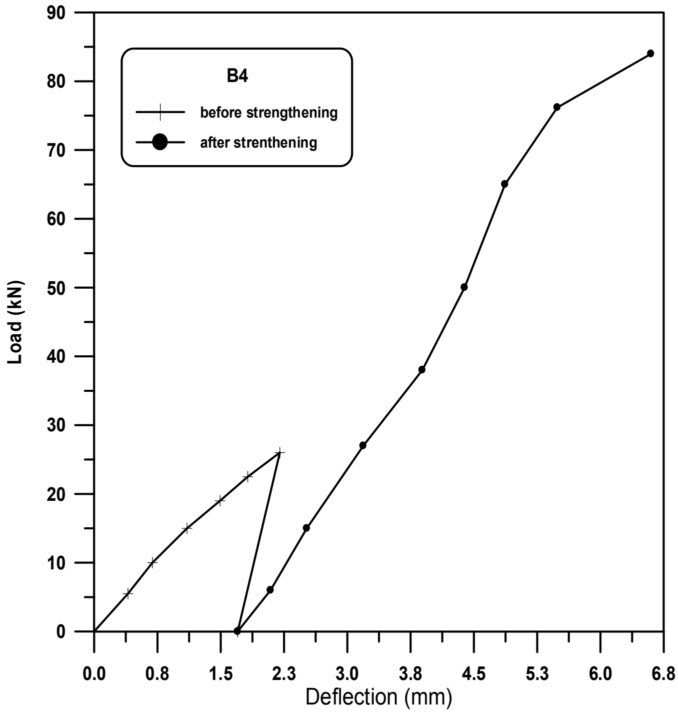


Figure 10: Load-deflection curve for beam B4

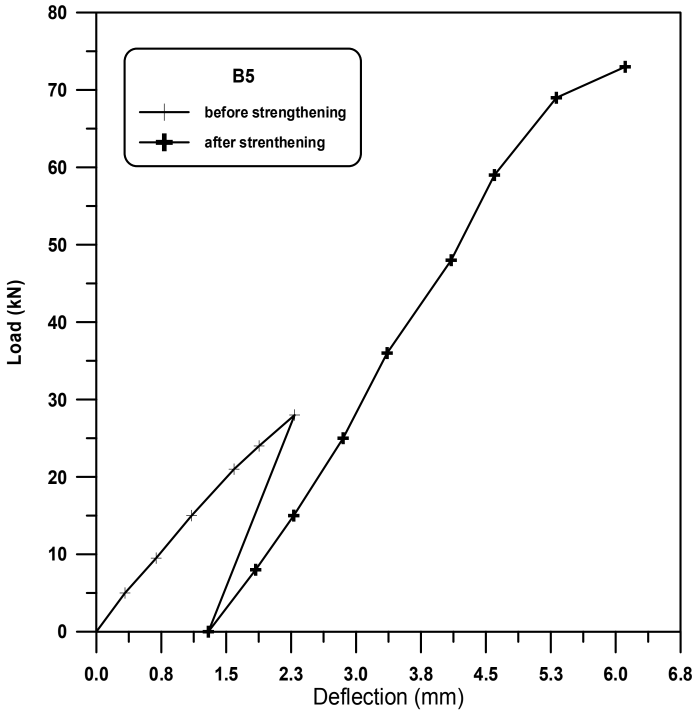


Figure 11: Load-deflection curve for beam B5

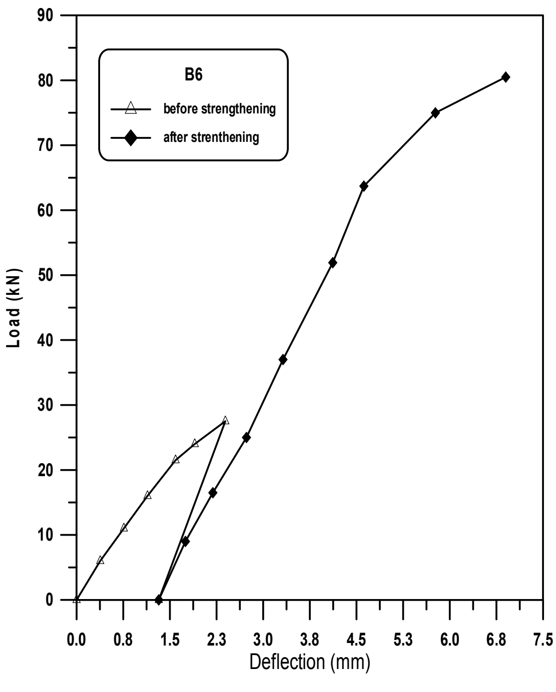


Figure 12: Load-deflection curve for beam B6

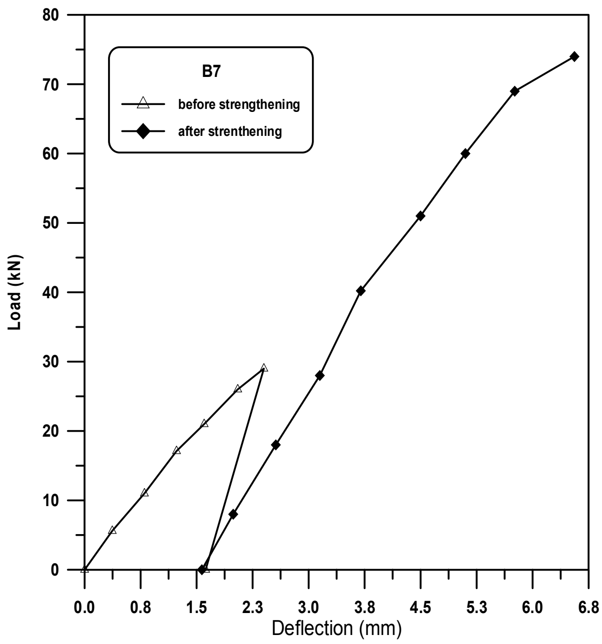


Figure 13: Load-deflection curve for beam B7

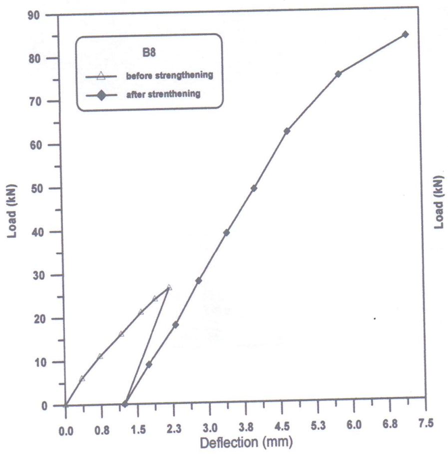


Figure 14: Load-deflection curve for beam B8

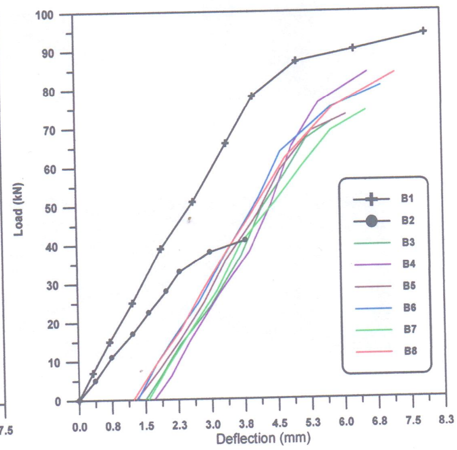


Figure 15: Load-deflection curve for refrences beams B1 , B2, and for beams B3,B4,B5,B6,B7 and B8 after strengtheneing

Figure 16: Types of failur of strengthened beams

4. Results and Discussion

The results obtained from the tests carried out on beams are discussed in the subsequent sections.

4.1 Load capacity

1. It is clear from test results inducted in Table 4 and Figures from 7 to 15 that the beams are strengthening by replacing the removed stirrup with external steel plate of an equivalent area have a good agreement with original beam B1 (with shear reinforcement), and an increase in the maximum load is higher than that in reference beam B2 (with no shear reinforcement).
2. The strengthening by continuous steel plate 1mm thickness that bonded with epoxy and anchored bolts with epoxy for beams B3 and B4 respectively provided about 76.06% and 89.36% of ultimate load from the reference beam B1 (with shear reinforcement) respectively, and an increase in ultimate load about 75.46% and 106.13% which higher than that of reference beam B2 (without shear reinforcement) respectively.
3. The strengthening by steel plate 1.5 mm thickness that bonded with epoxy and anchored bolts with epoxy for the beams B5 and B6 respectively provided about 77.65% and 85.64% of ultimate load of the reference beam B1 respectively, while the increase in ultimate load is about 79.14% and 97.55% which higher than that of the reference beam B2 respectively.
4. The strengthening by steel plate 2 mm thickness provides about 78.72% and 87.5% of ultimate load of the reference beam B1 for the beams B7 and B8 that bonded with epoxy and anchored bolts with epoxy respectively, while the increase in ultimate load is about 81.60% and 101.84% higher than that of the reference beam B2 respectively.
5. It was recognized from results, there is a difference in load capacity of strengthening beams between using epoxy and epoxy with anchored bolts, due to the effect of anchored bolts on fixing plates with concrete face.
6. Results showed that the behavior of the strengthening beams were quite the same because the same equivalent shear area used to compensate stirrups.

4.2 Failure modes

The reference beams damaged by the crushing of the concrete at the top of the beam after considerable flexural - shear crack for beam B1 with shear reinforcement, and shear failure for beam B2 with no shear reinforcement.

For the strengthening beams three failure mechanisms were recognized as shown in Figure 16, where the beams connected with external steel plates behave as a one structural unit. The first one was splitting of the steel plate from the concrete face in case of beam B3, B5, and B7. The separation was due to the tearing of the concrete above the epoxy glue. The second mechanism was a shear failure accompanied with splitting of the continuous steel plate from the concrete face in case of beam B4. The third mechanism was a traditional shear failure in the beams B6 and B8. From failure mode of strengthening beams noted that using anchored bolts with epoxy glue to bonded steel plate made the beam reach to maximum capacity before splitting of plate.

5. Conclusions

From the experimental results, the following conclusions can be stated:

1. The external steel plates bonded to the reinforced concrete beams using epoxy or epoxy with anchored bolts could be used to enhance the shear capacity of beams and it is a practical and successful method.
2. The strengthening with external steel plate as equivalent area of stirrups showed an increase in the maximum load higher than beam with no internal stirrups by about

(75.46 –106.13)% and have good agreement with reference beam with shear reinforcement reach to (76.06 – 89.36)% .

3. The capacity by using epoxy with anchored bolts is higher than the capacity with epoxy only by about (8 – 30 %), this difference is due to the effect of anchored bolts that delayed the splitting of the plate from the concrete face

4. Using separated plates is better than using continuous plates because the possibility to recognize any crack or failure on strengthening beams.

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