ERJ
Engineering Research Journal
Faculty of Engineering
MenoufiaUniversity

REPAIR AND STRENGTHENING OF RC SLABS USING FERROCEMENT LAYERS REINFORCED WITH DIFFERENT FRP MESHES

Ahmed M. Ramadan
Lecturer, Civil Engineering Department, Tanta Higher Institute of Engineering and Technology
E-Mail: ahmedramadan1957@gmail.com

ABSTRACT

Ferrocement is one of the recent methods for repair and strengthening of reinforced concrete members. It can be described as a type of thin composite material made of cement mortar reinforced with wire meshes. The wire meshes are uniformly distributed in continuous layers with relatively small diameters.

In this research, an experimental test program consists of eleven RC slab specimens repaired and strengthened by ferrocement layers reinforced by traditional steel reinforcement and steel wire meshes as well as manufactured glass and carbon fiber reinforced polymer meshes. The tested slabs classified in three groups. The first group consists of three specimens as reference slabs. The second group for repaired slabs consists of four specimens. They were loaded first by 80% of the ultimate loads and then cracks were repaired and then additional ferrocement layers with different wire meshes were added. The third group for strengthened slabs consists of four specimens. They were strengthened with additional ferrocement layers with different wire meshes without preloading.

Slab specimens were tested under two-point loading and subjected to incremental loads till failure. Performance of the tested slabs such as deflections, cracking and ultimate loads as well as crack patterns were investigated, analyzed and discussed in this research. The test results confirm that repair and strengthening technique using ferrocement layers gives good results. Intertwined manufactured carbon fiber wire mesh gave best results for increasing the flexural capacity of RC slabs.

ملخص البحث:

من الطرق الحديثة في أعمال الترميم والإصلاح طريقة التدعيم باستخدام طبقات فيروسيمنتيه من مونة اسمنتية مسلحة بشبك من الصلب أو المواد الأخرى وفي هذا البحث تم دراسة ومقارنة طرق الإصلاح والتدعيم للبلاطات الخرسانية المسلحة بعمل طبقات فيروسيمنتية مسلحة بحديد التسليح التقليدي وكذلك بشبك من الصلب وشبك من الألياف البوليمرية الزجاجية والكربونية المصنعة معملياً.

وقد تمت الدراسة بعمل برنامج عملي يشمل اختبار أحد عشر بلاطة خرسانية مسلحة تم تقسيمها إلى ثلاث مجموعات. المجموعة الأولي تحتوي ثلاث بلاطات مرجعية مختلفة تم تحميلها حتى الانهيار والمجموعة الثانية تحتوي أربع عينات تم تحميلها بحمل مسبق قدره 80% من حمل الانهيار ثم تم علاج الشروخ بها وإضافة طبقة إضافية من الفيروسيمنت المسلحة بطرق مختلفة. والمجموعة الرابعة تحتوي أربعة عينات تم تدعيمها بدون حمل مسبق بإضافة طبقة من الفيروسيمنت المسلحة بطرق مختلفة. وقد تم تحميل نماذج البلاطات بأحمال متزايدة وتسجيل قيم حمل التشرخ وحمل الانهيار والترخيم وشكل الشروخ للنماذج المختلفة أثناء التحميل ومقارنتها قبل وبعد التدعيم باستخدام الرسومات البيانية التوضيحية. وأخيراً تم عرض النتائج والتوصيات وقد اتضح من البحث مدى كفاءة الإصلاح والتدعيم بإضافة طبقة من الفيروسيمنت المسلحة بطرق مختلفة وأعطى التسليح بشبكة من الألياف الكربونية أفضل النتائج.

***Keywords*:** RC slab, Strengthening, Ferrocement, Steel reinforcement, Carbon fibers, Glass fibers.

1. INTRODUCTION

Structural members are usually designed to sustain required loading, however they may require upgrading or strengthening due to a variety of reasons including, human error, structural design and/or construction, amendments in practicing design standards/codes, structural deterioration due to ageing and environmental exposure, abusive use of buildings in the form of change in the utility of the structure resulting in an increase in the live load and stress concentration in structural members. The term "Strengthening" is, therefore, not only associated with existing structures but also newly built structures. Hence strengthening of structures is an essential domain for the researchers.

Nowadays, a large number of flat slabs may be considered structurally deficient by today's standards [1] as a result of introducing new methods and factors in the design procedure or need of structural upgrading to meet new seismic design requirements [2-5]. The rehabilitation and strengthening of structural members with composite materials, such as carbon, glass, kevlar, and aramid fiber-reinforced polymers (FRP), have recently received great attention [6]. Labor savings inherent with its lightweight and comparatively simple installation, its high tensile strength, and immunity to corrosion have made FRP an attractive alternative to traditional retrofitting techniques. Field applications over the last years have shown excellent performance of FRP retrofitted structures. Nowadays, carbon and glass fiber strips, rods and wraps woven in one or multi-directions are widely used as strengthening materials.

Many researchers have used FRP for strengthening the flexure strength of slabs [7-10]. Several studies have investigated the use of externally bonded FRP composites or near surface mounted (NSM) reinforcement to improve the strength and stiffness of RC slabs, but most have addressed flexural strength, not punching shear.

This paper reports on a series of tests conducted to assess and compare the ability and efficiency of traditional materials represented by steel bars as well as advanced composite materials (ACM) represented by glass and carbon reinforced polymers (GFRP and CFRP) woven wraps for repair and strengthening slabs.

After its first use by Joseph Louis Lambot in 1948, ferrocement was utilised in a number of practical applications such as repair of shear damaged reinforced concrete beams, beams and slab with excessive deflection, joints, repair/strengthening of brick masonry columns [11] as well as plain concrete column [12,13]; it has been found that use of ferrocement is advantageous in terms of enhancement of load carrying capacity [14-17], better cracking behavior, ductility, energy absorption properties [15,17], stiffness [18,19] and flexural capacity [18]. It may even lead to failure of RC section in a ductile manner, if a beam is designed for steel above the balanced reinforcement percentage [19].

Although the strengthening of RC slabs and beams in flexure has been successfully practiced using tensile overlay [20], steel plate [21,22], external post tensioned prestressing [23,24], fiber composites [25], external unbonded reinforcement [26], carbon fiber reinforced polymer (CFRP) [27] and other newer techniques, strengthening with ferrocement is gaining respect as well. The versatility of ferrocement technique is its low cost, readily available materials, simplicity in const-ruction, reasonable quality control along with good strength and cracking resistance, which makes ferrocement especially suitable for rural areas of the developing world. Concrete is used frequently in rural areas nowadays and the cement and sand is easily accessible. Even the wire-meshes are also readily available due to its use in many other household works. Ferrocement is also known to be a forgiving material and can, therefore, sustain varying atmospheric conditions satisfactorily [28]. Ferrocement can also sustain abuses due to lesser skill of rural workers in comparison to other construction techniques.

The present investigation focuses mainly on flexural strengthening of RC slab by varying the reinforcement of Ferro-mesh layers.

2. RESEARCH OBJECTIVES

The main objectives of the research are to determine and compare the improvement of the flexural strength of RC slabs using innovative methods. This research investigates advanced techniques for repair and strengthening RC slabs. The first method is executed by applying an additional ferrocement layer reinforced with glass fiber reinforced polymer GFRP mesh manufactured from intertwined GFRP roving wraps and epoxy resin. The second method of strengthening was done by adding an additional bonded layer of ferrocement reinforced by carbon fiber reinforced polymer CFRP mesh manufactured from intertwined GFRP roving wraps and epoxy resin. The third method of strengthening was done by adding additional bonded ferrocement layer reinforced by welded steel mesh. The results of the previous methods were compared with the traditional method of strengthening by applying an additional layer of concrete reinforced with steel bars. The comparative study was done to identify and compare the effectiveness of each method of strengthening.

3. EXPERIMENTAL TEST PROGRAM

An experimental test program was carried out to study the potentiality of using different methods and materials in the repair and strengthening of RC slabs failed by flexural stresses. The test specimens were designed to be simply supported along two edges and were tested under two concentrated loads up to failure. This test arrangement is convenient to simulate the actual boundary conditions in the prototype. The slabs were designed according to the ECP-203 [2] to fail in flexure, so that the strengthening laminates could be measured.

The experimental program consists of eleven specimens of simply supported slabs that have constant cross section with dimensions of 400 ×1100 mm, and effective span 1000 mm. Nine slabs of thickness 7 cm and has a lower longitudinal reinforcement 4ϕ6 mm of mild steel as a main flexural reinforcement in the long direction and 4ϕ6 mm of mild steel as a secondary reinforcement in the short direction as shown in Fig. 1. Additional two RC slabs as control slabs of thickness 9 cm and reinforced by reinforcement 4ϕ6 mm of mild steel in both directions with effective depth 6 cm and additional reinforcement of mesh 4×4 cm made from manufactured intertwined glass or carbon rods of diameter 2 mm with effective depth 8 cm.

The dimensions of repair and strengthening layers were 400×1100×20 mm. Four types of reinforcement were used for the additional ferrocement layers;

(a) longitudinal reinforcement 4ϕ4 mm of mild steel as a main flexural reinforcement in the long direction and 6ϕ4 mm of mild steel as a secondary reinforcement in the short direction,

(b) welded steel mesh with opening dimension 40×40 mm and diameter of the mesh bars 2 mm as shown in Fig. 2,

(c) mesh 40×40 mm made from manufactured intertwined glass fiber GFRP rods of diameter 2 mm as shown in Fig. 2,

(d) mesh 40×40 mm made from manufactured intertwined carbon fiber CFRP rods of diameter 2 mm as shown in Fig. 2.

Specimens were and classified in three groups as shown in Table 1.

Table 1: Experimental test program

Group No.	Slab Code	Pre-Loading (% of P_u)	Conditions	Description of ferrocement layer
Group 1	S0	-	Control	Solid slab 7 cm thickness reinforced by 4ϕ6 in each direction with effective depth 6 cm. Loaded up to failure without strengthening (Fig. 1).
	G0	-	Control	Solid slab 9 cm thickness, reinforced by 4ϕ6 in each direction and lower mesh 40×40 mm made from manufactured intertwined glass fiber rods of diameter 2mm loaded up to failure.
	C0	-	Control	Solid slab 9 cm thickness, reinforced by 4ϕ6 in each direction and lower mesh 40×40 mm made from manufactured intertwined carbon fiber rods of diameter 2mm loaded up to failure.
Group 2	RS	80%	Repair	Solid slab S0 loaded first till cracking stage and then repaired by cracking injection and additional layer reinforced by steel bars 4ϕ4 in longitudinal direction and 6ϕ4 in the short direction.
	RSM	80%	Repair	Solid slab S0 loaded first till cracking stage and then repaired by cracking injection and strengthened by additional ferrocement layer reinforced by steel welded mesh 40×40 mm of diameter 2mm.
	RG	80%	Repair	Solid slab S0 loaded first till cracking stage and then repaired by cracking injection and strengthened by additional mesh 40×40 mm made from manufactured intertwined glass fiber rods of diameter 2 mm.
	RC|	80%	Repair	Solid slab S0 loaded first till cracking stage and then repaired by cracking injection and strengthened by additional mesh 40×40 mm made from manufactured intertwined carbon fiber rods of diameter 2 mm.
Group 3	SS	-	Strengthening	Solid slab S0 strengthened by additional layer reinforced by steel bars 4ϕ4 in longitudinal direction and 6ϕ4 in the short direction (Fig. 2).
	SSM	-	Strengthening	Solid slab S0 strengthened by additional ferrocement layer reinforced by steel welded mesh 40×40 mm of diameter 2 mm.
	SG	-	Strengthening	Solid slab S0 strengthened by additional mesh 40×40 mm made from manufactured intertwined glass fiber rods of diameter 2 mm (Fig. 2).
	SC	-	Strengthening	Solid slab S0 strengthened by additional mesh 40×40 mm made from manufactured intertwined carbon fiber rods of diameter 2 mm (Fig. 2).

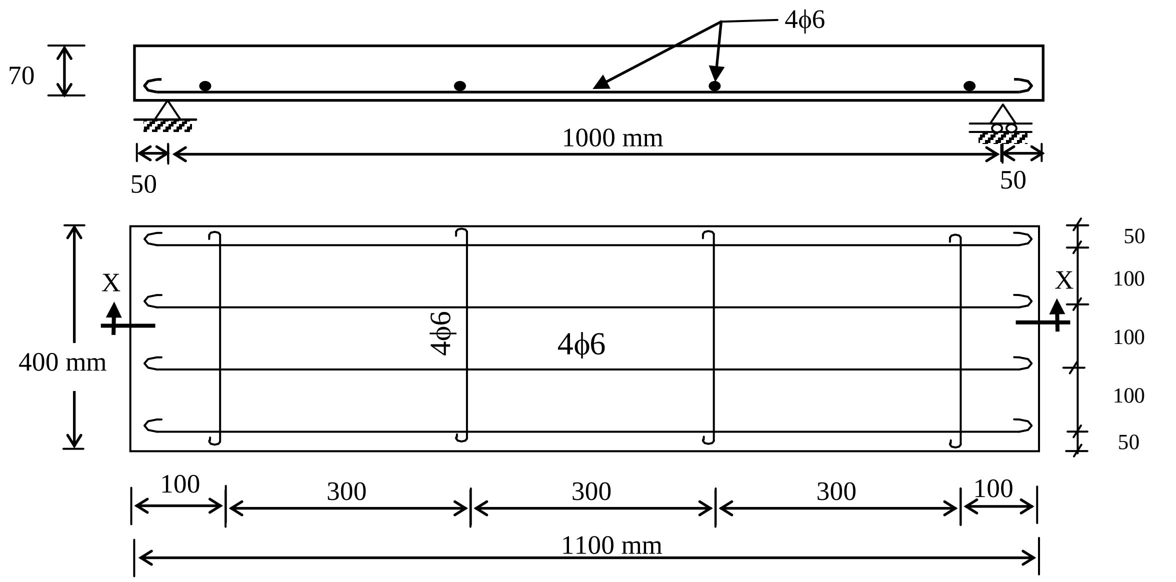

Fig. 1: Details of Specimen S0

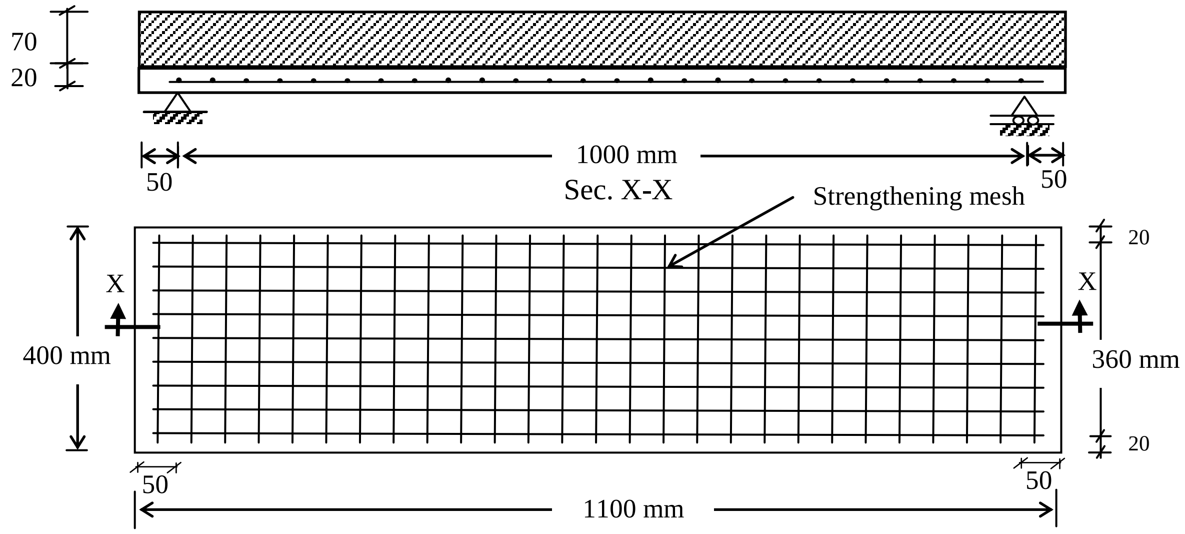

Fig. 2: Details of strengthening for specimens SSM, SG and SC

Test Set-up and Instrumentation

Slabs were tested under two concentrated loads up to failure. A steel frame of 40-ton capacity was used for testing slabs in Banha lab. Loads were applied in increments using a hydraulic jack of 20-ton maximum capacity as shown in Fig. 3. four dial gauges of 0.01 mm accuracy and a total capacity of 25 mm were installed to measure the deflection at mid-span, and under distances of 100 mm from the two supports as shown. Demec points were arranged and fixed on the painted side of each tested slab near top and bottom surfaces in two rows at the center of span. Concrete strains were measured by mechanical strain gauges of 300 mm gauge length and 0.001 mm accuracy. A magnifying lens was used to observe the crack propagation clearly. Cracks were traced and marked at each load increment. Figure 3 shows the arrangement of dial gauges and demec points and Fig. 4 shows tests specimen S0 during test.

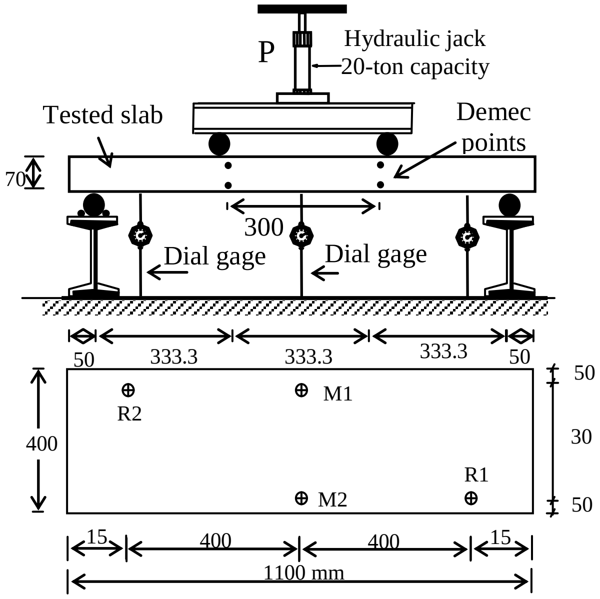

Fig. 3: Test setup and instrumentation

Fig. 4: Control slab S0 during test

Materials Properties and Design Mix

The specimens were cast using a normal density concrete. The concrete was produced in the Banha laboratory using Ordinary Portland cement complied with E.S.S.373/91 requirements, clean sand, crushed dolomite of maximum nominal size 14 mm as coarse aggregate and potable water.

Silica fume: product resulting from the industry of ferrosilicon alloys, the product is a rich silicon dioxide powder where the average size is a round 0.1 micrometers. It is used for ferrocement mortar.

Addicrete (BVF): The super-plasticizer used in this experimental to reduce the water content and increase the workability and strength. This product is from Chemicals for Modern Building [29].

Steel reinforcement: mild steel.

Steel mesh: welded steel mesh is used with property given in Table 3.

Testes were carried out according to ECP-203-12 [2] to define the properties for both concrete and steel. Table 2 summarizes the concrete mix properties used for casting the models while the properties of the used steel are given in Table 3. Table 4 gives the mechanical properties of the GFRP WR and CFRP wraps used in this work.

Table 2: Mix proportions for one cubic meter of concrete

Mix Proportions, N / m^3				Unit weight, kN/m^3	W/C	Compressive Strength, MPa	
Cement	Water	F.A.	C.A.			7 days	28 days
3500	1750	6020	12040	23	0.5	19.5	25.0

Where F.A.: sand as fine aggregate, and C.A.: gravel as coarse aggregate.

Table 3: Properties of steel

Steel Type	Yield Strength, MPa	Tensile Strength, MPa	Elongation, %	Young's Modulus, MPa
Mild steel	260	387	23.21	2.1x10^5
High tensile Welded Steel mesh	737	834	16	2.0 x10^5

Table 4: Physical and mechanical properties of used glass and carbon fiber

Property	Glass Fiber Woven Roving Wraps (WR)	CFRP (SikaWrap Hex-230C)
Fabric thickness, cm	0.17	0.12
Tensile strength, MPa	284	4020
Modulus of elasticity, MPa	13000	225000
Elongation %	2.0	1.7

Mix Proportions for Ferrocement Mortar

The ferrocement mortar consisted of sand, ordinary Portland cement, and silica fume. 15 % of the cement by weight was replaced with silica fume. Sand to cement/silica fume ratio of 2 was used in the present research. Water to cement/silica fume ratio of 0.40 was used. Super plasticizer with ratio of 1.5 % by weight of cement/silica fume was used to improve workability of the mixtures.

Repair and Strengthening Schemes

Control specimens in Group 1; SO, SG and SC were loaded by incremental loads of 200 kg until failure.

Repaired specimens

Specimen in Group 2; RS, RSM, RG and RC were loaded first by 80% of the ultimate load of control specimen. Cracks were then repaired and strengthened by adding additional layer of ferrocement reinforced by different methods. Table 1 summarizes and describes the method of repair.

Strengthened specimens

Specimens in Group 3; SS, SSM, SG and SC were strengthened before loading by additional ferrocement layers to enhance the strength of slabs. Table 1 summarizes and describes the method of strengthening.

After repair and strengthening, specimens were loaded under two concentrated loads till failure.

Figure 5 shows the different FRP used for repair and strengthening slabs and Figs. 6 and 7 shows the manufacture GFRP intertwined roving in nails on loom. Figure 8 shows the specimen SG strengthened by an additional ferrocement layer reinforced by GFRP mesh. Casting concrete for strengthening layer is shown in Fig.9.

Figure 10 shows the test machine for determining the tensile strength for the manufactured intertwined GFRP rod.

(a) GFRP woven roving wraps (b) E-Glass-roving (c) Sika Wrap Hex -230C

Fig. 5: Different FRP used for strengthening slabs

Fig.6: Fixing GFRP roving in nails on loom

Fig.7: Intertwined GFRP roving submerged in epoxy

Fig.8: Strengthening slab by an additional ferrocement layer reinforced by GFRP mesh, SG

Fig.9: Casting concrete for strengthening layer

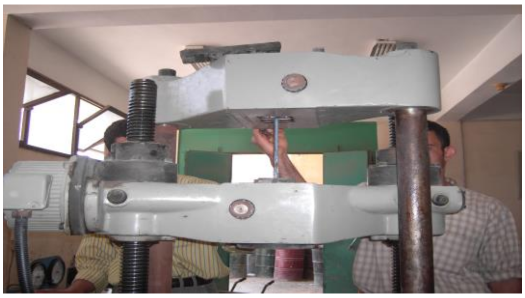

Fig. 10: Testing intertwined GFRP rods

4. ANALYSIS OF THE TEST RESULTS

slabs in different groups were tested under incremental load up to failure. The results were analyzed and compared in different stages of loadings. The load-deflection curves were plotted, the first cracking and failure loads were recorded and compared. Finally, the crack propagations were marked after each load increment and photographed at failure.

Deflection

Figure 11 compares the load deflection curves at mid-span for the control slabs S0, G0 and C0 in Group 1. At the ultimate failure load of the control slab S0, deflections of control slabs G0 and C0 were about 23% and 13% of the maximum deflection of S0 respectively. This may be attributed to increasing the thickness by 2 cm as well as using additional mesh reinforcement of intertwined rods of GFRP and CFRP. Figure 12 shows the load deflection curves for control slabs G0, S0 and strengthened slab SG, SC. It is shown that the results of each strengthened slabs match the results of the corresponding control slabs except before failure. This may be due to de-bonding of the strengthening layer before failure.

Figure 13 compares the load deflection curves at mid-span for the repaired slabs RS, RSM, RG and RC in Group 2. It is shown from the figure that slab repaired using ferrocement layer reinforced by carbon fiber mesh, RC gave the least deflection at the same loading as well as gave the maximum capacity with respect to the other specimens. It is noticed also that using steel wire mesh as reinforcement for repairing ferrocement layer gave better results than using traditional steel reinforcement.

Figure 14 compares the load deflection curves at mid-span for the repaired slabs SS, SSM, SG and SC in Group 3. It is shown from the figure that slab strengthened using ferrocement layer reinforced by carbon fiber mesh, RC gave the least deflection at the same loading as well as gave the max. capacity with respect to the other specimens. It is noticed also that using steel wire mesh as reinforcement for strengthening ferrocement layer gave better results than using traditional steel reinforcement.

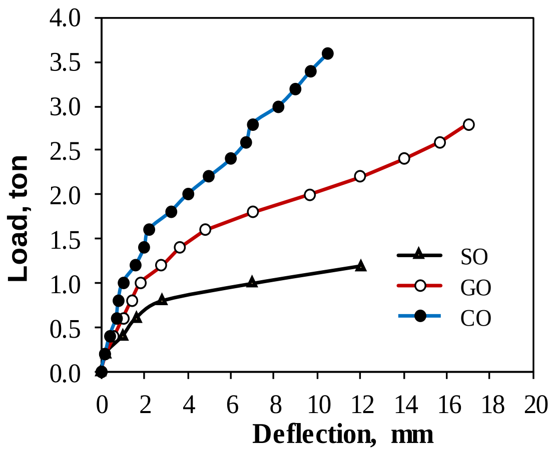

Fig.11: Load-deflection curves at mid-span for control slabs

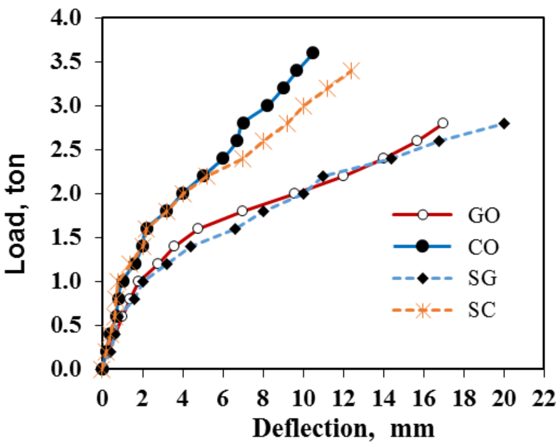

Fig.12: Load-deflection curves at mid-span for control slabs GO, SO and strengthened slabs SG and SC

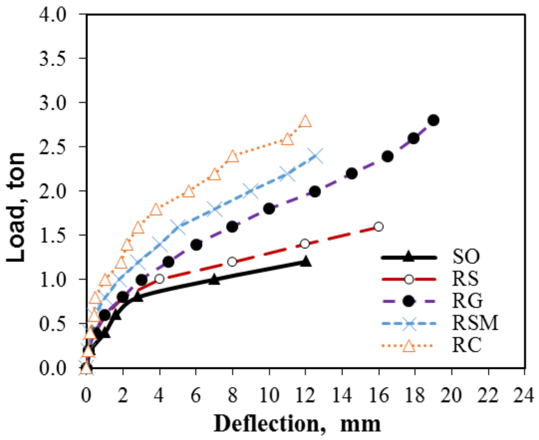

Fig.13: Load-deflection curves at mid-span for repaired slabs (Group 2)

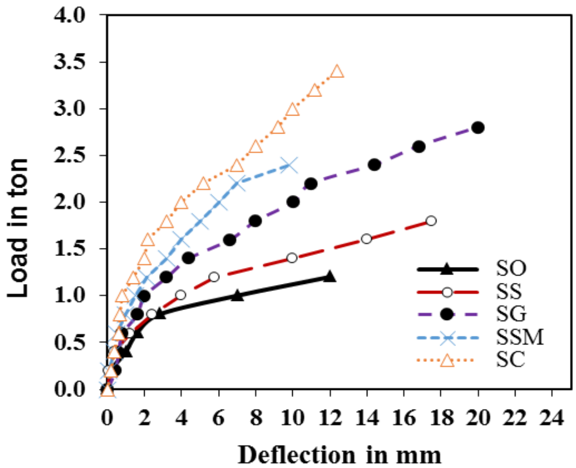

Fig.14: Load-deflection curves at mid-span for strengthened slabs (Group 3)

Cracking and Ultimate Loads

First cracking and ultimate failure loads were recorded for all tested slabs. Figure 15 compares both cracking and failure loads for all tested specimen in the different groups. It is noted that the slabs strengthened by carbon fiber mesh showed the highest cracking and ultimate failure loads. The failure loads of slabs repaired by ferrocement layers RS, RSM, RG and RC increased by about 46%, 67%, 88% and 129%, with respect to slab S0, while for strengthened slabs SS, SSM, SG and SC the failure loads increased by about 67%, 108%, 129% and 170%, respectively.

It is observed that repaired or strengthened slabs with carbon fiber mesh, showed a distinct gain in the load carrying capacity compared to the corresponding reference slabs. The increase in the capacity was about 30% with respect to the slab strengthened by ferrocement layer reinforced with welded steel wire mesh. This confirms the efficiency of utilizing the carbon fiber mesh as reinforcement for ferrocement layers.

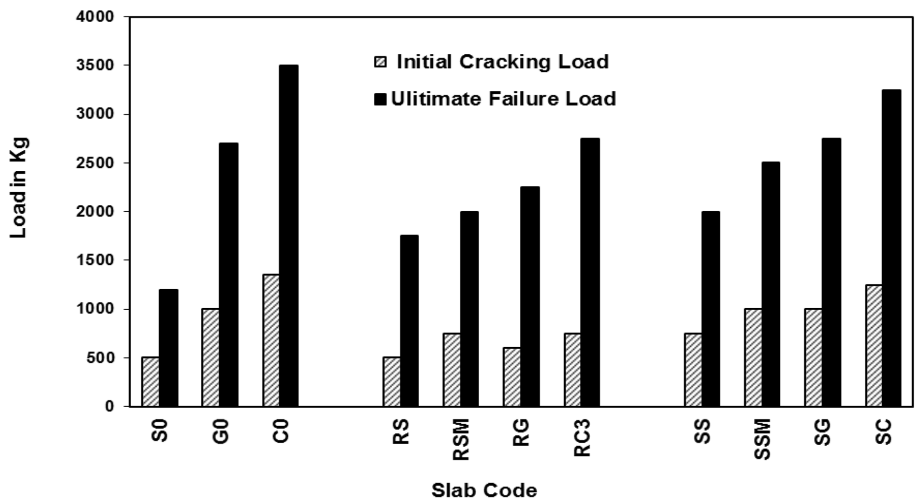

Fig.15: Comparison between cracking and ultimate loads

Cracking Patterns

Figures 16 show the crack patterns at failure for control specimens CO and GO while Fig. 17 shows the crack patterns for repaired slabs in Group 2. Figure 18 shows the crack patterns for strengthened slabs in Group 3. Cracks starts at the middle of the slabs normal to the long direction. When load increases cracks propagate adjacent to the middle of the slab in both directions. It is noticed that repair and strengthening with ferrocement layers reinforced by manufactured carbon fibers showed the maximum cracking loads and minimum cracking width with respect to the other repaired and strengthened slabs.

Fig.16: Crack patterns for control slabs (Group 1)

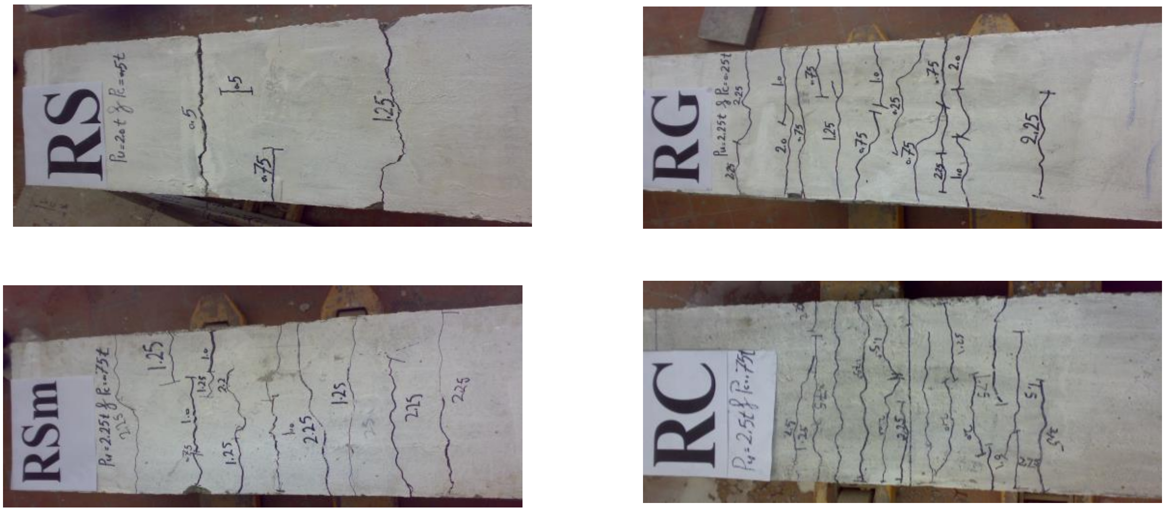

Fig.17: Crack patterns for repaired slabs (Group 2)

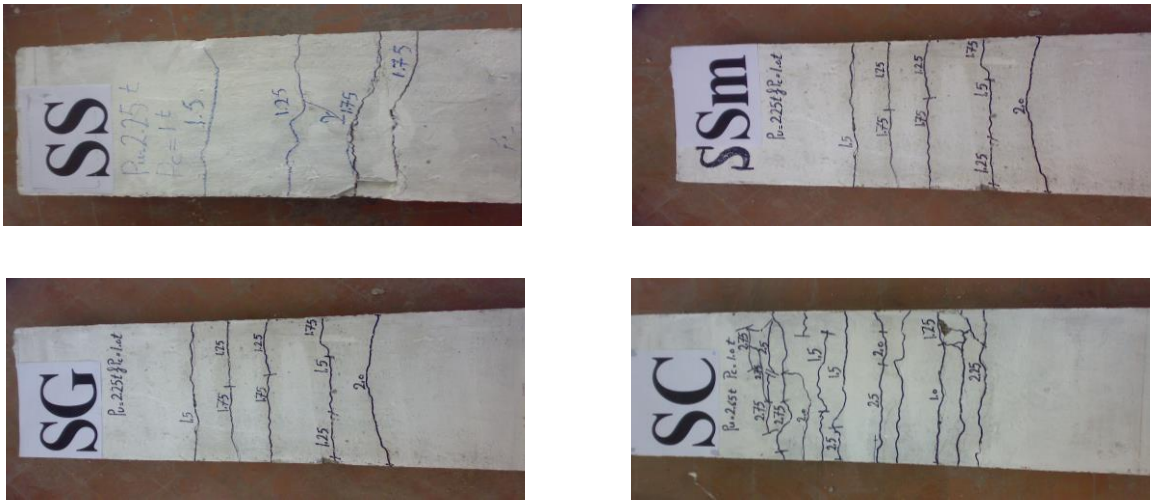

Fig.18: Crack patterns for strengthened slabs (Group 3)

Ductility

Ductility of slab is defined as the ratio between the maximum deflection at the ultimate load and the maximum deflection at the first cracking load. The Ductility of slabs RS, RSM, RG and RC increased by about 105%, 44%, 107% and 63% in comparison to slab S0, while slabs SS, SSM, SG and SC decreased by about 15%, 29%, 8% and 3%, respectively. It is noticed that slab repaired by adding ferrocement layer reinforced by mesh of manufactured glass fibers improves the ductility more than other reinforcement.

5. CONCLUSIONS

From the experimental investigation reported in this research, the following conclusions could be drawn.

1- Repaired or strengthening slabs with ferrocement layers showed distinct gains in loads carrying capacity compared to the corresponding reference slabs as well as reasonable reduction in deflections.

2- The failure loads of slabs repaired by ferrocement layers RS, RSM, RG and RC were increased by about 46%, 67%, 88% and 129%, respectively in comparison to slab SO. The increase in the capacity for slab repaired by ferrocement layer reinforced by manufactured carbon fiber mesh was about 38% with respect to the slab strengthened by same ferrocement layer but reinforced with welded steel wire mesh.

3- The failure loads of slabs strengthened by ferrocement layers SS, SSM, SG and SC the failure loads were increased by about 67%, 108%, 129% and 170%, respectively in comparison to slab SO. The increase in the capacity was about 30% with respect to the slab strengthened by same ferrocement layer but reinforced with welded steel wire mesh.

4- Using ferrocement layers reinforced by manufactured intertwined carbon fiber mesh for repair and strengthening improved the cracking behavior by increasing the cracking loads and decreasing the crack widths.

5- Ductility was increased for repaired slabs. Using manufactured glass fiber mesh as reinforcement for wire mesh increase the ductility by about 107%.

6. REFERENCES

[1] Jones, A. E. K. and Morrison, J., "Flat slab design: past, present and future", Proceedings of ICE, Structures and Buildings, Vol. 158, Issue 2, April 2005, pp.133-140.

[2] Egyptian Code of Practice: ECP 203-2012, "Design and Construction for Reinforced Concrete Structures", Ministry of Building Construction, Research Center for Housing, Building and Physical Planning, Cairo, Egypt, 2007.

[3] ACI Committee 318-08, "Building Code Requirements for Reinforced Concrete ACI 318-08 and Commentary", American Concrete Institute, Detroit, 2008.

[4] British Standard BS 8110-1-2002, "Structural Use of Concrete - Part 1: Code of Practice for Design and Construction", British Standard, BSI, 2002.

[5] Eurocode 2: DD ENV 1992-1-2-2004, "Design of Concrete Structures - Part 1: General Rules and Rules for Buildings", British Standard, BSI, 2004.

[6] Chen, Z. F. and Wan, L. L., "Evaluation of CFRP, GFRP and BFRP Material Systems for the Strengthening of RC Slabs", Journal of Reinforced Plastics and Composites, January, 2008.

[7] Balendran, R.V., Rana, T.M., and Nadeem, A., "Strengthening of Concrete Structures with FRP Sheets and Plates", Journal of Structural Survey, Vol. 19, No. 4, 2001, pp. 185-199.

[8] Teng, J.G., Cao, S.Y., Lam, L., "Behavior of GFRP-Strengthened RC Cantilever Slabs", Journal of Construction Building Material, Vol. 15, No. 7, 2001, pp.339–349.

[9] Ebead, U., Marzouk, H., and Lye, L.M., "Strengthening of Two-Way Slabs Using FRP Materials: A Simplified Analysis Based on Response Surface Methodology", 2nd World Engineering Congress, Sarawak, Malaysia, 22-25 July 2002.

[10] Mosallam, S.A. and Mosalam, K.M., "Strengthening of Two-Way Concrete Slabs with FRP Composite Laminates", Journal of Construction Building Material, Vol. 17, No.1, 2003, pp. 43–54.

[11] Information on http://bhedasgaonkar.com/tech_papers.asp, Access date: October (2010).

[12] Waliuddin, A. and Rafeeqi, S. F. A., "Study of the Behavior of Plain Concrete Confined with Ferrocement", Journal of Ferrocement, Vol. 24, 1994, pp. 139-151.

[13] Rafeeqi, S. F. A. and Ayub, T., "Investigation of Versatility of Theoretical Prediction model for Plain Concrete Confined with Ferrocement", Asian Journal of Civil Engineering (Building and Housing), Vol. 12, No. 3, pp. 337-352, 2010.

[14] Bansal, P. P., Kumar, M. and Kaushik, S., "Effect of Wire Mesh Orientation on Strength of Beams Retrofitted using Ferrocement Jackets. International Journal of Engineering (IJE), Vol. 2, 2008, p. 8.

[15] Fahmy, E. H., Shaheen, Y. B. I. and Korany, Y. S., "Repairing Reinforced Concrete Beams by Ferrocement. Journal of Ferrocement, Vol. 27, 1997, pp.19-32.

[16] Shaheen, Y. B. I., Soliman N. M. and Kandil, D.E., "Influence of Reinforced Ferrocement Concrete Plates under Impact Load", International Journal of Current Engineering and Technology, Vol.3, No.4, 2013, pp.1528-1540.

[17] Onet, T., Magureanu, C. and Vescan, V., "Aspects Concerning the Behavior of Ferro-

cement in flexure", Journal of Ferrocement, Vol. 22, 1992, pp. 1-9.

[18] Ong, K., Paramasivam, P. and Lim, C., "Flexural Strengthening of Reinforced Concrete Beams Using Ferrocement Laminates", Journal of Ferrocement, Vol. 22, 1992, pp. 331-342.

[19] Seshu, D., "Flexural Strength Assessment of Ferrocement Confined Reinforced Concrete (FCRC) Beams", Journal of Ferrocement, Vol. 31, 2001, pp. 53-63.

[20] Misara, A. K., Bungey, J. H., Ghazali, M. Z. M. and Hassan, M., "Performance of Gunite Repaired Reinforced Concrete Beams", Proceedings of the Sixth International Conference on Structural Faults and Repairs, Extending the Life of Concrete, London, UK, Vol. 1, 1995, pp. 411-18.

[21] Swamy, R., Jones R. and Bloxham, J., "Structural Behavior of Reinforced Concrete Beams Strengthened by Epoxy-Bonded Steel Plates", Structural Engineer. Part A, Vol. 65,1987, pp. 59-68.

[22] Hobbs, B. and Roberts, M. M., "Structural Behavior of Externally Bonded, Steel Plated RC Beams after Long Term Exposure", Structural Engineer, Vol. 73, 1995, pp. 15.

[23] Bruggeling, A. S. G., "External Prestressing-A State of the Art", External Prestressing in Bridges. ACI, SP- 120, Edited by, Naaman A. and Breen J, 1990, pp. 61-81.

[24] Harajli, M., "Strengthening of Concrete Beams by External Prestressing", PCI Journal, Vol. 38, 1993, pp. 76-88.

[25] Hollaway, L. and Leeming, M. B., "Strengthening of Reinforced Concrete Structures: Using Externally-bonded FRP", Composites in Structural and Civil Engineering, CRC, 1999.

[26] Cairns, J. and Rafeeqi, S. F. A., "Behavior of Reinforced Concrete Beams Strengthened by External Unbonded Reinforcement. Construction and Building Materials, Vol. 11, Nos. 5-6, 1997, pp. 309-317.

[27] Kheyroddin, A., Naderpour, H., Amiri, G. G. adn Vaez, S. H., "Influence of Carbon Fiber Reinforced Polymers on Upgrading Shear Behavior of RC Coupling Beams", Iranian Journal of Science and Technology Transactions of Civil Engineering, Vol. 35, No. C2, 2011, pp. 155-169.

[28] Khan, A. M., Rafeeqi, S. F. A. and Lodi, S. H., "Performance of Park Structures Made by Ferrocement. International Symposium on Ferrocement and Thin Reinforced Composites (FERRO-9)", Green Technology for Housing and Infrastructure Construction, Bali, Indonesia, 2009, pp. 399-407.

[29] CMB - Chemicals for Modern Building International http:/*/www.cmbegypt.com/*

[30] Sika Egypt for Construction Chemicals S.A.E. International, http://www.Sika.com.

[31] The Egyptian Swiss Chemical Industries Co., Web Site: http://www.swisschem.com.