Strengthening Of R.C. Beams Byexternal Steel Plate Using Bonded And Unbonded Connectors

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ABSTRACT:

Structural rehabilitation represents an important aspect of the construction industry and its significance is increasing. Strengthening is the process of increasing of the existing capacity of a non-damaged structure or a structural component to a specified level. The main aim of this work is to compare the strengthening techniques by bonded and unbonded mechanical connection as well as studying of replacing internal tension bars by external steel plate with the traditional method of bonding by glues on ultimate strength of RC beams. The traditional method use the epoxy glues for interfaces bonding while the idea of these techniques is a connection of external steel plate with RC beams by shear connectorsmechanically. The experimental work involves flexural testing of six concrete beams of 100✕150✕1500mm. The test variable included the percentage of replacing the internal reinforcement with external steel plate. Comparison ofmethods of bonded and unbonded beams implemented with the method of strengthening by glue. Results show that beams reinforced with external steel plate behave as a composite action right up to ultimate load and the mode of failure occurs by yielding of external plate, pullout or yielding the shear connectors not by separation of plate. Using of external steel plate restrains of central deflection in the beam with increasing of load capacity by increasing thickness of plates.

Keywords: Steel plate, external reinforcement, bonded mechanical connection, composite action, bond failure, tension face, replacement ratio.

تقوية العتبات الخرسانية المسلحة بواسطة الصفائح الحديدية الخارجية بإستخدام الروابط المقيدة وغير المقيدة

الخلاصة:

يمثل تأهيل وتقوية المنشآت مبدأ مهما في مجال الصناعة الإنشائية و تزداد أهميته بسبب حاجة الأبنية لأعمال التقوية والصيانة. تقوية المنشآت هي زيادة لقابلية تحمل المنشأ أو العناصر الإنشائية غير المتضررة لمستوى معين. طريقة. الهدف الرئيسي لهذا البحث دراسة عملية ونظرية ومقارنة لطرق ربط الصفائح الفولاذية والعتبات الكونكريتية وإستبدال التسليح الداخلي بالتسليح الخارجي بإستخدام روابط القص المقيدة وغير المقيدة بطريقة

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ميكانيكية تختلف عن الأسلوب التقليدي في ربط الصفائح الخارجية بسطح العتبة الخرسانية باستعمال المواد الأيبوكسية اللاصقة. تتضمن هذه الدراسة فحص الانثناء لست عتبات خرسا نية (100 × 150 × 1500ملم) للتحقق من تأثير زيادة سمك الصفيحة وتأثير نسبة استبدال التسليح الداخلي بالصفيحة الفولاذية الخارجية ونوع الربط. أظهرت نتائج هذه الدراسة انه باستخدام أسلوب الربط الميكانيكي بين العتبة الخرسانية و الصفيحة الفولاذية يتصرف العنصر الإنشائي كوحدة واحدة الى حد الحمل الأقصى ويكون طور الفشل بخضوع حديد الصفائح الخارجية أو سحب وخضوع روابط القص ولا يحدث عزل بين العتبة والصفيحة إطلاقا. استخدام الصفائح الفولاذية كحديد تسليح خارجي أظهر تقييد في الإزاحات المقاسة في مركز العتبة وأدت الزيادة في سمك الصفيحة الى زيادة في قابلية تحمل المقطع

INTRODUCTION

Structural rehabilitation represents an important aspect of the construction industry and its significanceis increasing. Several methods are available, each withdifferent advantages and disadvantages.The practical solution of external strengthening methods utilized steel plates bonded to the tension surface of the structureby using epoxy resins.One of the popular methods in the strengthening of RC beams is by providing externallybonded reinforcement made of fiber reinforcedpolymer (FRP) laminates for additional flexural resistance.However, many tests carried out on RC beams strengthenedfor flexure with externally bonded FRP materials indicatedlow efficiency of this technique, caused by premature FRPdebonding failure. Near surface mounted (NSM)technique has become promising and attractive for flexuralstrengthening of RC beams[1].

Strengthening and repairing of reinforced concrete beams by using thin fibers concrete jacket have many advantages such as increasing of ultimate load, enhancement of serviceability limit state, resistance to fire and avoiding of corrosion problems that appear in steel plate jacket [2].

External prestressing of post-tensioning is another method of strengthening, in which tendons are placed entirely outside the concrete members and the prestressing forces are transferred to the member through anchorages and deviators. External prestressing is being used for strengthening of distressed concrete bridges and also for new bridges like segmental constructions [3].

All the above methods of strengthening still have main disadvantages of cost, debonding failure and difficulty of execution after construction. This paper presents a practical and cost solution and reports the test results of an experimental investigation carried out on reinforced concrete beams strengthened in flexure and shear using external steel plates by two techniques. The main concept of these methods is to overcome the older from the high cost of strengthening materials, weak of adhesion bonding and possibility of strengthening implementing after construction**.**

Object and Scope

The main aim of this workis to compare thestrengthening techniques by bonded and unbonded mechanical connection as well as studying ofreplacing internal tension bars by external steelplatewith the traditional method of bonding by glues[4]. The newtechniquescarried out by bondingthe external steel plate to the beams by bonded and unbonded connectors.The beams were tested up to the failure by subjection two points load on the top surface.

Experimental Work

Six beams of (100 x 150 mm) cross section and (1500 mm) long were tested up to failure by two point loads.The reference beam (R_1) was without external steel plates and reinforced with (2Ø6mm) in compression and (3Ø8mm) in tension reinforcement. The shear spans were provided with (Ø6mm) stirrups at (60mm) center to center .The beams (R_2, R_3 and R_4) werewith external steel plates have thickness of 0.5mm, 1mm and 1.5mm respectively. The mechanical connection of these beams was by bonded connection. The sufficient thickness and equivalent area of external steel plate substitute the tension steel bars strength in each beam. The mechanicalbonded connection achieves adequate bonding and composite action between concrete beam and external steel plate[5].The common and traditional technique of bonding external plates with concrete beam is by epoxy (glue). The main idea of mechanical connection based on connecting the internal and external steel by screws, washers and nuts. The vertical stirrups were machinery screwed to the required design diameter. Also, two rows of circular holes with suitable diameters were made in the steel plate with the same position of stirrups to ensure of penetrating each rod into the corresponding hole. The main advantages of this technique are the very low cost of providing screwed stirrups without needing of any other expensive materials and lobar and achieving a full bonding between the R.C beam and steel plate during loading test up to the failure. Thebeams (R_5) reinforced with only flexural steel and substitute the shear reinforcement by vertical external steel plates on both beam sides, while the beam (R_6) reinforced with shear reinforcement only and substitute the flexural steel by external steel plate under the bottom face of beam. The mechanical connection of beams ($R_5$and R_6) implemented by unbonded technique. The main idea of unbounded mechanical connection based on connecting the external steel plate by screw rods passing through embedded tubes into RC beam with washers and nuts.Theadvantage of this technique is a possibility of making the strengthening for the structural members after construction and applying service loads, depending upon the state of the structure and the desired performance level. Plates (1) and (2) illustrate the bonded and unbondedmechanical connection technique respectively. Figure (1) shows the beams with external steel plates. The details of the beams variables in the test are shown in Table (1).

Plate (1) Bonded Mechanical Connection Technique

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Plate (2) Unbonded Mechanical Connection Technique

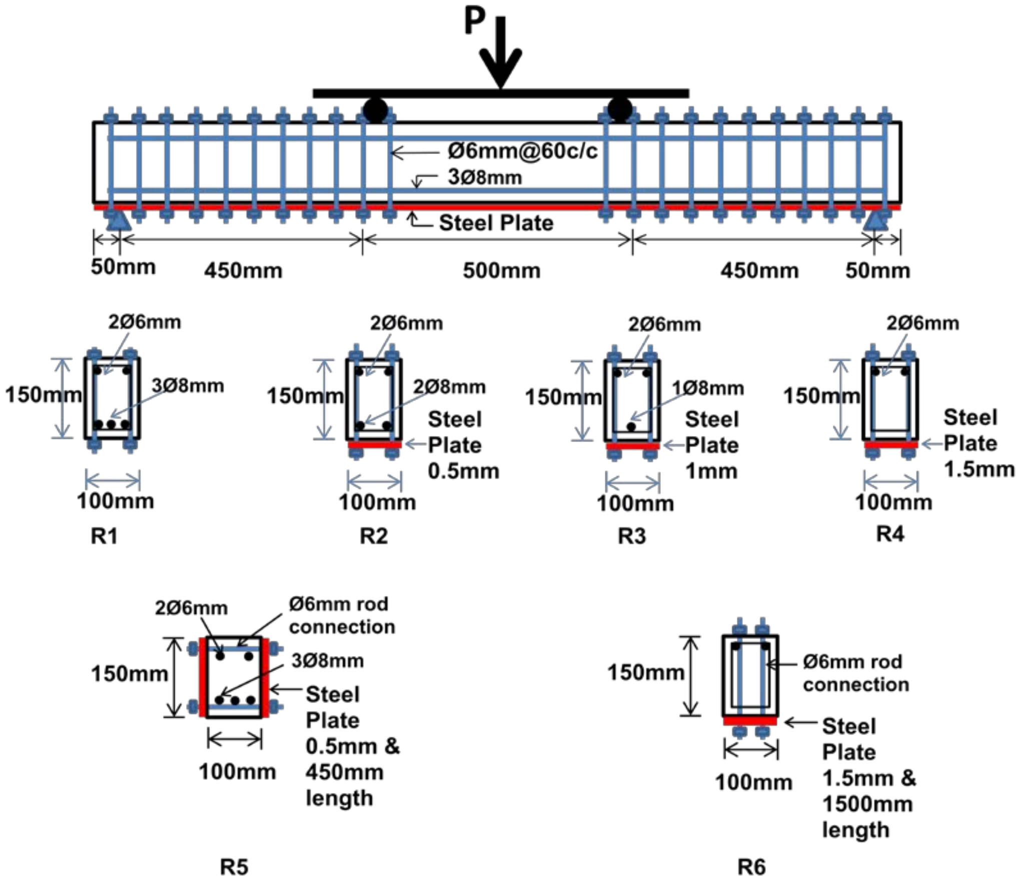

Figure (1) RC Beams Reinforced Externally by Steel Plate

Table (1) Details of the Beams

Beam Symbol	Tension Reinforcement	Shear Reinforcement	Plate Thickness mm	Area of Plate mm^2	Length of Plate	Ratio of Replacement %
R1	3 Φ 8	6mm@60mm	-	0	0	0
R2	2 Φ 8	6mm@60mm	0.5	50	1500	33
R3	1 Φ 8	6mm@60mm	1.0	100	1500	67
R4	-	6mm@60mm	1.5	150	1500	100
R5	3 Φ 8	-	0.5	250	2x450	100
R6	-	6mm@60mm	1.5	150	1500	100

Plates(3) and (4) show the bonded and unbondedbeam casting repectively.

Plate (3)Bonded Beam Casting

Plate (4)Unbonded Beam Casting

Materials Properties

Ordinary Portland cement type (I) was used. The coarse aggregate was 14mm maximum size crushed gravel and the fine aggregate was sand (AL-Ukhaider), zone (2) according to IQS:45 1984 with 2.71 fineness modulus. Cylinders and prisms for control tests were cast and stored with each beam and then tested when the beam was tested. The mix proportions and the average results of cylinder strength f'c, modulus of rupture f_r for all beams are given in Table (2).

Table (2) Mix Proportions and Mechanical Properties of Concrete

Mix Properties	Weight Constituent kg/m^3					Mechanical Properties MPa(28 Days)		
	Cement	Sand	Gravel	Water	SP	f'_c	f_r	†f_r
	430	645	1289	129	6.5	30.8	3.81	3.88

† $f_r = 0.7\sqrt{f'c}$

Deformed steel bars of diameter 8mm were used for the main reinforcement and steel bars of diameter 6mm were used for stirrups. Steel plates with different thicknesses of 0.5, 1.0 and 1.5 mm were used as external reinforcement instead of the same area of tension reinforcement. Properties of the steel bars and the plates are shown in Table (3).

Table (3) Properties of Steel Reinforcement

Reinforcement	Bar Diameter mm	Plate Thickness (t_p) mm	Yield Stress (f_y) MPa	Ultimate Stress (f_u) MPa	Modulus of Elasticity (E_s)GPa
Steel Bars	6	-	383	545	200
	8	-	424	602	200
Steel Plates	-	0.5	283	351	200
	-	1.0	280	347	200
	-	1.5	280	347	200

Test Method

The beams were tested simply supported over a span of 1400mm and loaded at the third points. Load was applied, by means of a hydraulic jack, with increments of 5kN throughout the test. Central deflection was measured at each load increment and concrete cracks were detected and drawn on the face of the tested beam and their width observed. Testing was continued until the beam showed a drop in load carrying capacity with increasing deflections.

Failure Mode

The comparison conducted amongthe old technique of beam strengthening by steel plate using epoxy glue and the methods of bonded and unbonded shear connectors techniques.The epoxy glue method shows that the failure mode of the beams take place by separation of steel plate that occur before the beam reach its load capacity as shown in the Plate (5).The beams ofbondedshear connectors with external steel plates behave as a one structural unit and the mode of failure is always by yielding of external steel plate and crashing of the concretewith showing of significant increasing in the beam load capacity.No splitting or pullout of shear reinforcements occurs under low and high loading of this type of connection.The beams of unbonded shear connectors with external steel plates, also behave as a one structural unit but the ultimate load capacity less than the bonded beams.Pullout and yielding of shear connectors occurs in the unbonded technique. Plates (6) and (7) illustrate the failure modesof the bonded and unbonded beams techniques respectively. Table (4) shows the experimental failure load of the beams.

Plate (5)Failure Mode by Separating Steel Plate

Plate (6)Failure Mode by Yielding of Steel Platefor bondedTechnique

Plate (7)Failure Mode by Yielding of Steel Platefor UnbondedTechnique

Table (4)Experimental Failure Load

Beams	**Experimental Failure Load kN**	**Experimental Failure Load* kN**	**Increment of Experimental Failure Load %**	**Theoretical Failure Load kN**	**Exp.Failure load / Theo. Failure Load**	**Mode of Failure**
R1	37.5	22	41	35	1.07	**Concrete cracking**
R2	45	23	48	40	1.125	**Steel plate yielding with concrete**
R3	52	21	59	47	1.106	**Steel plate yielding with concrete**
R4	58	7	88	53	1.09	**Steel plate yielding with concrete**
R5	47	-	-	42	1.12	**Steel plate yielding with concrete**
R6	44	7	84	41	1.07	**Steel plate yielding with concrete crushing and splitting or cutting of rod connectors**

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The beams under loading machine illustrate in Plate set (8).

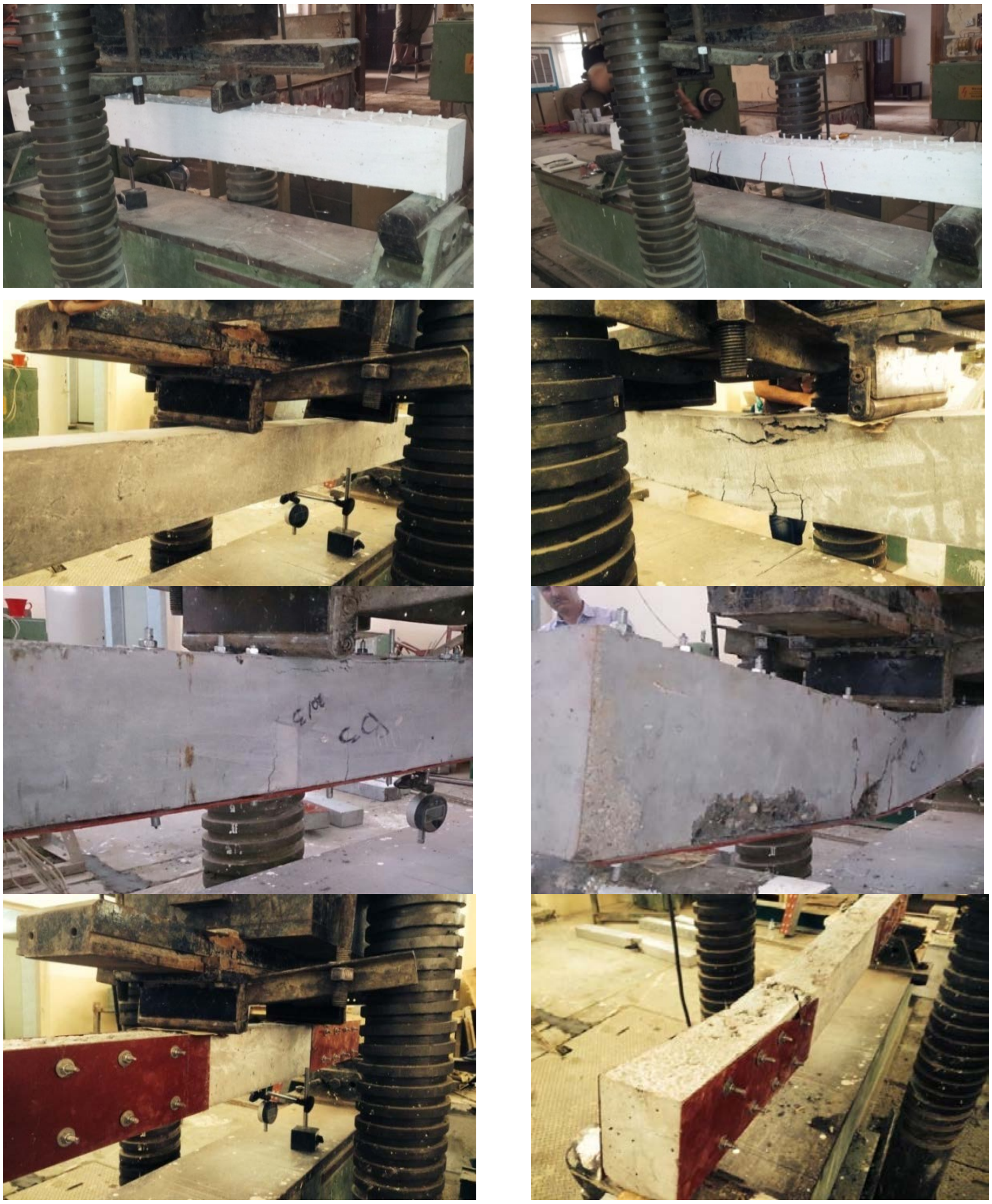

Plate Set (8)Beams under Loading Machine

Results and Discussion

Deflection results of the beams had been drawn in the load deflection curves.Figures (2) to (7) show the experimental deflection relations of the beams ($\mathbf{R_1}$) to ($\mathbf{R_6}$). It is considered from the figuresthat the deflections of the beams decreasewith replacing the internal tension steel by the external steel plate under the same load. The beams of unbonded techniques show larger deflections than the beams of bonded technique. The reference beam $\mathbf{R_1}$ with 150mm^2 of internal tension steel and no external plate shows the largest central deflection while the beam $\mathbf{R_4}$ with no internal tension steel and 150mm^2 of external steel plate shows the smallest deflection of the bonded beams. For bonded technique, the experimental failure load increase by 48%, 59% and 88% for the beams R2, R3 and R4 respectively while the failure load increase by 84% for unbonded technique than the bonding by glues.The external steel plate has larger effective depth than the internal steel tension bar and the moment of inertia of the composite section is also larger than the moment of inertia of the reinforced concrete section without of external plate, so the increase of bending effective depth increases the moment capacity of the beam section causing smaller deflection. The higher membrane forces resulting from constraining the internal and external steel reinforcements generate axial forces which prevent increasing of deformations. Figure (8) shows the experimental central deflections comparison of the six beams. The results from these figures also support the above conclusions.

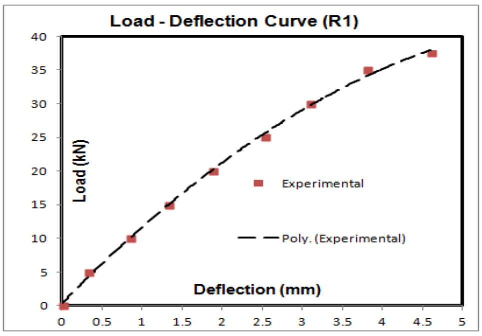

Figure (2)

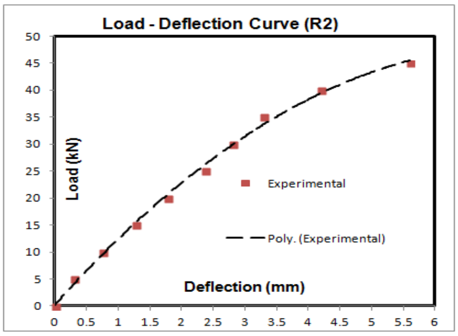

Figure (3)

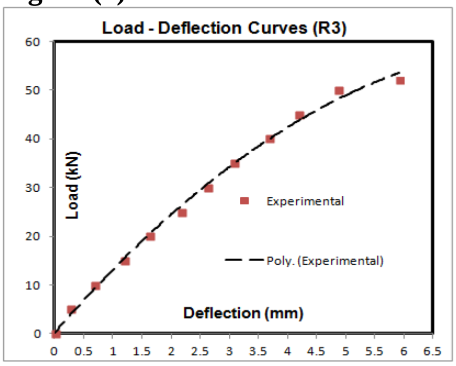

Figure (4)

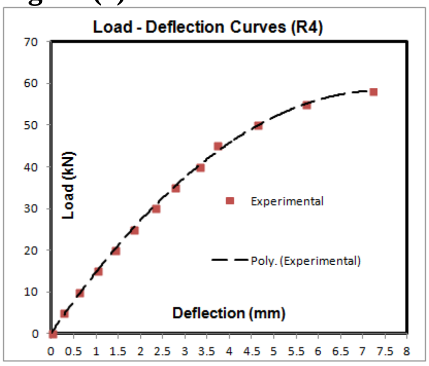

Figure (5)

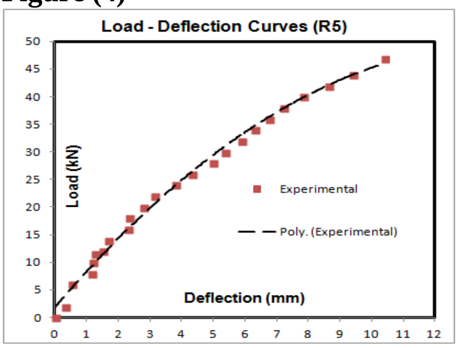

Figure (6)

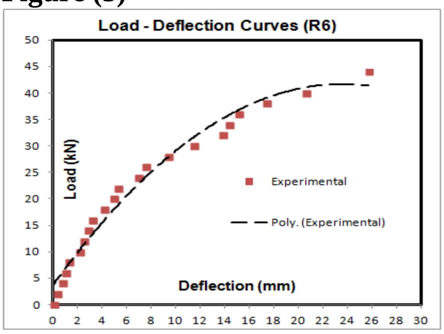

Figure (7)

Experimental Load Deflection Curves for Each Beam

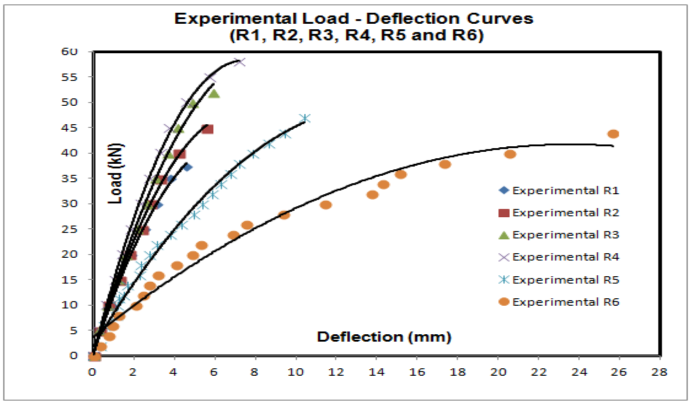

Figure (8)Load Deflection Comparison Curves for the Six Beams

CONCLUSIONS

The following remarks can be observed from current study:

- For the beams of bonded technique, a full composite action exists between the plate and concrete and the failure occurs by plate yielding without needing any surface bond materials.
- For the beams of unbonded technique, the failure modes occurby pullout, splitting or shear connector yielding before the steel plate yielding.
- Considerable significant bond between the RC beams with the external steel plate by using the bonded and unbonded mechanical techniques of shear connection.
- Very low cost of material and labor technique comparingwith the traditional technique by glues.
- Increment of experimental failure load occurs when use the mechanical connection.
- The unbonded technique is suitable to implement before or after construction of structural system while the bonded technique is possible only before construction.

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