International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

An Experimental Study on Strengthening and Retrofitting of Damaged Reinforced Concrete Beams using Steel Wire Mesh and Steel Angles

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***Abstract*—This paper concerned with strengthening and retrofitting of reinforced concrete beams completely damaged due to flexural failure. The strengthening technique consists of steel wire mesh with and without additional longitudinal steel angles. Twenty four beams 100 mm width, 160 mm depth and 1250 mm overall span (1050 mm effective span) were casted and tested under two points loading. All beams were tested and loaded monotonically to failure, and then cracks were filled with grout mortar. The beams were strengthened and retrofitted under the existing deformation using two and three external plies of expanded galvanized steel wire mesh with square grids in the form of U-jacket. The investigated parameters were the size of longitudinal steel angles (10x10x3 mm, 20x20x3 mm and 30x30x3 mm) which were added at the bottom corners of beams inside the steel wire mesh. In addition, numbers of vertical steel clamps (2, 4 and 6) were used to fix the jacket to eliminate the debonding. The strengthened and retrofitted beams were again tested under two points loading. The results showed that strengthening and retrofitting reinforced concrete beams with steel wire mesh with and without additional longitudinal steel angles had a considerable increase in ultimate load carrying capacity. Retrofitting beams used 2 and 3 steel wire mesh plies only fixed with 2, 4 and 6 vertical clamps resulted in an increase beam carrying capacity from 26.59% to 49.55%. Also, increasing the angle size used at the bottom corners of beams inside the wire mesh increases the beam carrying capacity up to 72.51% and 172.51%. In addition, increasing number of vertical clamps increases the beam carrying capacity from 26.59% to 49.55%. In other hand, increasing angle size, number of clamps and number of wire mesh plies decreases beams deformation.**

Keywords*— *Beam, damaged, strengthening, retrofitting, steel wire mesh, steel angles, experimental

I. INTRODUCTION

Strengthening and retrofitting of reinforced concrete structural elements is one of the most difficult and important tasks of civil engineering. This research foxed on strengthening and retrofitting of damaged reinforced concrete beams by using steel wire mesh with and without additional longitudinal steel angles. Several experimental and analytical studies have been conducted on strengthening and retrofitting of beams over recent years. Basunbul, I. A. et al. (1990) made a comparison between repair methods for reinforced concrete beams subjected to different levels of cracking. Four methods of repair were studied: epoxy injection; ferrocement; steel-plate bonding; and a method combining epoxy injection and ferrocement. Levels of damage studied ranged from cracking of the beams at service load to complete failure of the beams. Experimental data on strength and ductility characteristics of repaired beams were obtained, and comparisons were made. Epoxy injection is shown to restore strength and ductility at all levels of damage studied, while ferrocement increases the strength and partially restores ductility, depending on the level of damage. Steel-plate bonding repair technique leads to an increase in strength but with a concomitant, considerable reduction in ductility of the repaired beams, regardless of the level of damage. The combined method of repair leads to both increases in strength and ductility. The increase in ductility depends on level of damage. Ghaleb, B. M. N. (1992) focused on the use of external fiber glass plates to strengthen damaged flexure and shear beams. Ghaleb investigated the performance of repairing flexure reinforced concrete beams after damaging them to a level loading corresponding to 10 mm central deflection. The level of damage was decided upon after testing two control beams to failure. These beams were then repaired using external fiber glass plates of different thicknesses. The performance of R.C. shear beams strengthened with external web reinforcement of the fiber glass. Two control beams were tested upon failure was evaluated. It was decided then to damage the beams up to the appearance of the first shear crack in the shear span. Three repair techniques were tried in the form of side plates (wings), strips and a newly suggested technique in the form of U-jacket. A criterion to evaluate the plate thickness to be used for repair any beam in reality was presented based on the ultimate flexural capacity of the section as well as the maximum interface shear and normal stresses at the plate ends. Maslehuddin, M. et al. (1994) presented an investigation includes the durability performance, namely, resistance to reinforcement corrosion of reinforced concrete beams repaired with ordinary cement mortar, polymer-based cementitious mortar and ferrocement mortar. The effect of temperature fluctuations, representative of the environmental conditions in the arid regions, on the corrosion-resisting characteristics of these repair materials was also evaluated. The performance of these materials was compared with unrepaired concrete beams. Results indicate superior performance by ordinary cement mortar compared to other materials. However, in the structural components subjected to thermal variations, ferrocement mortar was observed to be more beneficial. Foley, C. M. and Buckhouse, E. R. (1998) investigated and evaluated the use of bolted steel channels to existing R.C. beams as the primary means of additional flexural reinforcement. A design procedure is developed for the flexural reinforcement of existing R.C. beams using structural steel channel shapes. An experimental program involving nine concrete beams, 10"(w) x 18"(h) x 15'-6", was conducted to test the design procedure developed. The experimental program consisted of fabrication of nine test specimens: three control beams without external reinforcement, three externally reinforced members with wedge type expansion anchors, and three specimens with epoxy adhesive anchors. The beams were designed for shear failure of the mounting anchors for reasons to be highlighted and discussed. Testing was done to investigate the increase in flexural strength and stiffness of the externally reinforced R.C. beams. Each of the nine beams was tested to failure using four points loading. During testing, the applied load, vertical deflection of the beam centerline, strain in the internal reinforcing steel, and strain in the web and flanges of the structural steel channel were recorded. The measured ultimate loading was also recorded. An analytical technique is developed for predicting the ultimate load; load deformation response; and strains in the internal and external reinforcement. The theoretical values obtained using the design procedure and analytical methods are compared to the experimental results. Al-Kubaisy, M. A. and Jumaat, M. Z. (2000) investigated the flexural behavior of rectangular reinforced concrete beams strengthened or repaired using ferrocement laminate attached onto the tension face of the beam. The experimental program comprised the testing of 11 simply supported rectangular beams, loaded at mid span. The investigated parameters were type and spacing of shear connectors and the volume fraction of reinforcement in ferrocement laminate. The results showed that strengthening or repairing reinforced concrete beams with ferrocement laminate had resulted in a considerable increase in the ultimate load capacity, a reduction in the crack width at both service and near ultimate load, and a reduction in the mid span deflection. Increasing the spacing of the shear connectors seemed to have negligible effect on the overall behavior of the tested beams. Composite action was achieved with all types of connectors; however, beams with bolts as shear connectors developed horizontal cracks at the interface between the reinforced concrete beam and the ferrocement laminate (delamination) just before failure. Kashif, S. A. (2004) studied a novel approach to steel plate composite beam in which bond between the concrete and the steel plate is provided by welding the steel plate to the legs of the uniformly spaced stirrups. Experimental investigation showed that the parameters such as interface connections, geometric dimensions, stirrups spacing and thickness of steel plate have a great influence on the strength, deformation and failure characteristics of such composite beams. A finite element model has been developed using commercial software, ABAQUS, to predict the strength of such composite beams and its performance is validated through experimental results. The direct finite element simulation of proposed composite beams with developed finite element model gives an average of experimental to predicted strength ratio of 0.99, which confirms the accuracy of prediction. The finite element model is then used to simulate a large number of numerical beams with varying geometric and material properties to formulate design guidelines. Design charts were developed and their performance is validated through test results. Design procedures for such beams were illustrated with calculated design examples. Such design procedures can be adopted in the actual design of proposed composite beams in practical applications. Al-Enezi, A. S. (2006) proposed an experimental programmer to evaluate Strengthening and rehabilitation of reinforced concrete beams by using steel plate with and without clamps, steel angles with and without clamps and CFRP under different load . Al-Enezi casted thirty-two reinforced concrete beams of 120 mm×200 mm cross-section and 1750 mm total length and tested under two points loading. Fifteen beams were strengthened with steel plates, steel angles and CFRP and tested. Thirteen beams were loaded by 50 % of ultimate load and rehabilitated with the same methods and tested. All the tested beams have the same reinforcement. Different methods of strengthening reinforced concrete beams were carried out including variation of fixation methods especially using clamps and variation of fixation bolts number. Analysis and comparison between different methods of strengthening and rehabilitation of reinforced concrete beams as well as variation of fixation methods are presented. Elsamny, M. K. et al. (2006) made an experimental program for testing R.C. beams. A program was conducted to strengthening and rehabilitation of R.C. beams with different methods. The tested elements were 24 R.C. beams divided into 3 beams as control beams and loaded until failure load. 9 beams as first group of beams strengthened and loaded until failure load. 12 beams as second group of beams which first loaded until 50% of failure load then unloaded and strengthened then loaded until failure load. The methods of strengthening and rehabilitation used in the program were steel angles, steel plates with and without steel clamps.The beams strengthened by steel angles and steel plates showed an increase in the flexural strength. The beams strengthened or rehabilitated using 3, 5, and 8 plies steel mesh showed an increase in the flexural strength. Bansal, P. P., Kumar, M. and Kaushik, S.K. (2008) conducted an experimental program to investigate the effect of wire mesh orientation on the strength of stressed beams retrofitted with ferrocement jackets. The beams are stressed up to 75 percent of safe load and then retrofitted with ferrocement jackets with wire mesh at different orientations. The results showed that the percent increase in load carrying capacity for beam retrofitted with ferrocement jackets with wire mesh at 0, 45, 60 degree angle with longitudinal axis of beam, varies from 45.87 to 52.29 percent. Also a considerable increase in energy absorption is observed for all orientations. However, orientation at 45 degree shows higher percentage increase in energy absorption followed by 60 and 0 degree respectively. Xing, G. et al. (2010) tested five one-third-scale simply supported RC T-beams. Four-point bending flexural tests were conducted up to failure on one control beam. The objectives of this investigation were to study the effectiveness of steel wire mesh (SWM) and polymer mortar composites in increasing the flexural strength of concrete beams and to study the construction technology for further development. The main test parameters included the amount of longitudinal SWM reinforcement. The results demonstrated the feasibility of rehabilitating and strengthening RC members with SWM composites. A design procedure is presented with aim to predict the flexural strength of T-beams strengthened with SWM composites. Good agreement between experiment and predicted values was achieved. Sivagurunathan, B. and Vidivelli, B. (2012) revealed the work associated with the behaviour of strengthening the predamaged reinforced concrete beams by using ferrocement plates. The study elaborated the mechanical properties of ferrocement with three different volume fractions of reinforcements. Ferrocement laminates are introduced to enhance the overall performance of reinforced concrete beams. Eight beams of size 125mm width, 250mm depth and 3200mm overall length were cast and tested for flexure. Out of eight beams two beams were treated as control beams and the remaining six beams were loaded to a predetermined damage level, and strengthened by fastening ferrocement laminates. Fastening of ferrocement laminates onto the surface of the predamaged beam was done by using epoxy resin adhesive. The strengthened beams were again tested for ultimate load carrying capacity by conducting flexural test. A comparative study was made between the control beams and the predamaged beams strengthened by ferrocement laminates. The test results have shown that ferrocement can be used as an alternative strengthening material for the reinforced concrete beams damaged due to overloading. Makki, R. F. (2014) presented experimental works to investigate the behavior of reinforced concrete beams retrofitted by ferrocement to increase the strength of beams in both shear and flexure, ten reinforced concrete beams were casted in order to study different parameters such as shear reinforcement (stirrups), different diameters of wire mesh used in rehabilitation, two types of rehabilitation were used first (strengthening) and second (repairing) the beams are initially stressed to a different prefixed percentage of the ultimate load and finally mechanical method was used to fixed the wire mesh of ferrocement (using bolts) to eliminate the debonding of ferrocement and trying to reach the full maximum tensile strength of ferrocement. The experimental results indicated that the rehabilitation technique (strengthening and repairing) of R.C. beams by using ferrocement system is applicable and can increase the ultimate load in case of strengthening and repairing. Also, the test results for strengthening beams showed that the effect of diameter of ferrocement wire mesh on the ultimate strength of R.C. beams will have an increase relation. Also for repairing beams the results state 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 relation. Elsamny, M.K. et al. (2015) investigated strengthening and retrofitting of beams by using steel wire mesh with different number of plies with or without external horizontal steel bars in tension side of beams. The steel wire mesh was fixed by cement grout and fisher bolts and confining the steel wire mesh and steel bars with one vertical strap at both ends of beam. Twenty six reinforced concrete beams with cross-sectional dimensions 100 mm×160 mm and 1250 mm total length (1050 mm effective length) were casted and tested 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 obtained test results showed that the beams strengthened as well as retrofitted by a different numbers of steel wire mesh plies without external horizontal steel bars gives an increase in the load carrying capacity up to (63.05%) of the control ultimate capacity. However, adding external horizontal steel bars in steel wire mesh jacketing gives an increase in the load carrying capacity up to (74.21%) of the control ultimate capacity. Results illustrated that increasing the number of wire mesh plies used in strengthening or retrofitting beams increase the load carrying capacity of beams and decrease the mid span deflection.

II. DETAILS OF RETROFITTING AND STRENGTHENING PROPOSED TECHNIQUE

The beams were loaded to failure then cracks were filled with grout mortar. After which, the beams were strengthened and retrofitted using expanded galvanized steel wire mesh with square grids plies around three sides of beams by three methods as follows:

- Wrapping the beams with expanded galvanized steel wire mesh plies only (2 and 3 plies).
- Fixation of the galvanized steel wire mesh by using steel bolts with different number of vertical steel clamps (2, 4 and 6) with 25 mm width and 1.2 mm thickness as shown in Figures (1-a), (1-b) and (1-c).
- Two longitudinal steel angles with 3 mm thickness with different sizes 10, 20 and 30 mm were used at the bottom corners of beams inside the galvanized steel wire mesh as shown in Figures (2-a), (2-b) and (2-c).

ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

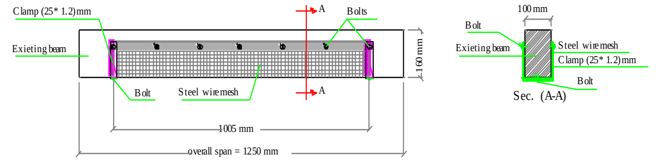

Figure (1-a) Fixing steel wire mesh plies with 2 clamps and bolts .

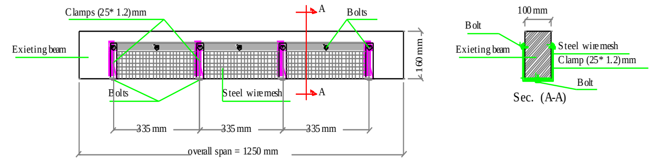

Figure (1-b) Fixing steel wire mesh plies with 4 clamps and bolts .

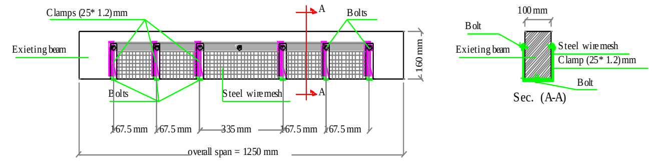

Figure (1-c) Fixing steel wire mesh plies with 6 clamps and bolts .

Figure (1) Strengthening and retrofitting beams using 2 and 3 expanded galvanized steel wire mesh plies only around three sides of beams fixed with 2, 4 and 6 clamps and bolts .

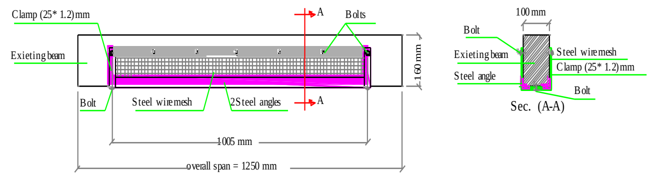

Figure (2-a) Fixing steel wire mesh plies and longitudinal steel angles (10x10x3 mm, 20x20x3 mm and 30x30x3 mm) with 2 clamps and bolts .

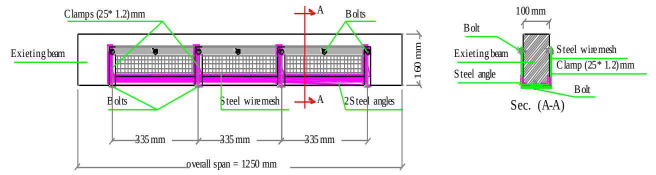

Figure (2-b) Fixing steel wire mesh plies and longitudinal steel angles (10x10x3 mm , 20x20x3 mm and 30x30x3 mm) with 4 clamps and bolts .

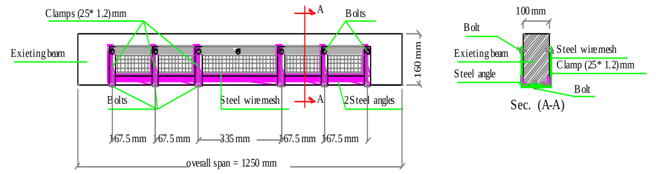

Figure (2-c) Fixing steel wire mesh plies and longitudinal steel angles (10x10x3 mm , 20x20x3 mm and 30x30x3 mm) with 6 clamps and bolts .

Figure (2) Strengthening and retrofitting beams using expanded galvanized steel wire mesh plies around three sides of beams with two longitudinal steel angles (10x10x3 mm, 20x20x3 mm and 30x30x3 mm) were used at the bottom corners of beam fixed with clamps and bolts .

III. EXPERIMENTAL PROGRAM

Twenty four beams with cross section (100 mm ×160 mm) and 1250 mm overall span (1050 mm effective span) were casted and tested. All beams have two normal mild steel bars 8 mm diameter as a bottom reinforcement and two normal mild steel bars 6 mm diameter as a top reinforcement. Also, beams were provided with stirrups of normal mild steel 6 mm diameter and 100 mm spacing as shown in Figure (3). All beams were tested under two point loads.

All beams were tested and loaded to failure before strengthening as shown in Figure (4). Beams cracks were filled with grout mortar. After which, the beams were strengthened and retrofitted using different number of steel wire mesh plies with and without additional external two steel angels having different size as shown in Figure (5). Steel wire mesh was fixed to beams under the existing deformations using steel bolts and vertical steel clamps as shown in Figure (6).

The strengthened and retrofitted beams were divided into the following groups:

Group 1: six beams were strengthened and retrofitted using only 2 and 3 plies of expanded galvanized steel wire mesh fixed to beam with 2, 4 and 6 vertical clamps and bolts.

Group 2: six beams were strengthened and retrofitted using 2 and 3 plies of expanded galvanized steel wire mesh with two inside longitudinal steel angles 10x10x3 mm at the bottom corners of beam.

Group 3: six beams were strengthened and retrofitted using 2 and 3 plies of expanded galvanized steel wire mesh with two inside longitudinal steel angles 20x20x3 mm at the bottom corners of beam.

Group 4: six beams were strengthened and retrofitted using 2 and 3 plies of expanded galvanized steel wire mesh with two inside longitudinal steel angles 30x30x3 mm at the bottom corners of beam.

Table (1) shows all details of the tested beams.

Cetorex grout was used as grout of steel wire mesh jacket by 10 % water/grout ratio as shown in Figure (7). During testing, the applied load, vertical deflection of the beam at the mid span point, strain in the internal reinforcing steel, and strain in the steel angels were recorded. Also, the measured ultimate load and the maximum mid span vertical deflection for control beams were recorded.

TABLE 1. FAILURE LOAD AND THE MAXIMUM MID SPAN VERTICAL DEFLECTION FOR CONTROL BEAMS

Specimen symbol	Failure load (kN)	Average failure load (kN)	Maximum deflection at mid span (mm)	Average maximum deflection at mid span (mm)
B1	33.05		17.60	
B2	33.11		17.20	
B3	32.96		17.50	
B4	33.10		17.60	
B5	33.03		17.50	
B6	32.94		17.30	
B7	33.22		17.80	
B8	33.15		17.70	
B9	33.19		17.45	
B10	32.98		17.10	
B11	33.04		17.45	
B12	33.11	33.10	17.60	17.40
B13	33.24		17.70	
B14	33.08		17.20	
B15	33.06		17.20	
B16	32.97		17.05	
B17	32.81		17.30	
B18	33.14		17.25	
B19	32.98		17.00	
B20	33.32		17.30	
B21	33.38		17.50	
B22	33.08		17.40	
B23	33.17		17.70	
B24	33.29		17.20	

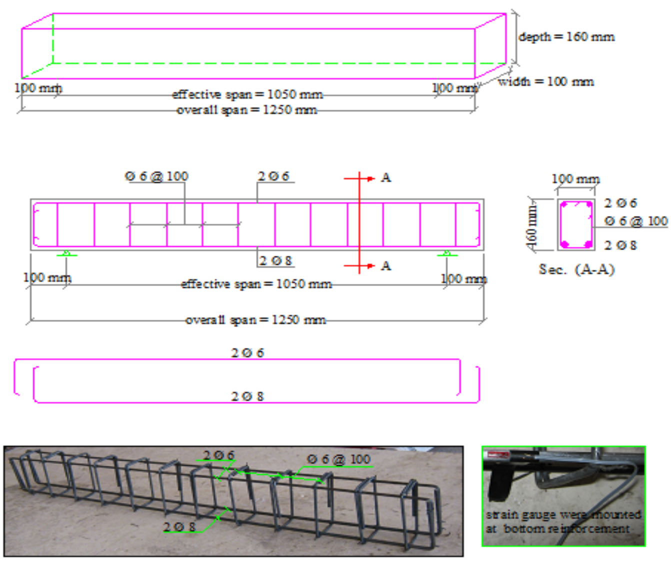

Figure (3) Beam dimensions and reinforcement .

Fig.4 The beams after loading to failure

Fig.5 Expanded galvanized steel wire mesh with and without two longitudinal steel angles 10x10x3 mm, 20x20x3 mm and 30x30x3 mm

Fig.6 Expanded galvanized steel wire mesh with and without two longitudinal steel angles were used at the bottom corners of beams fixed to beams with 2, 4 and 6 clamps and bolts.

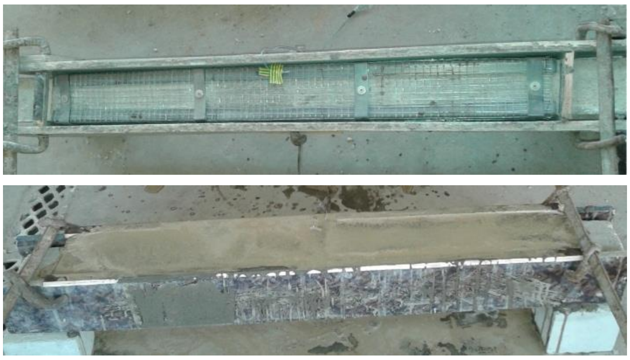

Fig.7 grouting steel wire mesh jacket using Cetorex grout

IV. USED MATERIALS

Beams were constructed using concrete and normal mild steel bars as internal reinforcement. External jacket consisted of expanded galvanized steel wire mesh plies with or without additional external two steel angels at the bottom corners of beams having different size. The steel wire mesh and the steel angels were fixed to beams using steel bolts and different numbers (2, 4 and 6) of vertical steel clamps.

- Crushed stone which has a maximum nominal size of 10.0 mm (size 1) was used as the coarse aggregate. Graded sand having sizes in the range of (0.6 - 0.2 mm) was used as the fine aggregate. All beams were molded using the same batch. The cement used was fresh product and achieved the requirements of the Egyptian standard for the mechanical and physical properties of ordinary Portland cement. Clean fresh potable pure (free from impurities) water was used for mixing and curing the beams. The concrete mix used in all specimens was designed according to the Egyptian code of practice. The concrete mix was designed to obtain target strength of 25 N/mm2 after 28 days.
- Normal mild steel bars St24/37-smooth rebar's of diameter 6.0 and 8.0 mm were used as internal reinforcement.
- Cetorex grout was used as grout of steel wire mesh jacket. Cetorex grout is a mixture of specially processed cement with carefully graded fine aggregate and additives to impart controlled expansion characteristics reduce the necessary water, increase bonding strength, produce fluidity, and high early and final strength.
- The galvanized welded square steel wire mesh used has a specification 12.7x12.7 mm panel size and 1.6 mm wire diameter.
- The steel angles have a yield stress of 325 N/mm2 and tensile strength of 420 N/mm2 with an elongation percentage of 30%.
- The strain gauges used 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 is 2.1 ± 1.0%.

V. TEST SETUP AND PROCEDURE

All the twenty four simply supported beams were tested with an effective span of 1050 mm, under two points loading. The beams were tested using a 100 kN capacity hydraulically testing machine connected to a data acquisition system through the load cell mounted in the RC laboratory of Al-Azhar University. The data acquisition system used in the present study consisted of a Laptop computer, a Keithley-500A Data Acquisition System. The beam deflection was recorded using LVDT placed at the mid span of beam. The test setup is shown in Figure (8).

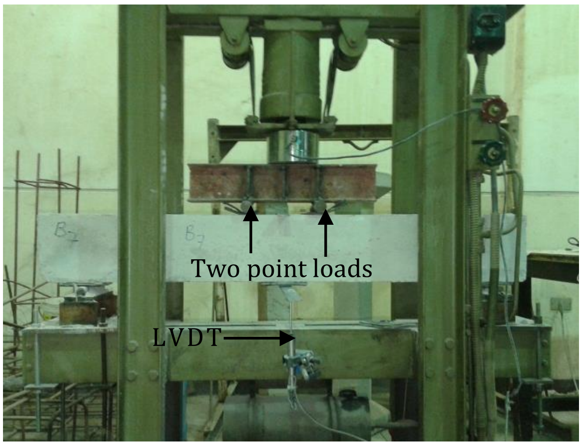

Fig.8 Test setup

VI. TEST RESULTS

A. *Load carrying capacity for strengthened and retrofitted beams*

Table (2) presents the failure loads and the percent of increase in load carrying capacity.
Figure (9), (10) and (11) show the relationships between angles size and the percent of increase in load carrying capacity for beams retrofitted using 2 and 3 steel wire mesh plies fixed with 2, 4 and 6 clamps respectively.
Figure (12) shows the relationship between angles size and the increase in load carrying capacity for beams retrofitted using 2 steel wire mesh plies fixed with 2, 4 and 6 clamps.
Figure (13) shows the relationship between angles size and the increase in load carrying capacity for beams retrofitted using 3 steel wire mesh plies fixed with 2, 4 and 6 clamps.
Figure (14) and (15) show the relationships between number of clamps and the percent of increase in carrying capacity for beams retrofitted using 2 and 3 steel wire mesh plies respectively with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).
Figure (16) shows the percent of increase in load carrying capacity for all retrofitted beams.

B. *Deflection of strengthened and retrofitted beams*

Table (3) presents the maximum mid span vertical deflection for strengthening and retrofitting beams.
Figure (17) and (18) show the relationships between angles size and the maximum mid span deflection of beams retrofitted using 2 and 3 steel wire mesh plies respectively fixed with 2, 4 and 6 clamps respectively.
Figure (19) and (20) show the relationships between number of clamps and the maximum mid span deflection of beams retrofitted using 2 and 3 steel wire mesh plies respectively with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).
Figure (21) shows the maximum mid span deflection of all retrofitted beams.
Figure (22), (23) and (24) show the deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies only fixed with 2, 4 and 6 clamps respectively.

Figure (25), (26) and (27) show the deformed of beams retrofitted using 2 and 3 steel wire mesh plies with and without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm) fixed with 2, 4 and 6 clamps respectively.

The experimental results indicated that the retrofitting technique of R.C. beams by using system of steel wire mesh with additional steel angles inside them is powerful and can increase the ultimate load carrying capacity. In addition, numbers of vertical steel clamps which used to fix the wire mesh jacket to beams increase the ultimate load carrying capacity of retrofitted beams.

TABLE 2. FAILURE LOAD OF STRENGTHENING AND RETROFITTING BEAMS

groups	Specimen No.	Strengthening and retrofitting technique			Failure load (kN)	% Increase in load carrying capacity/ control failure load
		Wire mesh plies No.	longitudinal steel angles	Vertical clamps No. (25 x 1.2 mm)		
Group 1	B022	2	-----	2	41.90	26.59
	B032	3		2	42.50	28.40
	B024	2		4	44.10	33.23
	B034	3		4	45.30	36.86
	B026	2		6	47.20	42.60
	B036	3		6	49.50	49.55
Group 2	B122	2	2 angles 10 x 10 x 3mm	2	57.10	72.51
	B132	3		2	59.20	78.85
	B124	2		4	59.00	78.25
	B134	3		4	61.72	86.47
	B126	2		6	62.30	88.22
	B136	3		6	64.63	95.26
Group 3	B222	2	2 angles 20 x 20 x 3mm	2	65.70	98.49
	B232	3		2	67.34	103.44
	B224	2		4	68.00	105.44
	B234	3		4	69.94	111.30
	B226	2		6	70.20	112.08
	B236	3		6	73.80	122.96
Group 4	B322	2	2 angles 30 x 30 x 3mm	2	69.90	111.18
	B332	3		2	71.70	116.62
	B324	2		4	77.20	133.23
	B334	3		4	82.60	149.55
	B326	2		6	83.50	152.27
	B336	3		6	90.20	172.51

TABLE 3. THE MAXIMUM MID SPAN VERTICAL DEFLECTION FOR STRENGTHENING AND RETROFITTING BEAMS

groups	Specimen No.	Strengthening and retrofitting technique			Maximum deflection at mid span (mm)
		Wire mesh plies No.	longitudinal steel angles	Vertical clamps No. (25 x 1.2 mm)	
Group1	B022	2	-----	2	23.17
	B032	3		2	22.04
	B024	2		4	22.93
	B034	3		4	21.85
	B026	2		6	22.81
	B036	3		6	21.66
Group2	B122	2	2 angles 10 x 10 x 3mm	2	21.47
	B132	3		2	20.14
	B124	2		4	21.26
	B134	3		4	20.06
	B126	2		6	20.90
	B136	3		6	19.82
Group3	B222	2	2 angles 20 x 20 x 3mm	2	20.24
	B232	3		2	18.68
	B224	2		4	19.91
	B234	3		4	18.57
	B226	2		6	19.49
	B236	3		6	18.55
Group4	B322	2	2 angles 30 x 30 x 3mm	2	18.56
	B332	3		2	16.94
	B324	2		4	18.00
	B334	3		4	16.54
	B326	2		6	17.21
	B336	3		6	16.13

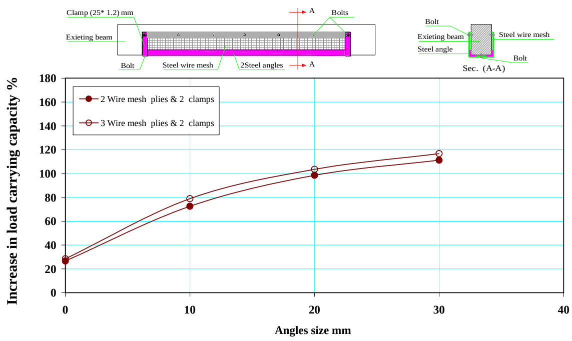

Figure (9) The relationship between angles size and the increase in load carrying capacity for beams retrofitted using 2 and 3 steel wire mesh plies fixed with 2 clamps.

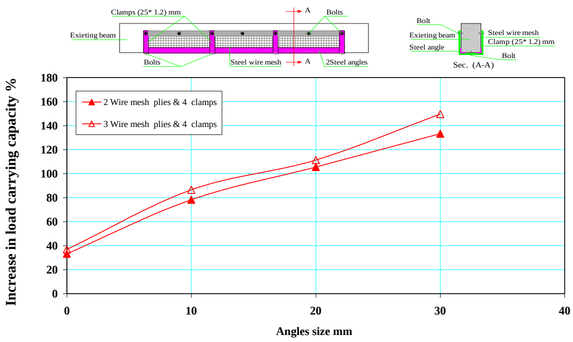

Figure (10) The relationship between angles size and the increase in load carrying capacity for beams retrofitted using 2 and 3 steel wire mesh plies fixed with 4 clamps.

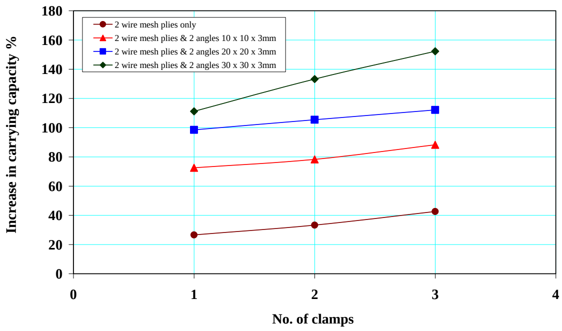

Figure (14) The relationship between number of clamps and the increase in carrying capacity for beams retrofitted using 2 steel wire mesh plies with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).

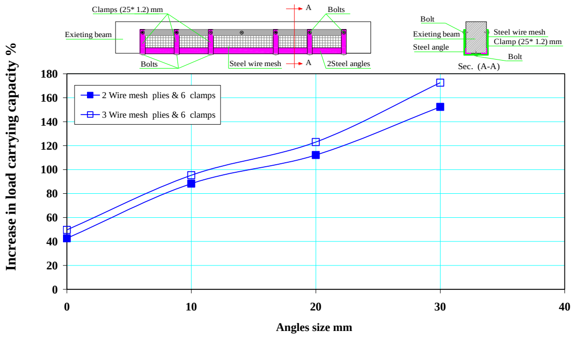

Figure (11) The relationship between angles size and the increase in load carrying capacity for beams retrofitted using 2 and 3 steel wire mesh plies fixed with 6 clamps.

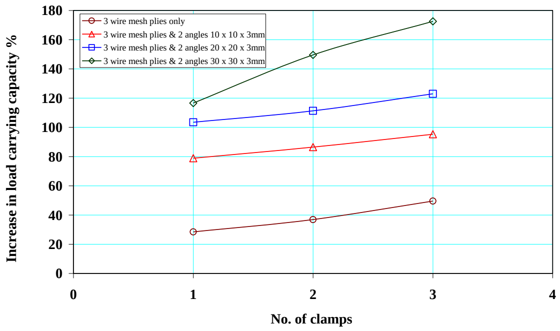

Figure (15) The relationship between number of clamps and the increase in load carrying capacity for beams retrofitted using 3 steel wire mesh plies with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).

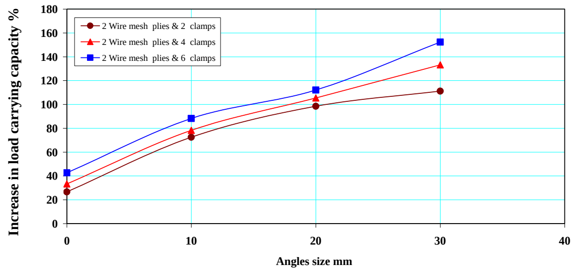

Figure (12) The relationship between angles size and the increase in load carrying capacity for beams retrofitted using 2 steel wire mesh plies fixed with 2,4 and 6 clamps.

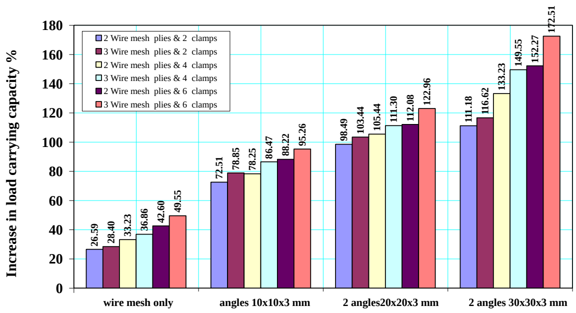

Figure (16) The increase in load carrying capacity for all retrofitted beams.

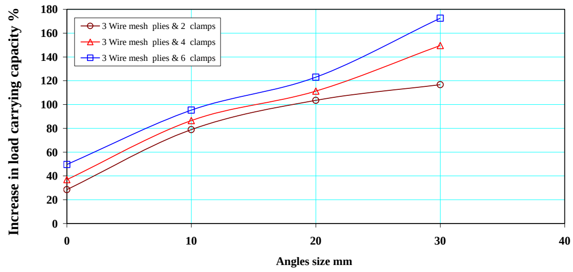

Figure (13) The relationship between angles size and the increase in load carrying capacity for beams retrofitted using 3 steel wire mesh plies fixed with 2,4 and 6 clamps.

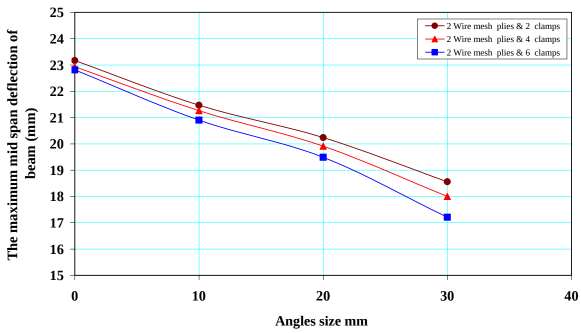

Figure (17) The relationship between angles size and the maximum mid span deflection of beams retrofitted using 2 steel wire mesh plies fixed with 2, 4 and 6 clamps.

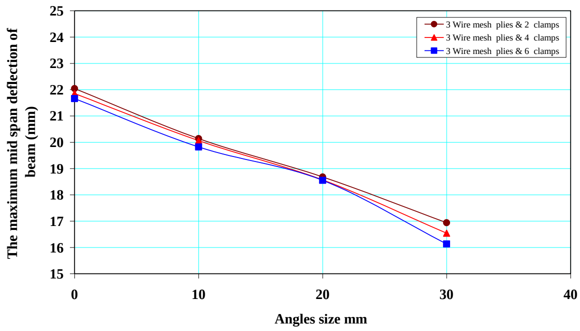

Figure (18) The relationship between angles size and the maximum mid span deflection of beams retrofitted using 3 steel wire mesh plies fixed with 2, 4 and 6 clamps.

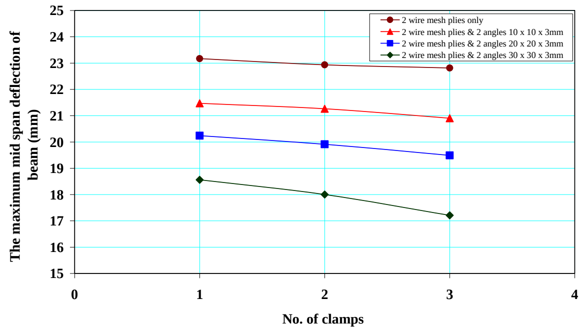

Figure (19) The relationship between number of clamps and the maximum mid span deflection of beams retrofitted using 2 steel wire mesh plies with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).

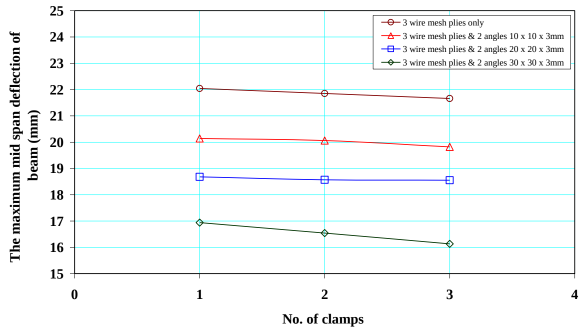

Figure (20) The relationship between number of clamps and the maximum mid span deflection of beams retrofitted using 3 steel wire mesh plies with or without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm).

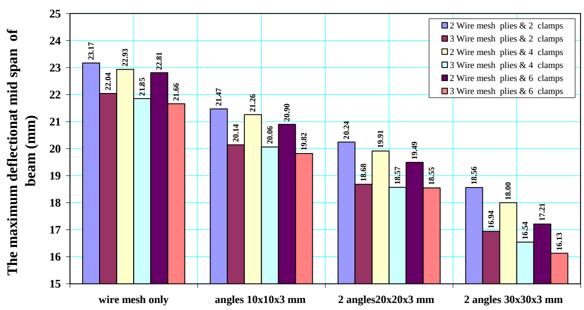

Figure (21) The maximum mid span deflection of all retrofitted beams.

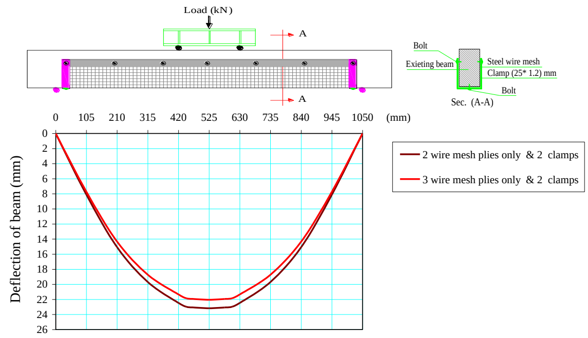

Figure (22) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies only fixed with 2 clamps.

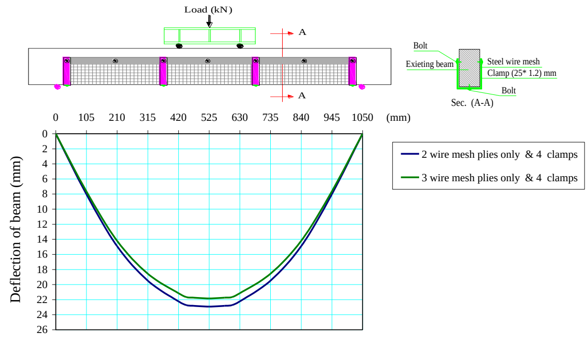

Figure (23) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies only fixed with 4 clamps.

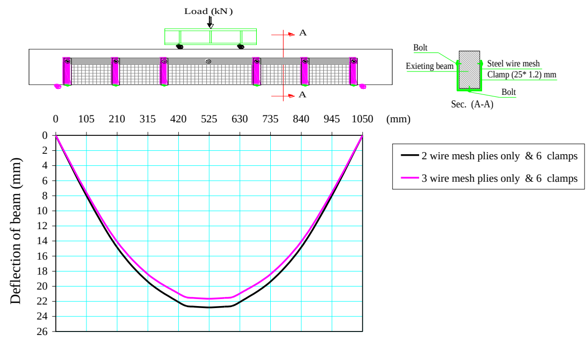

Figure (24) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies only fixed with 6 clamps.

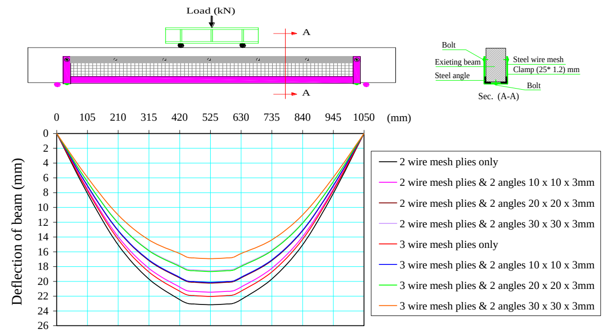

Figure (25) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies with and without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm) fixed with 2 clamps.

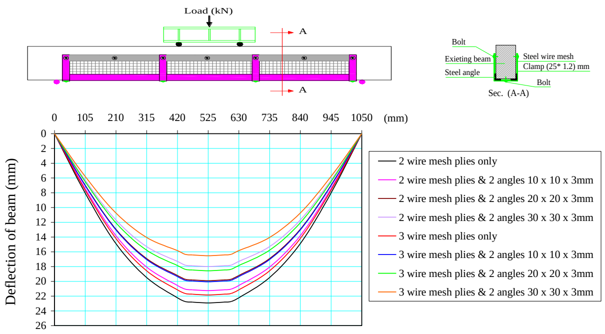

Figure (26) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies with and without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm) fixed with 4 clamps.

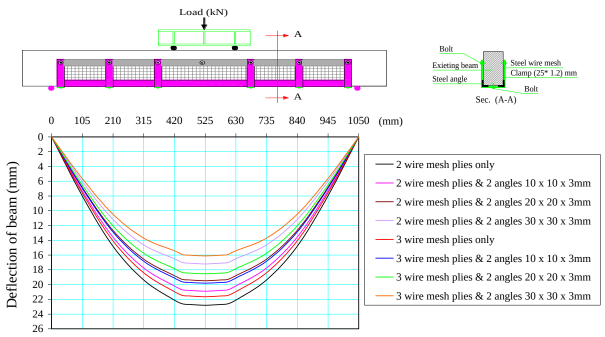

Figure (27) Deformed shape of beams retrofitted using 2 and 3 steel wire mesh plies with and without 2 angles (10x10x3 mm,20x20x3 mm and 30x30x3 mm) fixed with 6 clamps.

VII. CONCLUSIONS

From the above, the following conclusions are drawn:

- Increasing numbers of steel wire mesh plies fixed with 2, 4 and 6 vertical clamps without external steel angles increase the beam carrying capacity from 26.59% to 49.55%.
- Increasing number of the vertical clamps increases the beam carrying capacity up to 26.59% and 49.55%.
- Increasing the angle size used at the bottom corners of beams inside the wire mesh fixed with 2 vertical clamps increases the beam carrying capacity up to 72.51% and 116.62%.
- Increasing the angle size used at the bottom corners of beams inside the wire mesh fixed with 4 vertical clamps increases the beam carrying capacity up to 78.25% and 149.55%.
- Increasing the angle size used at the bottom corners of beams inside the wire mesh fixed with 6 vertical clamps increases the beam carrying capacity up to 88.22% and 172.51%.
- The deformation of retrofitted beams decreases by increasing the wire mesh plies.
- Increasing number of the vertical clamps decreases the beams deformation.
- Increasing the angle size used at the bottom corners of beams inside the wire mesh decreases the beams deformation.

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