PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 22 No. 1 March 2018 pp: 52:62

Experimental and Analysis Study on Structural Behavior of Ferrocement Frames

Hassan Ibrahem.[1], Mostafa Marzok[2], Ezzaat sallam[2], and Elham Mohamed [3]

ABSTRACT

Ferrocement gained an increasing research effort in the last decades due to its low weight and different uses in the developing countries. Ferrocement elements can be used as roofing, flooring elements, or either framed structures. This research presents an experimental and analytical study of the structural behavior of Ferrocement frames. The main objective of the research is to study the effect of combined actions as shear, flexure and normal on the structural behavior of Ferrocement joints. An experimental program including thirty test specimens in form of box shaped panels was conducted. The panels were classified into three groups to draw out the necessary conclusions from the studied parameters. The included parameters are reinforcement schemes and corner reinforcement ratios. The effects of the selected parameters are presented in form of cracking, failure loads and load deflection comparisons. From the study, it is observed clearly that there is significant influence of reinforcement on the overall panels. As the amount of reinforcement increases, the action load increases indicating a higher section capacity to resist more load and delay cracking and yielding of reinforcement. Moreover, the location of the reinforcement helps in enhancing the behavior.

Keywords: Ferrocement, Flexural, Shear, Normal Behavior, Wire Mesh, Panels, Closing Joint, Opening Joint.

1. Introduction

The ferrocement is one of the construction materials which may be able to fill the need for building light structures. Ferrocement composite consists of cement-sand mortar and single or multi-layers of steel wire mesh to produce elements of small thickness having high durability, resilience and when properly shaped it has high strength and rigidity. These thin elements can be shaped to produce structural members such as folded plates, flanged beams, wall panels…etc. for use in the construction of cheap structures. The wide spread use of ferrocement in the west began only in the last three decades, gaining publicity with the famous ferrocement domes constructed for the Rome Olympics in1960[1][5].

Welded wire mesh produced using longitudinal and transverse wires welded together at the intersections. It has a higher stiffness than woven mesh. This is why the welded mesh leads to smaller deflections in the elastic stage. It is also more durable, more intrinsically resistant to corrosion and more stable in structures than woven mesh [6].

Ferroccement is used in shear strengthening techniques to improve the shear capacity of the beam. Increase in diameter of the mesh shows a significant increase in the ultimate strength of reinforced beam. It delays the first cracking load and tends to narrow the crack width causing large deflection at ultimate load [7] [14].

Ferrocement has found widespread applications in housing particularly in roofs, floors, slabs and walls. Ferrocement is considered as a suitable housing technology for developing countries attested by the increasing number of easily built and comfortable ferrocement houses. Ferrocement houses utilizing local materials such as wood, bamboo or bush sticks as equivalent steel replacement has been constructed in Bangladesh, Indonesia and Papua New Guinea. [5][9].

Its application as overlays on masonry walls can increase its total load capacity, tension and shear strength. It also provides the ductility, and. cracking control. Figures (1, 2) the application of ferrocement overlays is potential option in the situations where high performance of the walls is required [8].

[1]*Professor of Concrete Structures, Civil Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt*
[2]*Assistant professor of Concrete Structures, Civil Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt*
[3]*PhD student, Civil Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt*

Figure 1 Failed in filled frame with a prominent diagonal crack [8].

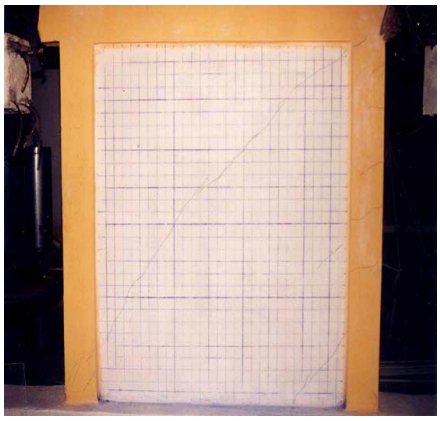


Figure 2 Cracks in the repaired frame. diagonal crack[8].

When a corner joint of a rigid frame tends to be opened by the applied moments, it is called 'opening joint'. Figure (3) shows the internal stresses and forces of an opening joint. It is clear that these forces cause tensile and compressive stresses. These stresses will cause cracking of concrete. Different detailing schemes were investigated by Nilson, 1973 under bending moments that tends to open the joint [4].

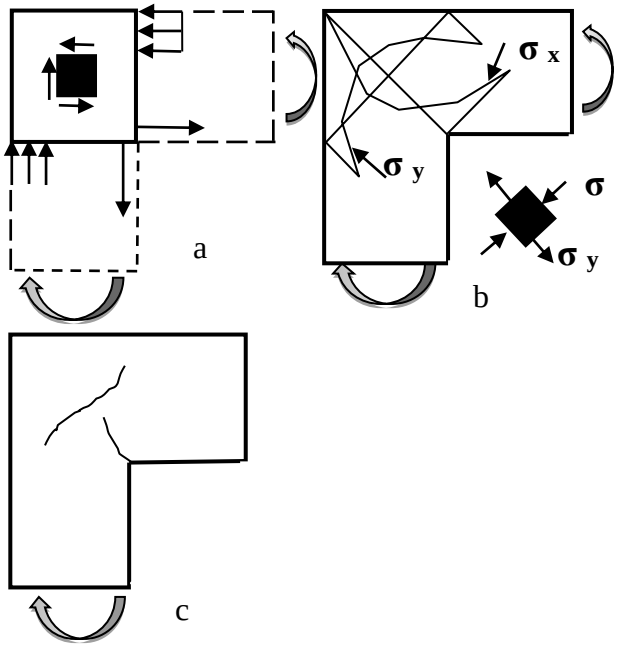


Figure 3: Opening Joints in Frames [4], (a) forces (b) stress, (c) crack.

If a corner joint of a rigid frame tends to be closed by the applied moments, it is called "closing joint". Fig. 4 shows the tensile, compressive forces in a joint and the reinforcement detailing and crack pattern.

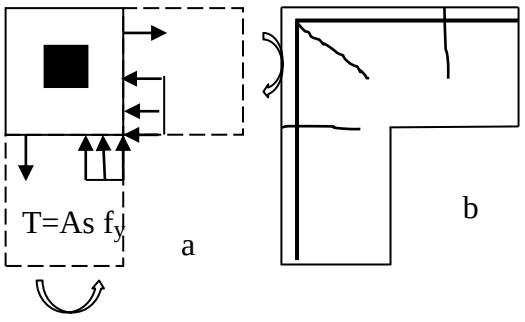


Figure 4: Closing Joints in Frames [4] Opening Joints in Frames, (a) forces (b) cracking pattern reinforcement.

One of specific research needs in ACI is test data for combined load conditions such as in-plane shear and

flexure, tension, and compression. An example is the use of ferrocement for folded plate roof elements in long span lightweight construction where in-plane shear and bending stresses are important. The current research works on it.

2. Ferrocement Structural Behavior

The structural behavior of ferrocement is different from conventional reinforced concrete. The dispersion of small diameter steel wires closely and uniformly in the entire volume of the ferrocement element improves many engineering properties like impact resistance, fatigue resistance, tensile strength, toughness and flexural strength. In ferrocement, there is a combined action of steel and mortar in tension zone even after cracking. Thereby, the tensile strength of mortar is improved due to close spacing of wires. The presence of steel phase improves the deformation characteristics of other phase i.e. mortar. Thus, ferrocement is defined as a two phase composite material, the steel phase acting as the reinforcement phase and mortar phase as the matrix.

3. Cracking Mechanism

Mechanism of crack formation in ferrocement can be explained in a way similar to the explanation given in the case of reinforced concrete, namely bond-slip hypothesis. When a ferrocement element is subjected to uniaxial tension, primary cracks form at random critical sections where the tensile stress in the mortar exceeds the tensile strength. At these cracks, bond is broken, a slip occurs between wires and mortar and all the load is taken by wires only. In between these cracks, tensile stresses exist in the mortar and as it stresses along the fibers, bond stresses are also present. With the increase of the further load, sections, which carry highest tensile strength, crack when the stresses exceed the tensile strength of the mortar and thus, new cracks are formed. This process continues till the spacing of the cracks becomes sufficiently small, so that the maximum tensile stresses in the mortar between the already formed cracks are just equal to or less than the tensile strength. At this stage, the number of cracks that formed have stabilized, no more new cracks form with further increase of load and spacing of cracks has reached its smallest possible value. [11][12][13]

4. Experimental Program

The test panels were designed to more or less simulate the in situ, which the panels were designed to study the combined loads conditions shear, flexure, tension and compression. Thirty panels were constructed in the Concrete Research Laboratory at the Faculty of Engineering of Port Said University.

4.1 Specimen Configuration

The test panels have the same cross-section as in Figure (5). The typical panel geometry was 500 mm width, 700 mm overall height, 30 mm thickness. Test panels were reinforced with one wire mesh Φ3 mm, with variable numbers of corner reinforcement ratio. The test panels were classified into three main groups.

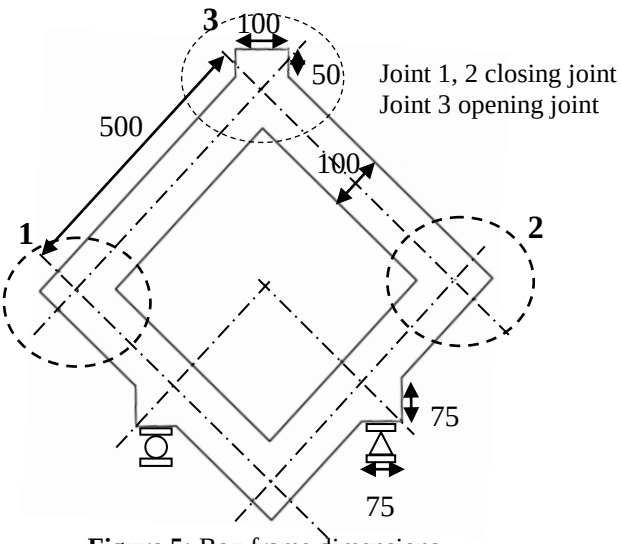


Figure 5: Box frame dimensions.

4.2 Materials and Mixing Proportions

Natural sand was used in the construction of concrete specimens. It was clean, graded, and free from deleterious materials. The sand, cement and water ratios by weight were chosen to be 2:1 and 0.5 respectively, to achieve a normal strength with good workability. The cement used in the experimental study was ordinary Portland cement complied with the Egyptian Standard Specifications No. 203-2003. Clean drinking fresh water was used in all mixes. Steel wire mesh fabric was used. Square opening (40X40 mms) steel wire meshes were used of 3mm with V_f(volume friction) 0.35%. The yield strength was 420 MPa.

A mechanical mixer was used to mix the concrete constituents; the period of mixing was about 3 minutes. Cement and sand were first dry mixed for about one minute until a homogeneous color for the mix was observed. Then, the water was gradually added while the mixing was in process and continued for 2 minutes, until concrete mix of suitable consistency was obtained. Average compressive stress was 45 MPa. Figure (12) shows placement of specimen reinforcement, Figure (11) shows specimen formwork.

Figure 6: Mortar cubes

Figure 7: The panel adjusted at the machine.

4.3 Specimen Grouping

The experimental program consisted of three groups. Groups A, B, C were tested under concentrated patch load. All specimens had a thickness of 30 mm. All specimens were cast in horizontal forms. Layer of ferrocement mesh was located at the center of the cross-section of the specimen. Welded square steel mesh (3mm) was studied. Test variables included corner details of reinforcement, and corner reinforcement ratio.

The specimens are identified using two terms; the first term represents the group type A, B, C. (i.e., A for motor corner only, B for no overlap, and C for overlap). The second term represents the number of 3mm bar at corners. (i.e. 0 for no bars, 1 for 1Φ, and 2 for 2Φ), Figures (6,9,10).

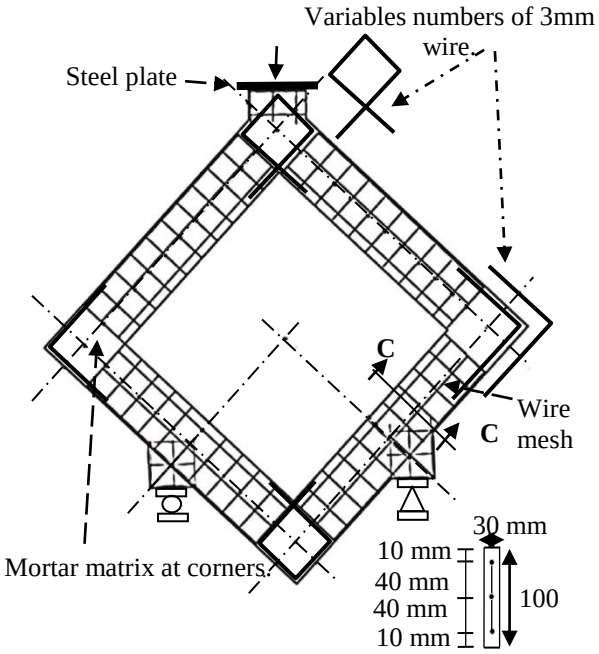


Figure 8: Details of group A Sec. C-C

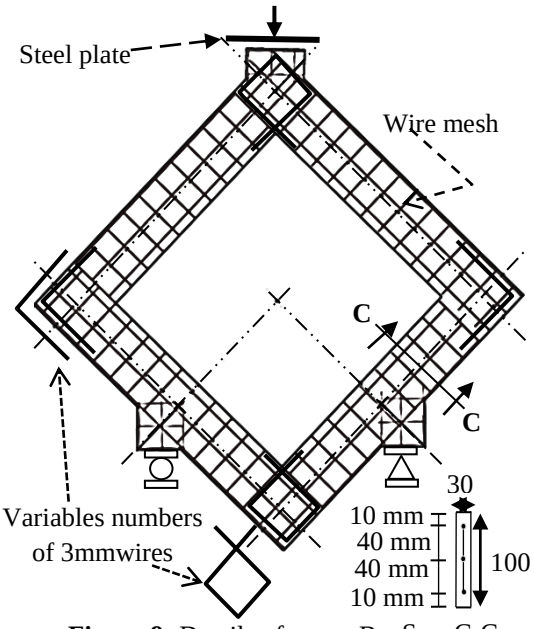


Figure 9: Details of group B Sec. C-C

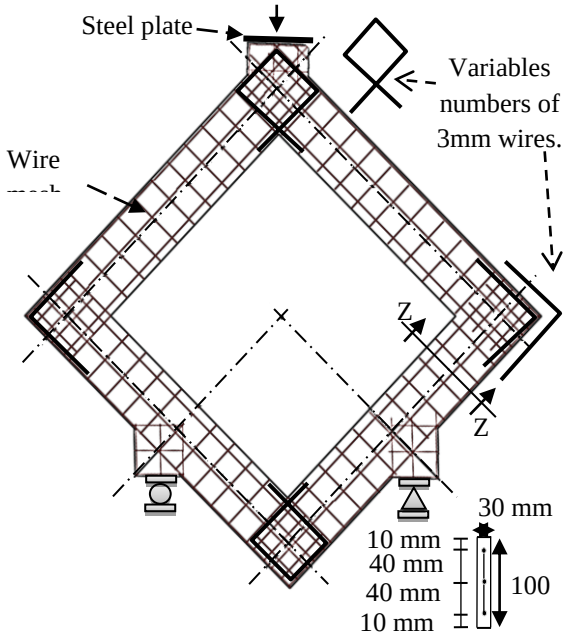


Figure 10: Details of group C Sec. Z-Z

4.4 Testing procedure

The specimens were tested under gradually increasing load at their center in a universal-testing machine. Figure (7) shows the test setup as well as the load and support configurations. Dial gauge accuracy (LC = 0.01 mm) was fixed at the bottom of upper joint (3) to measure deflection. Initiation and propagation of cracks have been visually detected while the specimens

were incrementally loaded up to failure. The cracking patterns were traced and recorded.

Figure 11: Specimen formwork

Figure 12: Placement of specimen reinforcement

5. Results and Discussion

The main purposes of the test program were to investigate the effect of reinforcement on opening shapes (closed frame), and study the structural behavior of test panels.For all test box frames, cracking patterns, deflection, absorbed energy, and ultimate load are recorded and discussed herein.

5.1 Load Deflection and Failure Load.

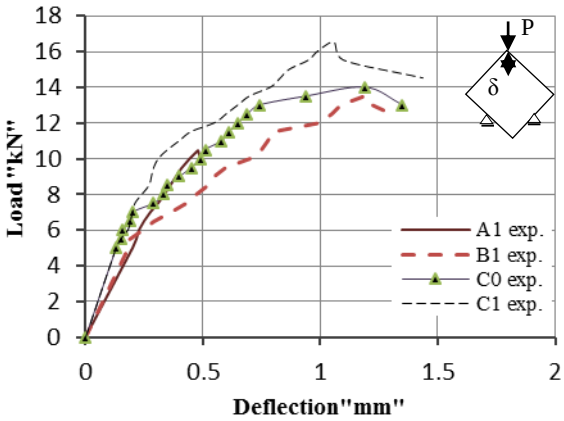


Figure 13: Load- Deflection response of ferrocement specimens for one 3 mm wire.

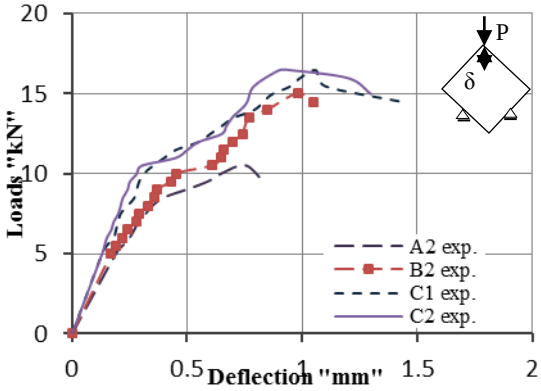


Figure 14:Load- Deflection responses of ferrocement specimens for three 3 mm wire.

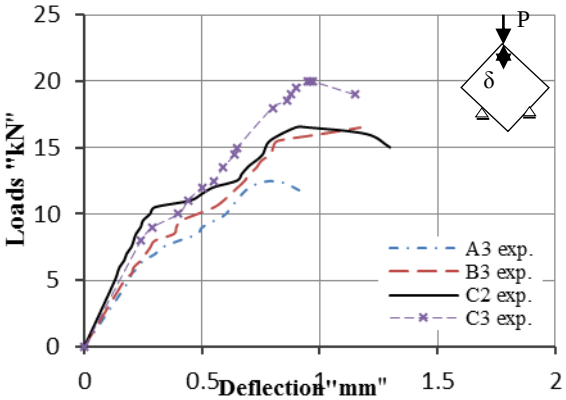


Figure 15: Load- Deflection response of ferrocement specimens for two 3 mm wire.

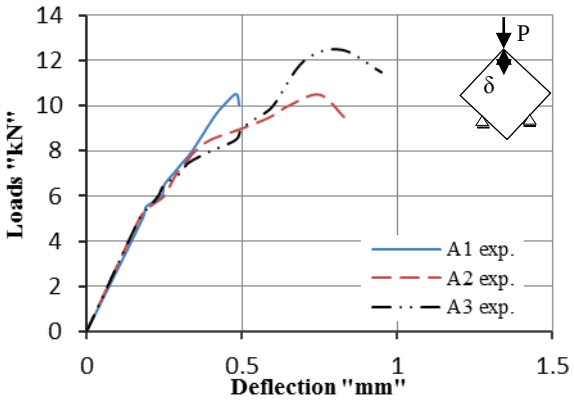


Figure 16: Load- Deflection response of ferrocement specimens of group A.

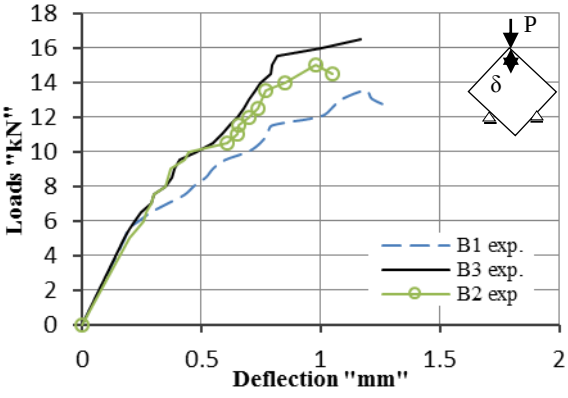


Figure 17: Load- Deflection response of ferrocement specimens of group B

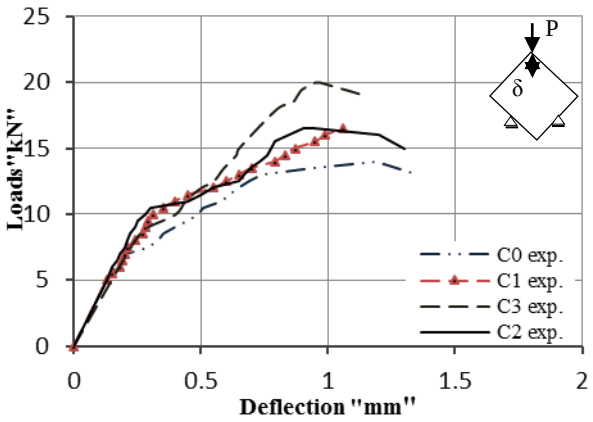


Figure 18 Load- Deflection responses of ferrocement specimens of group C.

In Figure (13), the maximum load capacity was 10.50, 13.50, 14.00 and 16.50kN, and failed in flexure with deflection 0.49, 1.30, 1.35,and 1. 44 mm to A1, B1, C0, and C1 in order.A1 was the worst structural behavior connection performance.

In Figure (14), the maximum load capacity was 10.50, 15.00, 16.50, and 16.50kN, and failed in flexure with deflection 0.83, 1.05, 1.44, and 1.30 mm to A2, B2, C1, and C2 in order. C2 had maximum load capacity more by 36, and 9 % than A2, and B2, but C1with overlap wire mesh plus additional one wire 3mm has the best maximum deflection by 10% than C2.

In Figure (15), the maximum load capacity of 12.50,16.50, 16.50,20.00 kN and failed in flexure with deflection 0.95, 1.17, 1.30, and 1.15 mm to A3, B3, C2, and C3in order. Increase the reinforcement at the panels corners increase the load capacity.

Figure (16), shows load-deflection curves to group B. The maximum load capacity of 10.50, 10.50, 12.50 kN and failed in flexure with maximum deflection 0.49, 0.83,0.95 mm to A1, A2and A3 in order. Curves can be divided into different stages. First stage was liner, which no cracks until first cracks showed. Then yielding stage was at 8.5kN. Finally, was failure stage which the cracks become wider and can be seen clearly. The first crack was at 5.5 kN which represents52.4, 44% from peak loads to A1, A2, and A3.

Figure (17) shows load-deflection curves to group B. The maximum load capacity was 13.50, 15.00, and 16.50 kN, and failed in flexure with maximum deflection 1.3, 1.07, 1.17mm for B1, B2, and B3 in order. Curves divided into three stages, first liner where no cracks until first cracks showed until yielding at 10.5 kN then failure stages which the cracks can be seen. The first crack was at 6.50 kN which represents 48, 43, and 39.4% from peak loads to B1, B2, and B3.

Figure (18), shows load-deflection curves to group C. The maximum load capacity was 14.00, 16.50, 16.50, and 20.00kN, and failed in flexure with maximum deflection 1.35, 1.44, 1.3, and 1.15 mm for C0, C1, C2, and C3 in order. The first crack was at 7.50 kN which represents 54, 46, 46, and 37.5% from peak loads to C0, C1, C2, and C3. Curves have three stages, first liner where no cracks until first cracks showed until yielding at 10.5 kN then failure stages which the cracks can be seen.

General note, curves have almost same behavior. It probably due to all specimens has same concrete strength (average compressive stress 45 MPa) and the changes in reinforcement ratio(3mm mesh , 3 mm wires) not big between main three groups.

5.2 Cracking Pattern

In Figures (19, 20), cracking started at maximum bending moment at corner Z first than S. As the applied load increased, the developed cracks propagated rapidly to corners S and R. At failure, cracks were wider in Group A than B than C.

The first crack load varied with the variation of the steel mesh ratio. New cracks developed with the additional increase of the load. This pattern of crack development continued till the failure. The number of the developed cracks varied with the variation of the steel mesh ratio. The crack widths and numbers were big in group A than B than C. Because GA had less ratio of reinforcement, so it had less absorbed energy than G B, and, GC.

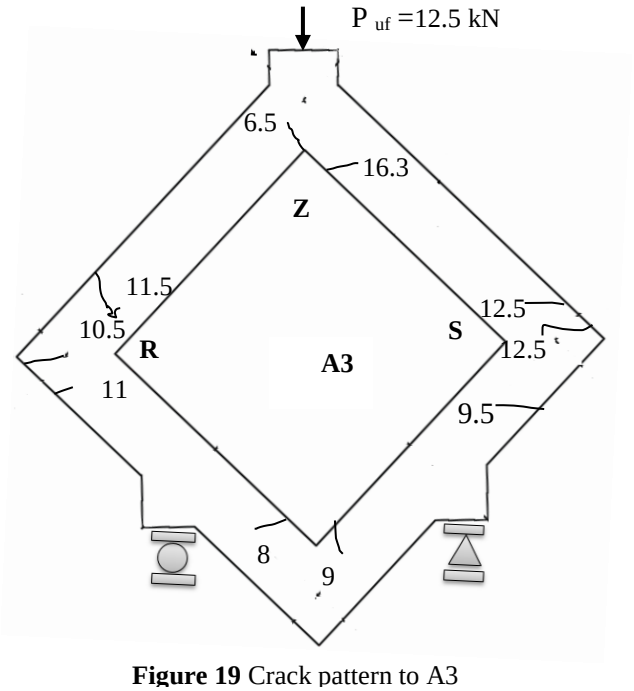


Figure 19 Crack pattern to A3

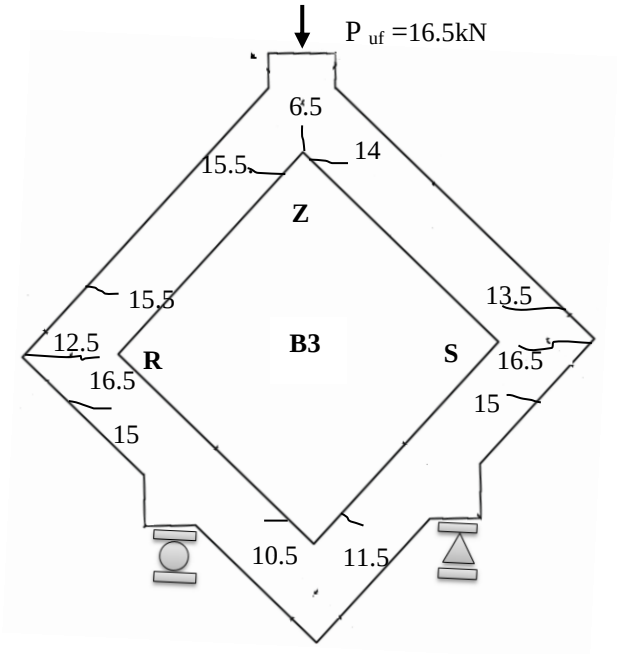


Figure 20 Crack pattern to B3

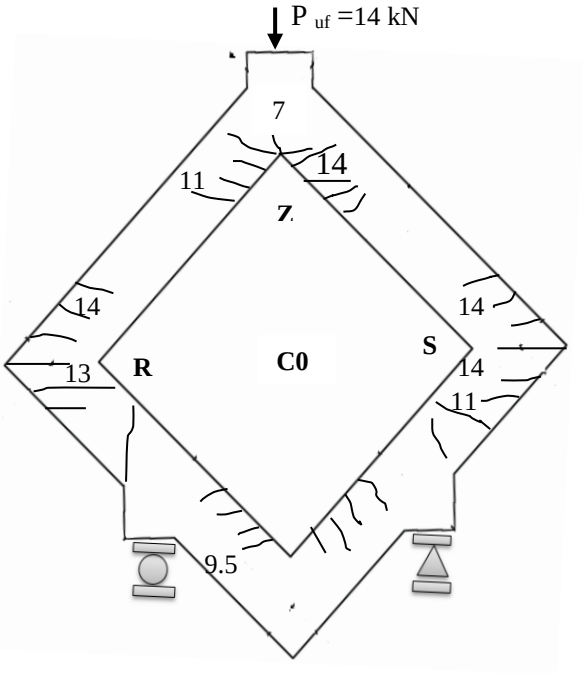


Figure 21 Crack pattern to C0

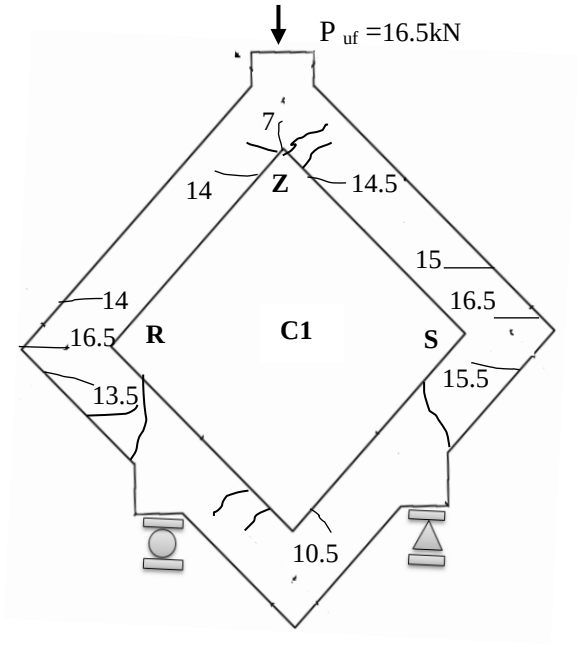
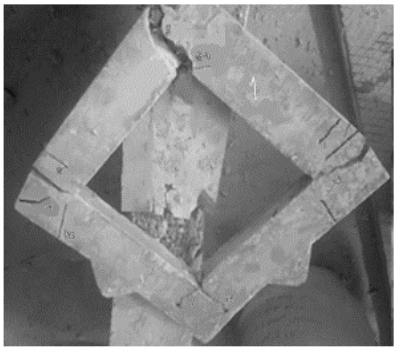


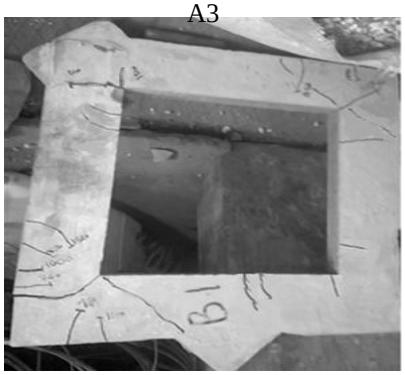
Figure 22 Crack pattern to C1



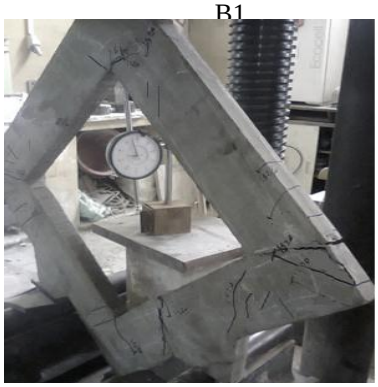
A1

A2

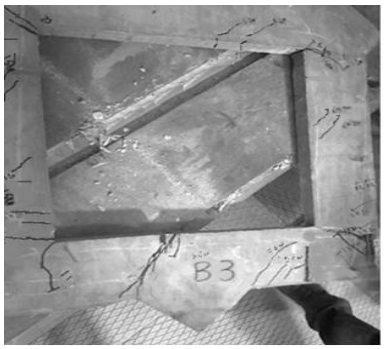
A3



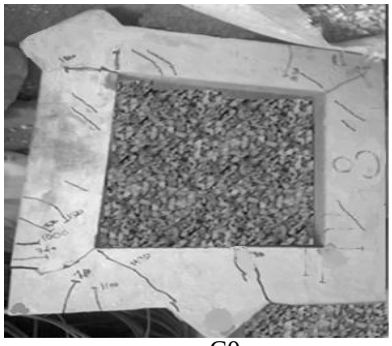
B1



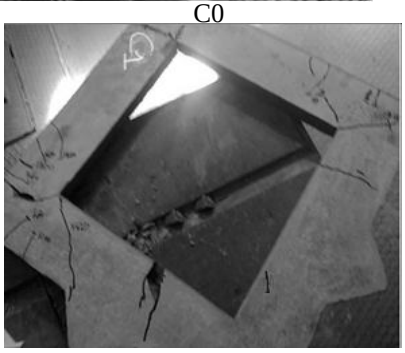
B2



B3

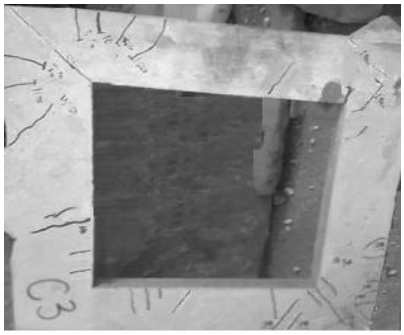


C0



C1

C2



C3

Figure 23: Failure load for different specimens.

6. Ductility and Absorbed Energy

Table (1) shows ductility ratio which is defined in this investigation as the ratio between the mid-span deflection at ultimate load to that at the first cracking load ($\Delta u/\Delta i$). Ductility is defined as the ability of the

structure to undergo plastic deformations without significant loss of strength.
Table (1) shows the aborted energy which is defined as the area under the load-deflection curve. To calculate the area under curve by integrated the equation of the load-deflection curve for each specimen as follow:

Energy absorbed $= \int_0^{\Delta u} L(\Delta) d\Delta$; Where L (Δ) is the equation of load-deflection curve, and Δu, is the mid-span deflection at ultimate.

Overlap connection with one additional wire had more ductility by 6 % than overlap connection with no additional wire, and best ductility ratio 6.86, and 6.50 respectively. Absorbed energy is important, which helps to have more resistance to more impact load, lateral load, ductility, and good distribution to cracks.

Panels cracking in a nature manner acts as a mean of load absorption. Panels subjected to loads should be designed in a way to sustain damage with enough ductility to break without shattering and thus avoids possible risks of causalities and injuries resulted from flying debris.

Table 1: Maximum deflection, ductility ratio, and absorbed energy for all tested box frames.

		Maximum Deflection (mm)	Ductility Ratio (Δu/Δi)	Absorbed Energy (kN.mm)
A	A1	0.49	2.23	2.86
	A2	0.83	3.77	6.05
	A3	0.95	4.75	7.84
B	B1	1.30	4.48	11.78
	B2	1.05	4.38	10.12
	B3	1.17	4.88	12.63
C	C0	1.35	4.66	14.30
	C1	1.44	6.86	17.38
	C2	1.30	6.50	15.83
	C3	1.15	4.79	14.75

7. Analytical Predication

Structural analysis by one-unit load on panels is shown in Figure (24 a, b, c). The moment structural capacity at different section according to Egyptian code [2] is determined. From structural analysis and calculated moment capacity the theoretical ultimate load can be predicted. Table (2) shows predicted ultimate load capacity compared to experimental results.

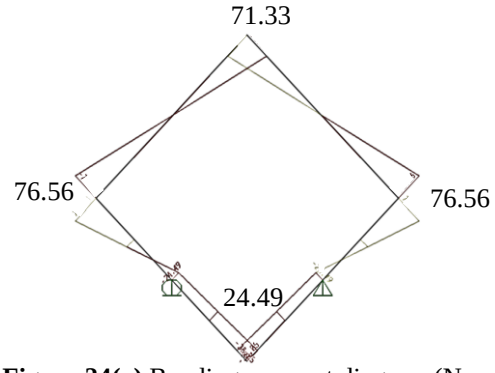


Figure 24(a) Bending moment diagram (N.mm).

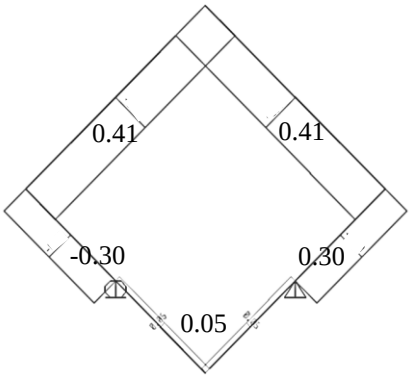


Figure 24(b) Axial force diagram (N)

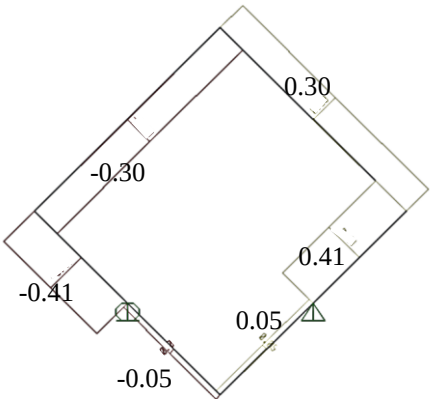
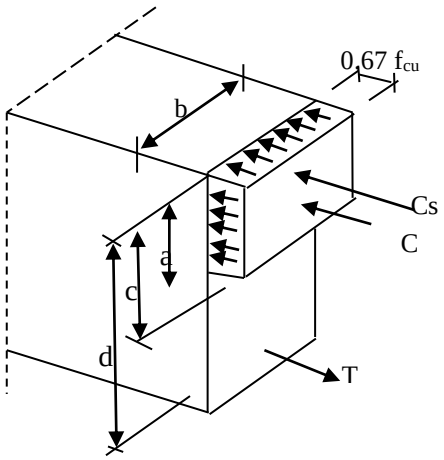


Figure 24(c) Shear force diagram (N)



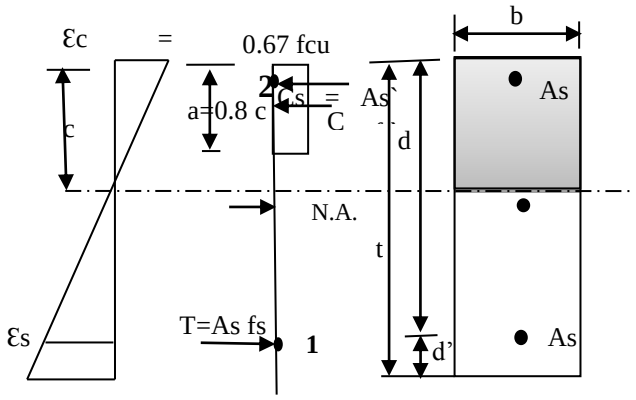


Figure 25: Forces & Strain in section under flexure and equivalent compression block

Table 2: Theoretical and experimental failure load for all tested panels**.**

Group	Specimen	Theoretical failure load 'KN'	Experimental failure load 'KN'	Pex. /Pth.
A	A1	10.69	10.50	0.98
	A2	13.83	10.50	0.76
	A3	16.96	12.50	0.74
B	B1	10.96	13.50	1.26
	B2	13.83	15.00	1.10
	B3	16.96	16.50	0.97
C	C0	12.18	14.00	1.15
	C1	15.32	16.50	1.08
	C2	18.45	16.50	0.89
	C3	21.59	20.00	0.93

8. Conclusions

Based on experimental tests and analysis, the following conclusions could be drawn out:

- In general, the ferrocement showed good stiffness, and ductility Increasing reinforcement of the panels increases the absorbed energy.
- From studied details overlap connection specimens showed reduced crack widths, large deflection at the ultimate load, a significant increase in the ductility ratio, and considerable increase in the energy absorption as well, making the components better equipped to resist dynamic loads.
- The best reinforcement for ultimate loads with best ductility for close and open joint were overlap connection with one additional wire (C1), then overlap mesh with no extra reinforcement (C0).
- Overlap connection with one additional wire had 15% load capacity and ductility by 6 % more than overlap connection with no additional wire.
- Applying more amount of corner reinforcement ratio results in slightly increase in panel specimen's ultimate failure loads.
- The code equations for reinforced concrete (RC) design can be used to predict ferrocement (FC) structural behavior as correlation between predicts and experimental was acceptable.

9. References

[1] ACI 549R-97, (2000). "State of Art Report on Ferrocement", ACI Committee 549, American Concrete Institute**.**

[2] ECP-203. (2007). Egyptian Code for Design and Construction of Reinforced Concrete Structures. Cairo, Egypt.

[3] Hassan M.H. Ibrahim. (2011), " Shear capacity of ferrocement plates in flexure" Engineering Structures 33 (2011) 168–1686

[4] James G. Mac Gregor, James K. Wight (2008), " Reinforced Concrete: Mechanics and Design" chapter 17. Departments of the University of Illinois

[5] Jain, A.K. (June 1981), "Ferrocement Folded Plate Roofing Industrial Sheds", India Concrete Journal, Vol. 55, No. 6, pp. 146-149.

[6] Jianqi Wang, (2013), Behavior of ferrocement columns under static and cyclic loading, PhD. thesis, Faculty of Engineering, Manchester University

[7] M.P. Sridhar, K.P. Senthilnathan, M. Priyaadharashini (2016), Shear Behavior of RC Composite Beams, International Journal of Chem. Tech. Research, Vol.9, No.03 pp 342-349.

[8] Fabiana, L.D.O. and De Hanai, J.B. (2002). "Experimental Analysis of Concrete Block Masonry Walls with Rectangular Openings Strengthened by Ferrocement Overlays". Journal of Ferrocement. 32(3): 179-191.

[9] Nagesh M. Kulkarni (2013), "Analysis and Design of ferrocement Panels an Experimental Study", (IJIES), Vol. 1, No.5, April 2013.

[10] P.Paramasivam, and Mansur, M. A. (1985),"Tensile and Flexural Behavior of Joints in Ferrocement Construction," ACI Journal, Proceedings, V.82, No. 5, Sept.-Oct. 1985, pp. 710-715.

[11] Surya Kumar, G.V., and Sharma, P.C. (1976), "An Investigation of the Ultimate and First Crack Strength of Ferrocement in Flexure", Indian Concrete Journal, Vol.50, No. 11, Nov.1976.

[12] Al-Kubaisy, M.A. and A.S. Alnuaimi, (2005) "Experimental Investigatuion of Reinforced Ferrocement Roof Slab Panels" Construction and Building Materials, 19, 31-37, 2005.

[13] Balaguru, P.,(1981). “Prediction of Crack Width in Ferrocement Beams” Journal of Ferrocement. 11(3): 203-213.
[14] Suksawang, N., Nassif, H.H. and Sanders, M. (2006). “Analysis of Ferrocement”. Proceedings of Eight International Symposium and Workshop on Ferrocement. 06-08 February, Bangkok Thailand, IFS, 141-150.