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Retrofitting and Strengthening of Reinforced Concrete Damaged Beams using jacketing of Steel Wire Mesh with Steel Plates

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***Abstract*— The purpose of this research is to use jacketing of steel wire mesh with steel plates for retrofitting and strengthening of damaged beams completely failed having deformation. Thirteen reinforced concrete beams having a cross section of (100x160) mm and a length of (1250) mm were tested until failure. All specimens were repaired and strengthened with their exiting deformation. The specimens were divided into five groups. Group one consisted of one specimen strengthened with only expanded three plies steel wire mesh. Group two consisted of three specimens strengthened with steel plates (20, 40 and 60 mm) signed inside three plies expanded steel wire mesh. Groups 3, 4 and 5 each consisted of three specimens strengthened with three plies wire mesh with additional external steel plates (20, 40 and 60 mm) fixed with different number (3, 5 and 7) of steel fisher bolts. The strengthened beams were incrementally loaded up to maximum load capacities. The results showed that the effect of strengthening with three plies wire mesh on the ultimate capacity of beams will have an increase about 30%. Also, the increase of cross sections area of steel plates increase the ultimate load capacity from 47% to 60%. The use of different number of fisher bolts contributed to an additional increase in the ultimate load capacity ranging from (2% to 4%). Increase of cross sections of steel plates as well as number of fisher bolts decreases the mid span deflection of beams from (1% to 14%)..**

Keywords:* *Beam, retrofitting, strengthening, damaged, steel plates and steel wire mesh

I.INTRODUCTION

The repair and strengthening of damaged reinforced concrete structures is important. In fact, the difficult is to repair and restore deformation of completely failed beams. Therefore, the importance of this research is to find a technique to retrofitting and strengthening of failed beams with their existing deformation. Christopher M. F. and Evan R. B. 1998 [1] tested nine reinforced concrete beams, 10"(w) x 18"(h) x 15'-6"(l) to evaluate the practical method of strengthening existing reinforced concrete beams using structural steel channel shapes bolted to the exterior soffit. Three beams served as control beams with no external reinforcement. The remaining beams consisted of three utilizing Rawl-Stud wedge style expansion anchors and three using threaded anchor rod with Rawl Foil-Fast® epoxy-adhesive for attachment of structural steel channel reinforcement. Each of the nine beams had been tested until failure using four points loading. The results showed that the used of external reinforcement of existing RC beams was adequate to improve the strength and stiffness of the member. Barnes et al. (2001) [2] tested nine reinforced concrete beams; two beams were tested as control specimens and four beams were strengthened with adhesively bonded steel plates. The last three beams were strengthened with bolted steel plates. The thicknesses of the used steel plates were 2mm with yield strength of steel 340 N/mm2. The experiments showed that the use of steel plates improves the shear capacity and flexural capacity as well as the ultimate capacity of section. Ren X.S. and Zhou B. (2011) [3] presented the design and analysis of composite beam formed by the original reinforced beam and the externally bonded H-type steel member. Steel member H-type no. 10 was used with area 5800 mm2 and externally bonded with JGN structural adhesive. The height and width of the original beam is 500mm and 250mm. The height of the retrofitted beam is extended from 500mm to 600mm. The beams were examined under concentrated load 120kN at the mid-span and a uniform load 15kN/m along the span of the beam. The analysis showed that the full shear link on the interface should be guaranteed by either the JGN structural adhesive or the anchor bolts. Demir A. and Tekin M. (2011) [4] strengthened damaged of Reinforced concrete beams using prefabricated RC rectangular section and RC U shape cross-section. The RC rectangular cross-section were bonded to the bottom sides of the beams by rods and epoxy. The RC having U shape cross-section were bonded to the three sides of the beams. The strengthened beams were incrementally loaded up to maximum load capacities. The results showed that the load carrying capacity of the beams increased by 41% with the strengthening by RC rectangular cross-section However when the strengthening by RC U shape cross-section were used, the capacity increased up to 76%. Sabahattin A. et al. (2013) [5] investigated the flexural behavior of externally steel plated RC beams. Thirteen full scale rectangular RC beams were tested. The effects on the behavior of the steel plate thickness, the anchorage of the plate to the beam through anchor bolts or side plates (collars), and the use of perforated plates instead of solid ones were investigated. The beams have a 200x500 mm rectangular cross section and a total length of 4.5 m. All of the beams were reinforced with 3 Ø14 tension and 2 Ø10 compression rebar's and Ø8=100 mm stirrups along the beam length. The experiments showed that the beam ductility increases as the plate thickness decreases. Anchor bolts had adverse effects on the ductility's of the beams with thin plates, and the use of perforated steel plates was found to be an efficient method for increasing the ductility of a strengthened beam. ALaa A. Bashandy (2013) [6] investigated strengthening reinforced concrete beams using concrete layer, reinforced concrete layer and steel plates. Thirty-nine 100x150x1100 mm reinforced concrete beams were cast. Three control beams were tested. The other thirty six beams were divided into three groups according to strengthening materials and method. Group "A" was strengthened using 2cm thickness concrete layer only (two types). Group "B" was strengthened using 2cm thickness concrete layer reinforced with meshes (steel and plastic). Group "C" was strengthened using steel plates with dimensions of 100x1000mm and 1.5 mm thickness. Test results indicates that for groups "A" and "B", the ultimate strength, stiffness, ductility, and failure mode of RC beams, with the same thickness strengthening layer applied were affected by the type of reinforcing mesh and type of concrete layer. For group "C" (steel plates), these parameters were affected by the fixation technique and adhesion type. Ragheed F. Makki (2014) [7] investigated the behavior of reinforced concrete beams retrofitted by Ferrocement. Ten reinforced concrete beams were casted with dimensions (140 X 240 X 2000) mm and reinforced with 2 steel bars of 8mm diameter at compression face and 2 bars of 10mm diameter at tension face. Two beams were tested as control and four beams were strengthened with steel wire mesh diameter1.2mm. The last four beams were repaired after stressed up to a specified limit from the ultimate load (50% or 70%) with steel wire mesh diameter 2.2mm. The experimental results indicated that the rehabilitation technique (strengthening and repairing) of R.C. beams by using ferrocement system is applicable and increase the ultimate load from (69.8-175% in case of strengthening) and from (50.94-125% in case of repairing). Also, the test results for strengthening beams showed that the effect of diameter of ferrocement wire mesh (changing from 1.2 to 2.2mm) on the ultimate strength of R.C. beams will have an increase from {(95-175% without steel stirrups) and (69.8-126.4% with steel stirrups)}. Tahmina T. Nahar and et al (2014) [8] tested nine specimens divided into three groups of RC beams with the same dimension (4", 6 "and span 5.5 ') up to ultimate load by one point loading system as a simply supported beam. Group no. one was repaired with 0.5 inches ferrocement layer on three sides. The second group was subjected to two layer of ferrocement on the bottom of thickness 1 inch and only one layer in a two sides. The last three beams were surrounded by total 1 inch ferrocement layer on three sides. The study presented a comparison on cracking load, ultimate load as well as deflection between the normal beams and repaired beams. The results showed that the ferrocement overlay can be used to repaired and restore performance of beams and improve structural behavior of the reinforced concrete beams. Elsamny, M.K. and et al (2014) [9] tested twenty six R.C. beams having cross-section 100×160 mm and length 1250mm under two points loading. Two beams were tested as control beams and were loaded until failure. Twelve beams were loaded by 60% of failure load and then retrofitted with square steel wire mesh only as well as with additional external horizontal steel bars (1 and 2Ø8). Twelve beams were strengthened with the same technique and tested. The test results showed that the beams strengthened and retrofitted by a different numbers of steel wire mesh plies gives an increase in the load carrying capacity up to (63.05%) of the control ultimate. In addition, the mid span deflection of beams decreases. However, using additional external steel bars in steel wire mesh jacketing gives an increase in the load carrying capacity up to (74.21%) of the control column, and decreases the mid span deflection of beams. From the above, the strengthening or retrofitting beams with steel plates or steel wire mesh is an applicable to reduce deflection and increase ultimate capacity of beams.

II.PROPOSED THE TECHNIQUES OF RETROFITTING AND STRENGTHING

Steel wire mesh jacketing with steel plates technique is used in the present study. The technique is replacing the loose concrete part by grout mortar. However, three different techniques were used to strengthen the beams as follows:

1- Covered the beams from three sides with only three plies expanded steel wire mesh as shown in figure 1.

2- Using steel plates with constant thickness 3mm and different width dimensions' (20, 40 and 60 mm) signed inside expanded three plies steel wire mesh as shown in figure 2.

3- Using different number of steel fisher bolts (3, 5 and 7) to fix the steel plates to beams and covered beam from three sides with three plies expanded steel wire mesh as shown in figure 3.

Two transverse steel straps (30x6) mm were used in all these techniques.

Figure 1 steel wire mesh and transverse steel straps.

Figure 2 steel wire mesh and steel plates (20, 40 and 60 mm)

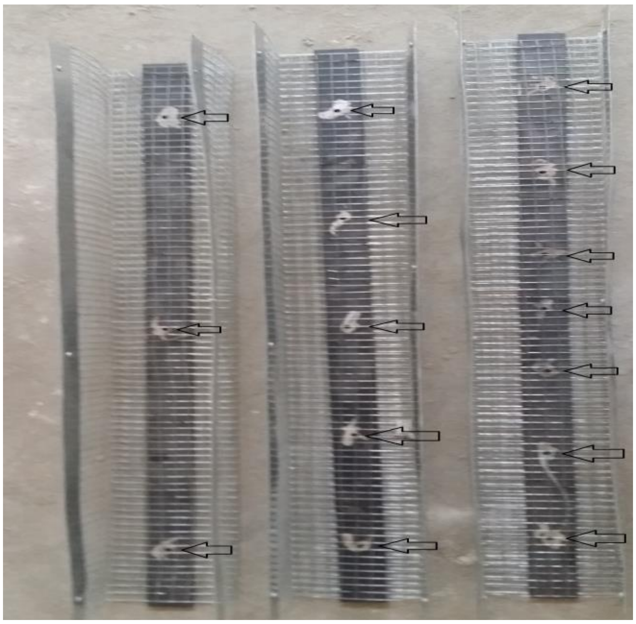

Figure 3 steel wire mesh and steel plates 20, 40 and 60 mm with 3, 5 and 7 fisher bolts

III.EXPERIMENTAL PROGRAM AND TESTING PROCEDURE

Thirteen reinforced concrete beams having a cross section of (100x160) mm and a length of (1250) mm were casted and cured for 28 days in water. All specimens contain two horizontal bars 8mm at bottom and two bars 6mm at top. The used stirrups were 6mm diameter at spacing of 100mm and strain gauges were mounted at maid span of the internal horizontal bottom steel bars as shown in figure (4). After that, all specimens were tested until failure under two point loading as shown in figure (5). The maximum deflection as well as the ultimate load capacity were measure as shown in table (1). Before retrofitting process total removed of damaged parts were replaced by grout mortar. The thirteen reinforced concrete beams were strengthened and tested till failure as divided in the following five groups:

Group 1: One of the specimens was strengthened with three plies U-shaped steel wire mesh only.

Group 2: Three specimens were strengthened with three plies wire mesh with additional external steel plates (20, 40 and 60 mm) signed inside.

Groups 3, 4 and 5: Each group contains three specimens strengthened with three plies wire mesh with additional external steel plates (20, 40 and 60 mm) signed inside fixed with different number of fisher bolts (3, 5 and 7).

All The specimens in groups 1, 2, 3, 4 and 5 were confined with two transverse straps (2straps30*0.6mm) at the ends of the three plies wire mesh.

All damage specimens were repaired and strengthened with their exiting deformation as shown in figure (6). Thereafter, all the specimens were grouted by The Cetorex grout by water/grout ratio = 0.10 as shown in figure (7). The specimens were cured for 7 days from the date of casting of grout jacketing. All casted specimens were kept in a dry place for a few hours. Thereafter, all beams were tested under two points loading using the testing machine mounted on the Material laboratory of Al-Azhar University, having an ultimate compressive load capacity of 100kN. The data acquisition system used in the present study consisted of a Laptop computer, a Keithley-500A Data Acquisition System. LVDT was used for measuring deflection at mid span zone and a load cell was used to measure the load as shown in figure (5)

Figure 4 details of reinforcement beams and location of strain gauge.

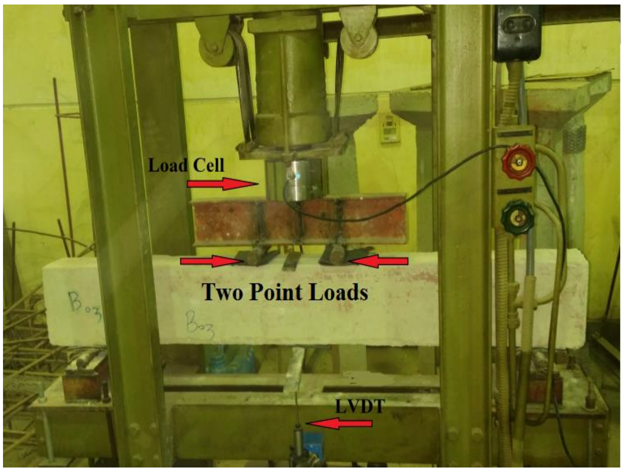

Figure 5 Test machine and test setup.

Table 1 Failure loads and maximum deflection of control beams.

Specimen name	Specimen description	Failure loads (KN)	Average ultimate load failure = 32.6 (KN)	Max. Deflection (mm)	Average Max Deflection = 17 (mm)
B1	Control Beam	32.5		17.5	
B2		32.7		16.8	
B3		32.7		17.6	
B4		32.9		17.4	
B5		32.5		17.5	
B6		32.8		17.1	
B7		32.7		16.5	
B8		32.5		17.8	
B9		32.7		17.65	
B10		32.8		16.5	
B11		32.8		16	
B12		32.5		17.1	
B13		32.8		16.5	

Figure 6 beams after failure and strengthened under the exiting deformation

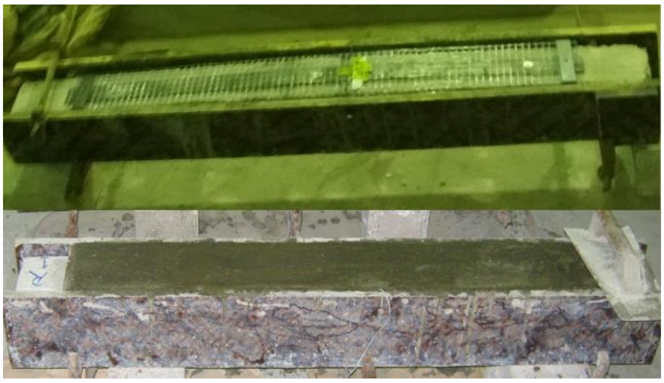

Figure 7 forms used for grout mortar

IV. USED MATERIALS

The followings are the used materials:

1. The concrete mix was designed according to the Egyptian code of practice to obtain target strength of 25 N/mm2 at the age of 28 days.
2. The used steel reinforcement was normal mild steel St24/37-smooth rebar of 6 and 8 mm diameter.
3. A cementations mix cetorex grout mortar which is requiring only the addition of water to produce high strength non-shrink mortar.
4. The used steel plates have a yield stress of 325 N/mm2 and tensile strength of 420 N/mm2 with an elongation percentage of 30%.
5. The used galvanized welded steel wire mesh has a specification 12.7x12.7 mm panel size and 1.6 mm wire diameter.
6. The used strain gauges were manufactured by KYOWA electronic instrument co, ltd. the type used was kfg-5-120-c7-11 l1m2r, which has a resistance of 119.6 ± 0.4% ohms at 24°c, and a gage factor of 2.1 ± 1.0%.

V.EXPERIMENTAL TEST RESULTS

A. *Ultimate Capacity of Repaired and Strengthened Reinforced Concrete Beams:*

Table no. 2 shows the ultimate loads capacity of beams and percentage of increase after repair and strengthening.

Figure 8 shows the percentage of increase in the ultimate load capacity from control beam after strengthening by three plies wire mesh with additional external steel plates (20, 40 and 60 mm) signed inside.

Figure 9 shows the percentage of increase in the ultimate load capacity from control beam after strengthening by external steel plates (20, 40 and 60 mm) fixed with different fisher bolts (3, 5 and 7) signed inside the wire mesh.

Figure 10 shows the effect of using different number of fisher bolts (3, 5 and 7) on ultimate load capacity from beams strengthening by three plies wire mesh with additional external steel plates (20, 40 and 60 mm) signed inside.

B. *Deformation of Repaired and Strengthened Reinforced Concrete Beams:*

Table no. 3 shows the obtained maximum deformation of tested beams after repair and strengthening. However, table no. 3 is divided into four groups each has a control beams as shown.

Figure 11 shows the additional deformation of beams tested with their existing deformation after strengthening by using three plies wire mesh with additional external steel plates (20, 40 and 60 mm) signed inside. The increase in cross-sectional steel plates to decreases the deformations of beams.

Figure 12 shows the additional deformation of beams tested with their existing deformation after strengthening using external steel plate 20 mm fixed with different fisher bolts (3, 5 and 7) signed inside the wire mesh.

Figure 13 shows the additional deformation of beams tested with their existing deformation after strengthening using external steel plate 40 mm fixed with different fisher bolts (3, 5 and 7) signed inside the wire mesh.

Figure 14 shows the additional deformation of beams tested with their existing deformation after strengthening using external steel plate 60 mm fixed with different fisher bolts (3, 5 and 7) signed inside the wire mesh.

From the above, the use of external steel plates (20, 40 and 60 mm) fixed with different fisher bolts (3, 5 and 7) signed inside the steel wire mesh gave an increase in the ultimate load capacity. Also, the increase number of fisher bolts (3, 5 and 7) helped to change the beam deformation shape from two concentrated loads to uniform distributed loads.

Table 2 ultimate loads capacity after repair and strengthening

Groups name	Specimen name	Strengthening Types			Failure loads		% Increase In ultimate capacity/control failure loads
		Wire mesh layer	Steel plates	Fisher bolts	Control	after Strengthening (KN)	
Group 1	B1	3 layer	--	--	Average ultimate load failure = 32.6 (KN)	42.6	130.67%
Group 2	B2		20mm	--		48	147.24%
	B3		40mm	--		50.4	154.60%
	B4		60mm	--		52.3	160.43%
Group 3	B5		20mm	3 f.b.		48.5	148.77%
	B6		20mm	5 f.b.		48.9	150.00%
	B7		20mm	7 f.b.		49	150.31%
Group 4	B8		40mm	3 f.b.		51.3	157.36%
	B9		40mm	5 f.b.		51.5	157.98%
	B10		40mm	7 f.b.		52.2	160.12%
Group 5	B11		60mm	3 f.b.		52.8	161.96%
	B12		60mm	5 f.b.		53.1	162.88%
	B13		60mm	7 f.b.		53.5	164.11%

Table 3 maximum deflection and percentage of decrease in deformation after repair and strengthening

Group name	Specimen name	Strengthening Types			Max. Deformation after Strengthening (mm)	% decrease in deformation
		Wire mesh layer	Steel plates	Fisher bolts		
Group I	B1	3 layer	--	--	22.30	control
	B2		20mm	--	21.80	2%
	B3		40mm	--	20.50	8%
	B4		60mm	--	20.00	10%
Group II	B2	3 layer	20mm	--	21.80	control
	B5		20mm	3 f.b.	19.74	9%
	B6		20mm	5 f.b.	18.80	14%
	B7		20mm	7 f.b.	19.74	9%
Group III	B3	3 layer	40mm	--	20.50	control
	B8		40mm	3 f.b.	20.36	1%
	B9		40mm	5 f.b.	19.03	7%
	B10		40mm	7 f.b.	18.30	11%
Group IV	B4	3 layer	60mm	--	20.00	control
	B11		60mm	3 f.b.	19.81	1%
	B12		60mm	5 f.b.	18.48	8%
	B13		60mm	7 f.b.	17.6	12%

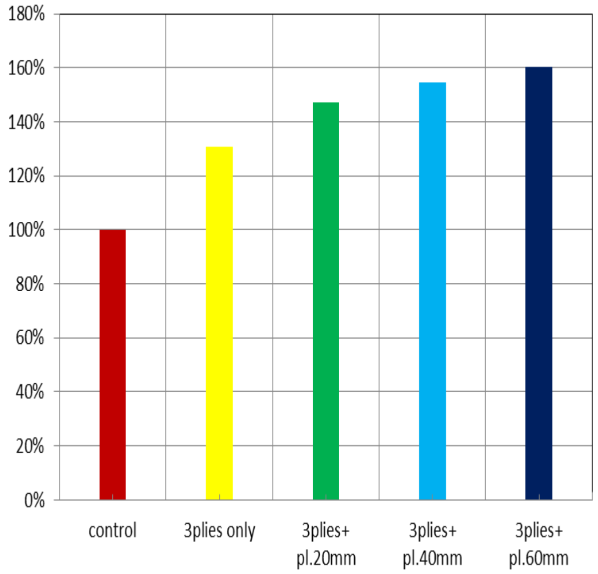

Figure 8 increase of ultimate load capacity due to strengthening by three plies steel wire mesh + (20, 40 and 60) mm

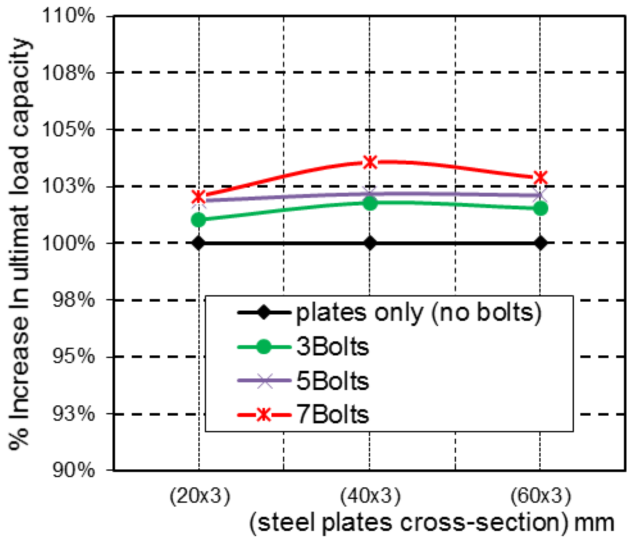

Figure 10 increase of ultimate load capacity due to strengthening by three plies steel wire mesh + (20, 40 and 60) mm only with different number fisher bolts (3, 5 and 7).

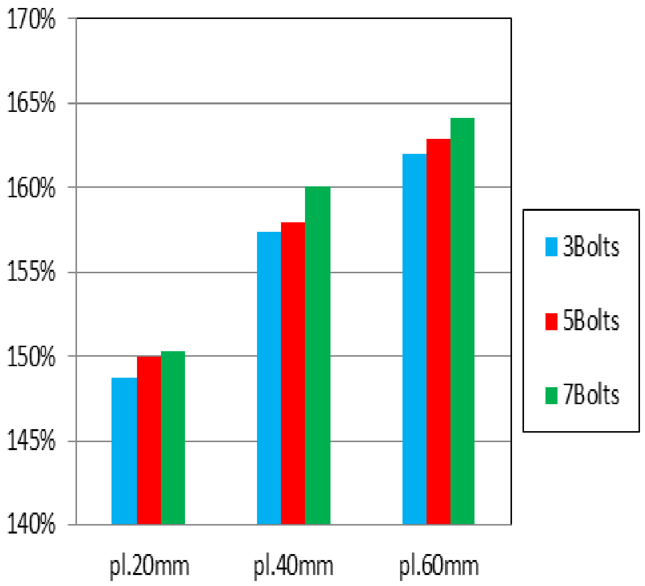

Figure 9 increase of ultimate load capacity due to strengthening by three plies steel wire mesh + (20, 40 and 60) mm with different fisher bolts (3, 5 and 7).

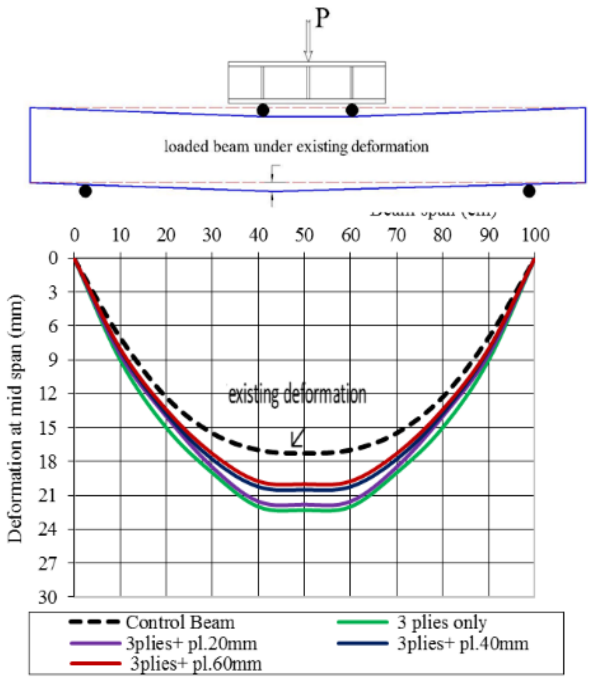

Figure 11 deformation of beams strengthened with 3plies steel wire mesh+ plats (20, 40 and 60) mm

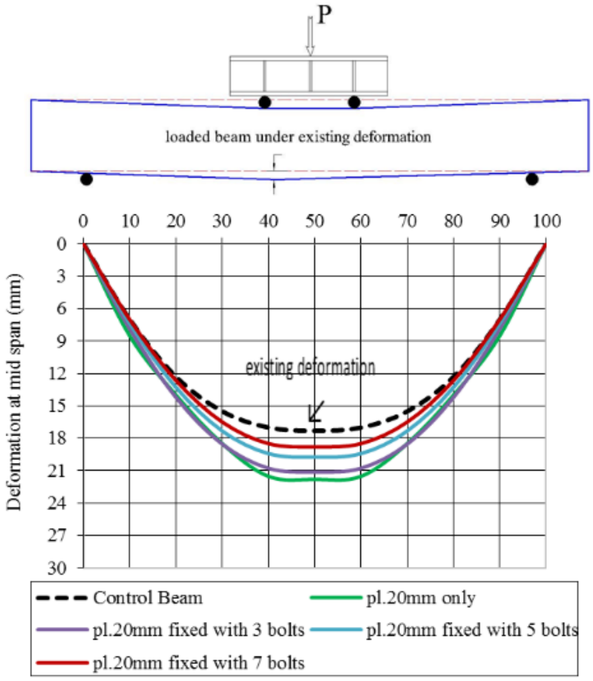

Figure 12 deformation of beams strengthened with 3plies steel wire mesh + plats 20 mm fixed with fisher bolts (3, 5 and 7).

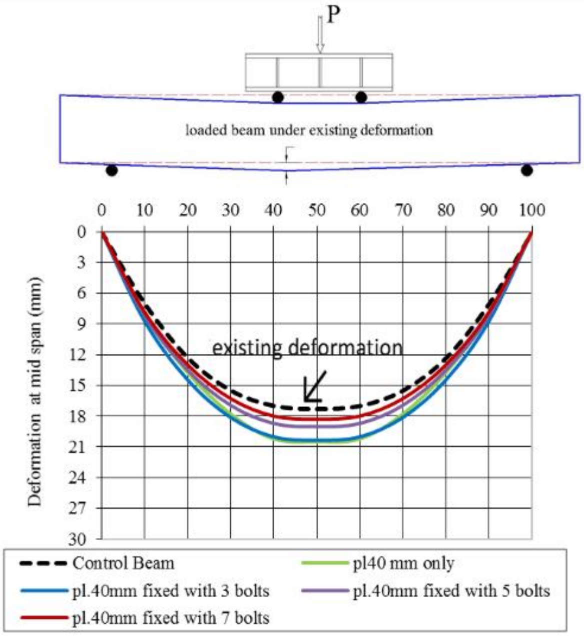

Figure 13 deformation of beams strengthened with 3plies steel wire mesh + plats 40 mm fixed with fisher bolts (3,5and7).

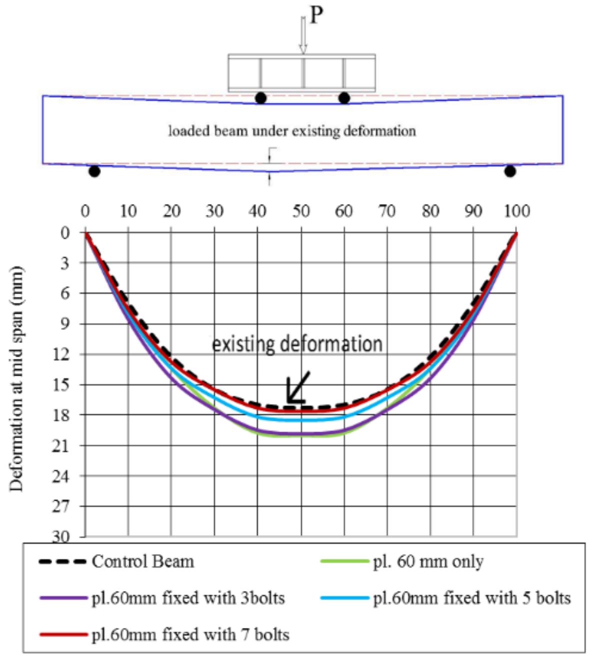

Figure 14 deformation of beams strengthened with 3plies steel wire mesh+ plats 60 mm fixed with fisher bolts (3, 5 and 7).

VI. CONCLUSIONS

From the above the followings are concluded:

- The use of only expanded three plies steel wire mesh jacketing increase the ultimate load carrying capacity by about 30%.
- The use of additional steel plates with cross-sections (20x3, 40x3 and 60x3) signed inside the steel wire mesh in strengthening of RC beams increases the ultimate load capacity from 47% to 60%.
- Fixing of the steel plates with different number of fisher bolts (3, 5 and 7) contributed to an additional increase in the ultimate load capacity ranging from (2% to 4%).
- Increasing of number of fisher bolts from 3 to 7 led to change the deformation shape from two concentrated loads to deformation shape of distributed loads.
- Using additional steel plates with cross-sections steel plates (20x3, 40x3 and 60x3) sign inside steel wire mesh decreases the beam deformation by 2% up to 10%.

- The increase number of fisher bolts from 3 to 7 decrease the deformation by 1% up to 14% from beam strengthened with steel plates only (20, 40 and 60 mm).

It can be said that the strengthening with jacketing of steel wire mesh with additional steel plates sign inside increase ultimate load capacity of RC beams. However, if the deformation does not meet the design criteria, the designer can increase number of steel wire mesh plies as well as increase cross-section of additional plates to enhance the deformations.

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