International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Strengthening of Two Way Reinforced Concrete Slabs using Different Techniques

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Accepted 01 May 2017, Available online 15 May 2017, **Vol.7, No.3 (June 2017)**

Abstract

This study presents an experimental investigation of the behavior of Sixteen simply supported two way reinforced concrete slabs, which were tested up to failure under the action of concentrated patch load to examine the effect of different types of strengthening on their behavior. All the slabs had the same overall dimensions and flexural steel reinforcement. Five types of strengthening were adopted. The first and second methods include applying either near surface mounted (NSM) or near reinforcement mounted (NRM) ferrocement layers. While the third method includes applying a concrete layer reinforced with welded wire fabric mesh of various diameters. The fourth and fifth methods include fixing CFRP rods and laminates, respectively, on the bottom face of slabs. Strengthening techniques were applied on the bottom surface of fifteen slab specimens. In addition, a control slab specimen without any strengthening was used for purpose of comparison. All the strengthening techniques made an enhancement in the ultimate and cracking strength. The test results showed that both carbon fiber laminates and rods greatly increase the cracking strength and also improve the ultimate load capacities and deflection response.

***Keywords**: Two-Way Slabs, Strengthening Techniques, Fine Wire Mesh, Welded Wire Fabrics, CFRP Rods, CFRP Laminates.*

Introduction

In the past, concrete structures were considered to have their strength and durability nearly permanent. However, in recent years, their deterioration and damage are becoming conspicuous, and the repair and strengthening of these structures are now a prime need. Several strengthening techniques have been developed in the past and used with some popularity. Five of these methods are included in this paper which are: fine wire mesh reinforced cement mortar (Internal ferrrocement), fine wire mesh reinforced cement mortar (External ferrrocement), welded wire fabric (WWF) reinforced concrete layer, CFRP bars and CFRP laminates. The advantageous properties of ferrocement, such as strength, toughness, water-tightness, lightness, durability, fire resistance and environmental stability, are good compared to any other construction material, While the fiber-reinforced polymer reinforcement is increasingly becoming significant in the strengthening and repairing of reinforced concrete structures. Where, it is commonly used as external strengthening for concrete slabs, beams and columns. Advantages of these techniques by FRP are common and keep growing, because of the easy installation, negligible losses, and high strength to weight ratio that these FRP materials can provide.

Essam and Banu and Ţăranu carried out experimental investigations for reinforced concrete slabs strengthened with welded steel meshes, known as ferrocement. Many other researchers like Enochsson, Garner, Soudki et al. and Al-Fatlawi and Abed studied FRP strengthening systems either sheets, laminates or bars.

Experimental Program

An experimental program was carried out to study the behavior of two way reinforced concrete slabs strengthened by different techniques. The study consists of constructing sixteen simply supported two way slabs under concentrated load. All slabs had the same dimensions 700x700x130 mm as shown in Figure 1. For all specimens, the main tension reinforcement consisted of five deformed steel bars having a diameter of 6 mm distributed at a spacing of 150 mm center to center in both directions which satisfy the minimum reinforcement recommended by ACI 318M-14. The specimens were classified into five

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groups GA, GB, GC, GD and GE, slab G0 was the control specimen. The parametric study was designed to classify slabs into five series as shown in Table 1. The nominal effective areas of strengthening (A_t) in Table 1 were calculated as:

$$A_t = A_b \times \frac{1000}{S} \quad (1)$$

Where, $\mathbf{A_b}$ is the area of a single steel wire in mesh reinforcement in groups A to C or CFRP bars or strip in groups D and E in mm^2, and, **S** is the spacing distance between wires, bars or strips, center to center, in mm.

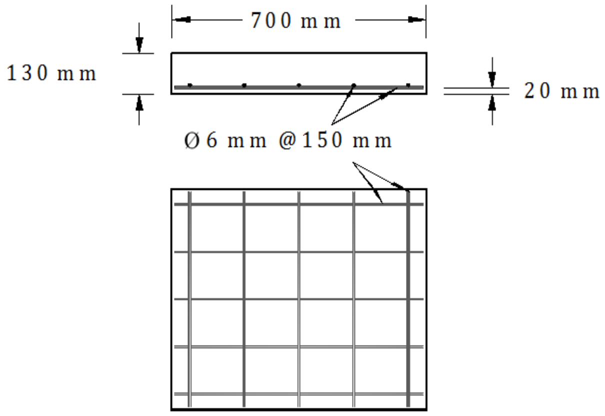


Fig. 1 Details and arrangement of reinforcement of slab specimen

Group A (Near reinforcement mounted ferrocement): This group consisted of three slabs (GA1, GA2, and GA3). These specimens are strengthened with a layer of ferrocement with different reinforcement ratios. The reinforcement used here is of 1.7 mm size and 25 mm spacing wire-mesh. GA1 is a specimen strengthened with ferrocement layer reinforced with one panel of wire-mesh that gives a nominal steel area of 90 mm^2/m. While GA2 and GA3 were strengthened with two and three panels of wire-mesh with nominal steel areas of 180 mm^2/m and 270 mm^2/m, respectively. Ferrocement layer was in direct contact with the main reinforcement of slabs after removing the concrete cover as shown in Figure 2.

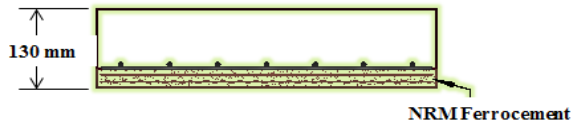


Fig. 2: Near reinforcement mounted ferrocement strengthening

Group B (Near surface mounted ferrocement): This group consisted of three slabs (GB1, GB2, and GB3). It is similar to the strengthening of group A but the ferrocement layer is added to the bottom face without removing the concrete cover. A screw of diameter 6 mm and spacing of 100 mm (both direction) were added to fix the ferrocement mesh, as shown in Figure 3.

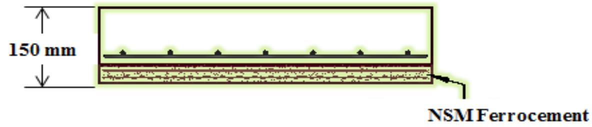


Fig. 3: Near surface mounted ferrocement strengthening

Group C (Steel Welded wire Fabric Strengthening): This group consisted of three slabs (GC1, GC2, and GC3). GC1 was strengthened with one layer of welded mesh wire panel with diameter of 4 mm and 150 mm spacing that gives a nominal steel area of 90 mm^2/m as shown in Fig. 4. GC2 was strengthened with one layer of welded mesh wire with diameter of 6 mm and 150 mm spacing which gives a nominal area of steel reinforcement of 180 mm^2/m. GC3 was strengthened with two layers of welded mesh wire panels, one of them with diameter of 4 mm and the other with diameter of 6 mm that gives a nominal steel area of 270 mm^2/m. Screw of 6 mm diameter and spacing of 100 mm (both direction) were added to fix WWF mesh on concrete bottom face, as shown in figure 4.

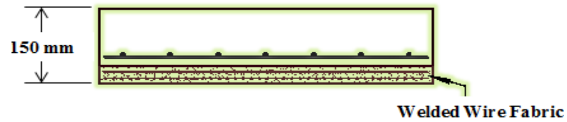


Fig. 4: Steel Welded Wire Fabric Strengthening

Group D (NSM CFRP Bars Strengthening): This group consisted of three slabs (GD1, GD2, and GD3). GD1 was strengthened with 3 CFRP bars of 6 mm diameter in each direction that gives a nominal area of 90 mm^2/m. GD2 was strengthened with 5 bars of 6 mm diameter in each direction with a nominal area of 180 mm^2/m and GD3 was strengthened with 7 bars also of 6 mm diameter with a nominal area of 270 mm^2/m in each direction. Carbon bars were attached to the bottom surface of the slabs using grooves of 18 mm depth and 10 mm width as shown in figure 5.

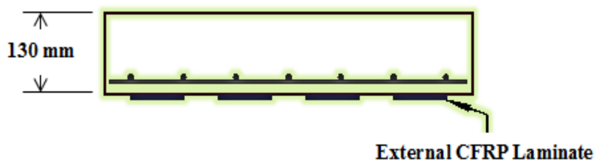


Fig. 5: NSM CFRP bars strengthening

Group E (NSM CFRP Laminates Strengthening): The last group has three slabs (GE1, GE2, and GE3). GE1 was strengthened with 5 strips of 1.2 mm thick CFRP laminates with width of 15 mm in each direction that gives area of 90 mm^2/m.GE2 was strengthened with 5 strips of CFRP laminates with width of 30 mm in each direction that gives area of 180 mm^2/m and GE3 was strengthened with 5 strips of CFRP laminates with width of 45 mm in each direction that gives area of270 mm^2/m as shown in figure 6.

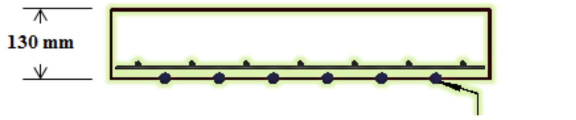


Fig. 6: NSM CFRP Laminates Strengthening

Table 1: Designation of Groups

Group	Samples	Type of strengthening	Nominal Area of Strengthening* (mm^2/m)	Description
G0	G0	Without strengthening	-----	Control specimen
GA	GA1	Strengthened by NRM ferrocement	90	One layer of wire mesh
	GA2		180	Two layers of wire mesh
	GA3		270	Three layers of wire mesh
GB	GB1	Strengthened by NSM ferrocement	90	One layer of wire mesh
	GB2		180	Two layers of wire mesh
	GB3		270	Three layers of wire mesh
GC	GC1	Strengthened by fabric wires	90	One layer of fabric wires with Ø4 mm @ 150 mm spacing
	GC2		180	One layer of fabric wires with Ø6 mm @ 150 mm spacing
	GC3		270	Two layers of fabric wires with (Ø4mm and Ø6 mm) @ 150 mm spacing
GD	GD1	Strengthened by CFRP bars	90	3 bars at each direction with Ø6mm
	GD2		180	5 bars at each direction with Ø6 mm
	GD3		270	7 bars at each direction with Ø6 mm
GE	GE1	Strengthened by CFRP laminates (1.2 mm thickness)	90	5 strips of carbon laminate with width of 15 mm
	GE2		180	5 strips of carbon laminate with width of 30 mm
	GE3		270	5 strips of carbon laminate with width of 45 mm

***From Eq.1**

Concrete mix

Many trial mixes were made to gain a suitable strength. The mix was designed to achieve cylinder strength of about 30 MPa at 28 days. The details of the mix which was used in this study are shown in Table 2. The mortar that used in groups GA, GB and GC was of cement-sand mix with proportions of 1:2.

Table 2 Normal concrete mix proportions

Cement (Kg/m^3)	Water (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	W/C
400	193	990	745	0.48

Test procedures

The mixing of concrete was done in an electric pan mixer with a capacity of 0.1 m^3. Three molds were made for casting the slabs which manufactured using side steel plates and plywood base. The three molds have the same dimensions 700x700x130 mm. The molds were well cleaned and their internal surfaces were lightly oiled to avoid the adhesion of hardened concrete to the internal surface of the molds. Before placing the concrete in the mold, steel reinforcement was placed in the bottom face of the slab's mold.

Table 3 Results for Compressive, Splitting, Flexural Strengths and Modulus of Elasticity

Samples	f'_c MPa-28 days	f_t MPa-28 days	f_r MPa-28 days	E_c GPa-*28 days*
G0	31	3	4.3	27.35
GA	30.03	2.83	3.96	26.5
GB	31.4	2.96	4.33	27.6
GC	31	3	4.3	27.3
GD	32.6	3.13	4.53	28.2
GE	31.3	2.8	4	26.8
Mortar for GA and GB	33.5	3.5	4.8	29.5
Mortar for GC	37	3.7	5	30.09

The aggregate and cement were first mixed dry for about 90 seconds, and then water was added and mixing continued for a further 90 seconds. The concrete was placed in the molds in layers. Then using an electrical concrete vibrator for one minute. After that, the top surface of the specimen was well finished using a steel trowel so that the upper surface of the steel block is kept level with the concrete surface. After 24 hours the molds were removed, and the slabs were put in a tank of water, and cured for 28 days. Nine standard cylinders of 150x 300 mm, three 150 mm cubes three prisms of 100x100x400 mm dimensions were cast. These specimens were used to determine the compressive strength of concrete, splitting tensile strength, flexural strength and the modulus of elasticity as shown in Table 3.

All concrete slab specimens were tested using a testing machine of 700 kN capacity. During the test, central deflection was recorded using a dial gauge with accuracy of 0.01 mm. The first crack was observed, and the crack patterns were marked. Steel plate of 200 x 200 x 25 mm was placed to represent patch load and to prevent local crushing of concrete.

Test response of individual groups of concrete slabs

The cracking loads (**P_{cr}**), crack widths(**W_{cr}**) at ultimate load, central deflections(**Δv**) at ultimate load, and ultimate load(**P_u**) are shown in Table 4 and plate 4. The control slab designed to fail in flexure. At low load levels, all the tested slabs behaved in an elastic manner where the cracks did not appear at any place and the central deflections are small and proportional to the applied load. Generally, at early stage all the slabs behaved in elastic range until first crack appeared. The first crack appeared at a load is higher than the load of the control slab.

Table 4 Experimental results of the tested slabs

Specimen	P_{cr} (kN)	W_{cr} (mm)	Δv (mm)	P_u (kN)	P_{cr}/P_u	P_{cr}/P_{cr}.Control	P_u/P_u.Control
G0	72.1	1.3	11.2	170	0.42	1	1
GA1	80.5	1	7.7	176	0.46	1.11	1.04
GA2	84	0.95	7.25	183	0.46	1.165	1.08
GA3	86	0.9	7	205	0.42	1.193	1.21
GB1	79.3	1	8.7	190	0.42	1.099	1.18
GB2	85	1	8.5	207.7	0.41	1.178	1.22
GB3	88.1	0.97	8.35	235	0.37	1.222	1.38
GC1	98.9	1.25	10.8	242.2	0.41	1.372	1.42
GC2	105	1.2	10	264	0.39	1.456	1.55
GC3	106	1.1	9	281.2	0.38	1.47	1.65
GD1	121.3	1	11	312	0.39	1.682	1.84
GD2	128.1	0.95	10	344.1	0.37	1.776	2.02
GD3	131.5	0.92	10	375.1	0.35	1.824	2.21
GE1	126.9	0.83	10.2	322	0.39	1.76	1.89
GE2	139.4	0.8	9.5	350.2	0.39	1.933	2.06
GE3	144.6	0.78	9.2	399.4	0.36	2.005	2.35

Plate 1: Slab specimens after failure

It is obvious from table 4 that all type of strengthening increase the ultimate load in compare with the control slab, also it can be seen that slab GE3 gave the highest ultimate load and the lowest crack width. The failure mode in the specimens that strengthened with ferrocement and BRC (GA1, GA2, GB1, GB2, GB3, GC1, GC2) was flexural failure while in the specimens that strengthened with CFRP rods and laminates was punching failure. Some specimens have a combined failure, which was flexural failure followed by punching failure as in (GA3, GC3). Slab GE1 failed in debonding manner. The results reflected the good ability of the CFRP in increasing the ultimate load capacity of the slabs as well as reducing the cracks width and the central deflection under the same load.

Load-deflection and crack width response

Deflection is considered important property of any structure. In this study, one dial gauge with accuracy (0.01mm) was used to determine the deflection. The dial gauge was attached to the center of slabs. At low load levels all the tested slabs behaved in an elastic manner where the cracks did not appear at any place and the central deflections are small and proportional to the applied load. The first crack appeared around the sides of the plate on the tension face of the slab and other cracks form at the central region of the slab. By increasing the load, these cracks widened and increased in number and spread to the support of the slab through a diagonal direction. Also new cracks appeared starting from the supports. Eventually the cracks are many and one or more of these cracks might penetrate into the compression zone at the loading positions.

Figure 7 shows the load-deflection relationship of the slabs tested. Clearly shows that the using of the five strengthening techniques reduces the deflection of the structure. It can be noticed that all specimens have undergone three stages of behavior during the entire load process.

In the first stage the linear behavior of the load deflection response is considered. This stage covers the region up to the first crack load, below this limit the material behave elastically and the cracks originating in the tensile regions of the specimens cross section are still stable. After this, the cracks propagate and their width increases with increasing load. Both the reinforcement for all groups and mortar for group GA, GB and GC in compression zone are still elastic.

In the second stage a nonlinear behavior of the load deflection response is noticed. This stage covers the region beyond the proportional limit. A gradual yielding of steel reinforcement occurs, because several layers of mesh are placed at different depths of section, many carbon rods are also placed near surface and several slices of carbon laminate were applied, these layers of strengthening were yield at different loading levels. At this stage, the increase in the load carrying capacity beyond the proportional limit is due to the increase in the tensile stresses accompanied with a continuous shift in the position of the neutral axis towards the compression zone.

Finally, as the applied load reaches near its ultimate value, the rate of increase in deflection is substantially exceeding the rate of increase in the value of applied load. The crack width versus applied load responses of the slab specimens are shown in Figure 8.

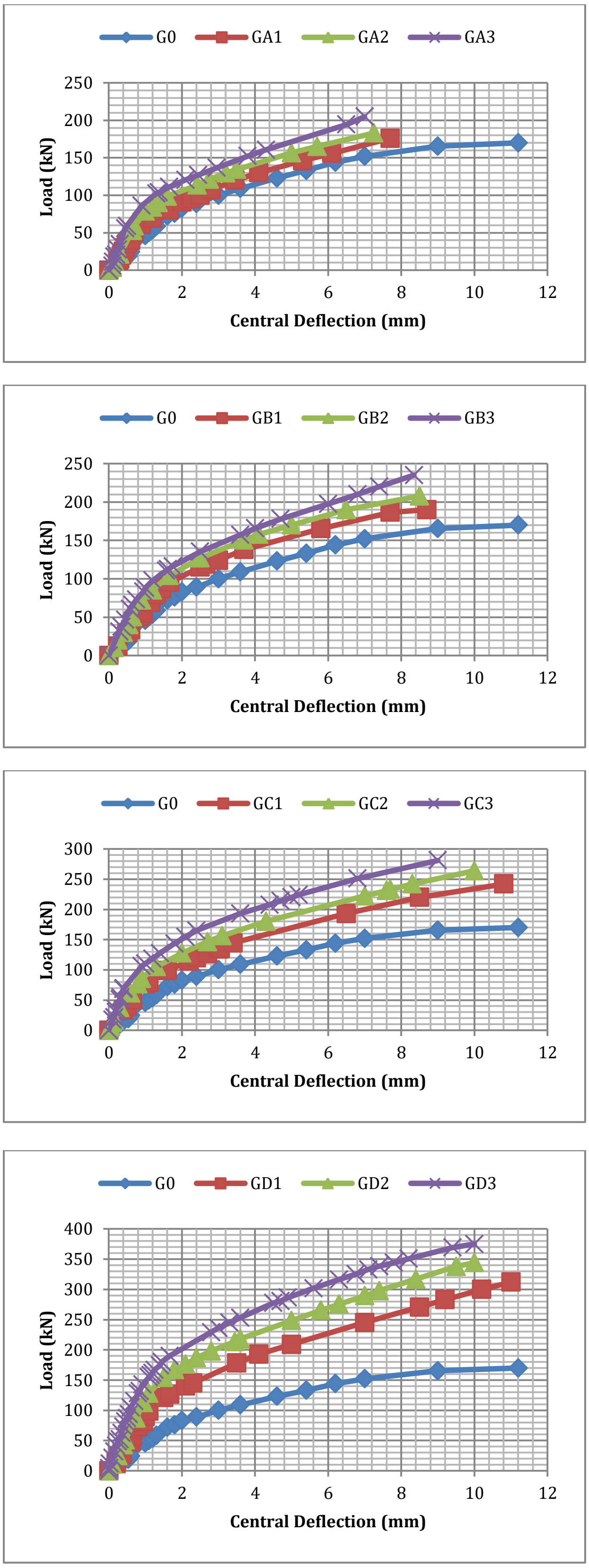


Fig. 7: Load – Deflection curves for GA, GB, GC and GD

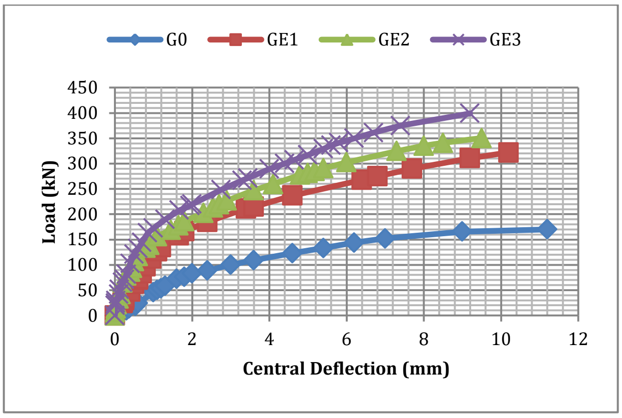


Fig. 7: (continued) Load – Deflection curve for GE

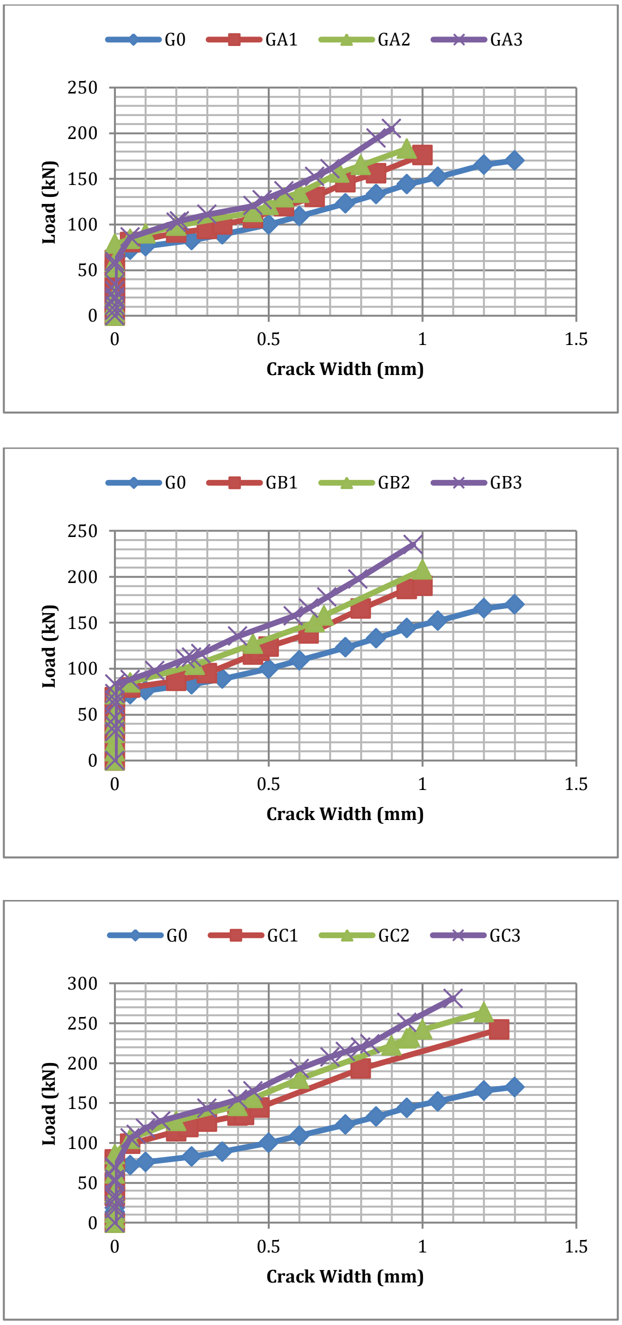


Fig. 8: Load – crack width curves for GA, GB and GC

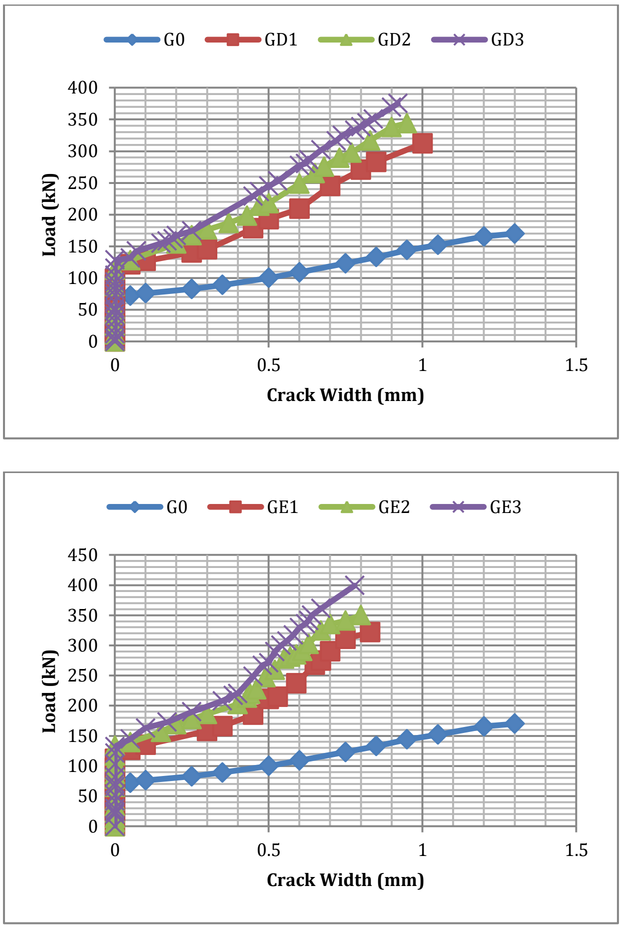


Fig. 8: (continued) Load – crack width curves for GD and GE

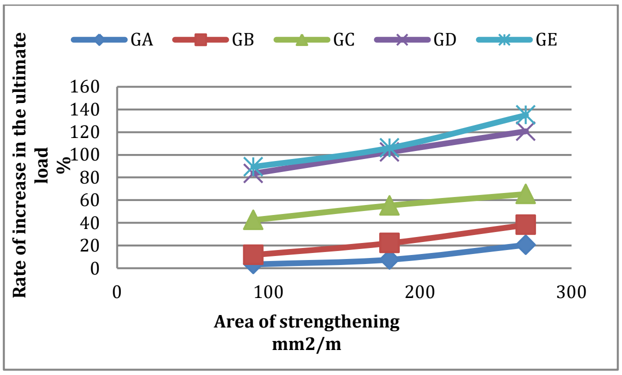
Comparison between different strengthening techniques

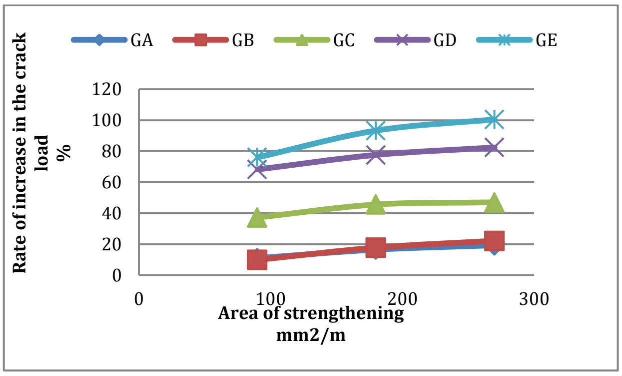
In all techniques used in this study, different ratios of strengthening were used. Strengthening ratio was increased by increasing areas of total reinforcement (wire mesh) in ferrocement to be 90, 180 and 270 mm^2 /m. It was tried to keep area of fabric wires and CFRP laminates and bars constant. For each strenghtening ratio (area) of each strengthening technique a comparison was made. The area ratio of the strengthening materials made a big change in the behavior, ultimate load, deflection as well as the crack width of the specimens.

Table 5 and Figure 9 show clearly the effect of different types of strengthening on the ultimate load, crack load and the decrease in the crack width for all specimens. It was seen that strengthening ratios within each strengthening technique had a clear effect on the behavior of the strengthened slabs. It was seen that the increasing in the ratio of strengthening led to an increase in the ultimate strength and the first crack load, also decrease the crack width in all types of strengthening with compare to the control slab.

Table 5 Rate of Increasing in Ultimate Load, Crack Load and Decreasing in Crack width with respect To the Control Slab

Area of strengthening mm²/m	Samples	Rate of increase in the ultimate load %	Rate of increase in the crack load %	Rate of decrease in the crack width %
----	G0	----	----	----
90	GA1	3.5	11	23
	GB1	11.8	9.9	23
	GC1	42.5	37.2	7
	GD1	83.5	68.2	23
	GE1	89.4	76	36
180	GA2	7 .6	16.5	27
	GB2	22.2	17.8	25
	GC2	55.3	45.6	12
	GD2	102.4	77.6	27
	GE2	106	93.3	39
270	GA3	20.6	19.3	31
	GB3	38.2	22.2	25.4
	GC3	65.4	47	15.4
	GD3	120.7	82.4	29.2
	GE3	134.9	100.5	40





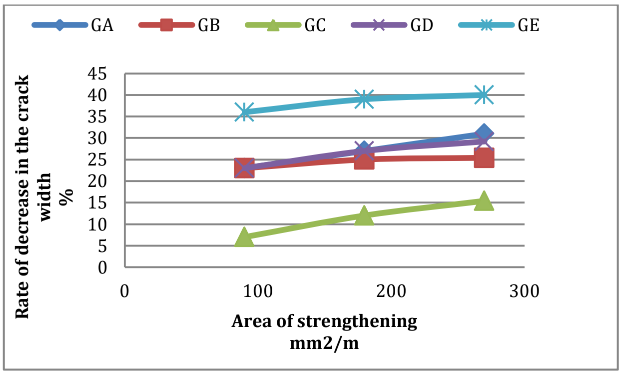


Fig. 9: Rate of Increasing in Ultimate Load, Crack Load and Decreasing in Crack width with respect to the Control Slab

Conclusions

From experimental program carried out in this study, the following conclusions can be drawn:

1. The behavior of all specimens were linear up to first cracking load. The load-deflection curve may be idealized by a bilinear or trilinear curve.
2. Strengthening by CFRP laminate shows higher ultimate strength and the cracking load between all types of strengthening techniques in comparison with the control specimen.
3. Strengthening in near reinforcement mounted (NRM) ferrocement shows the lower ultimate strength and the cracking load between all types of strengthening techniques in comparison with the control specimen.
4. The strengthening with CFRP laminate gave the minimum crack width.
5. Steel Welded Wire Fabric Strengthening gave the higher crack width.
6. CFRP laminates and rods provided higher flexural strength which led to punching shear failure mode.
7. The results reflected the good ability of the CFRP in increasing the ultimate load capacity of the slabs as well as reducing the cracks width and the central deflection under the same load.

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