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Experimental And Analytical Analysis Of Lightweight Fe rrocement Composite Slabs

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Abstract. Ferrocement is one of the earliest versions of reinforced concrete. In this, a challenge had been made to get out the flexural behavior of ferrocement experimentally and analytically. The slab panels of dimensions 600 mm × 1200 mm with a thickNess of 300 mm. The slab panels are tested under the two-point loading 300mm load distance. The analytical study was carried out by Ansys 14.5. The analytical results showed good agreement with the experimental results. The results demonstrated that the expanded slab panels showed less deflection and more flexural strength compared with the welded slab panels.

Keywords: Ferrocement, welded wire mesh, expanded wire mesh, nonlinear finite element analysis (NLFEA), Ansys 14.5.

1. Introduction

In order to provide essential infrastructure services as suitable housing units to the millions of people, low price building materials had become a vital issue. Researchers recommend that ferrocement can be another material for roofing as it is economical.

Ferrocement, also nominated as reinforced concrete, is produced by mixing cement with sand mortar and using the mixture over some layers of woven Skudra. A.A. (1994) or welded G. Singh and Xiongsteel G.J. (1992) mesh with small diameter holes in ACI Committee 549 (2009). It is also applying in shipbuilding in Naval Ship Systems Command and A.W. Greenius, (1975), water and food storage tanks Y.B.I. Shaheen, B. Eltaly, M. Kamel (2013), water transport tubing by National Academy of Sciences (1973), silos byACI Committee 549 (1989), roofs byA.W. Hago, K.S. Al-Jabri, A.S. Alnuaimi, H. Al-Moqbali, M.A. Al-Kubaisy(2015) and Y. Yardim, A.M.T. Waleed, M.S. Jaafar, S. Laseima (2013), urban and rural houses W.N. Al-Rifaie (2012), and structure repair K.M. Amanat, M.M.M. Alam, M.S. Alam (2007) and D. Rajkumar, B. Vidivelli (2010). Ferrocement is especially accepted because its raw materials are accessible, it is easy to arrange and shape, and it is fire challenging V. Greepala, P. Nimityongskul (2008) and Yousry BI. Shaheen, G. Ramadan Ahmed (2012).

It is also kNown to endorse the seismic resistance of masonry structures S. Shang, K. Liu, F. Yao (2010). Researchers showed that using additives such as fibers C. Soranakom, B. Mobasher(2006), M. Jamal Shannag, Tareq Bin Ziyyad (2007) and S. DeepaShri, R. Thenmozhi (2012), silica P. Rathish Kumar(2010) and M.A. Mashrei, G.M. Kamil, H.M. Oleiwi,] A. Booshehrian (2011), fly ash by L. Andal, M.S. Palanichamy, M. Sekar (2008), and resin in Kumar (2010) to improve the strength of
mortar in ferrocement. Other experimental studies recommended that the applicability of polymer fibers as a replacement for meshes in ferrocement. Furthermore, ferrocement slabs are employed as secondary roof structures to protect against heat in V. Greepala, R. Parichatprecha, T. Tanchaisawat, P. Nimityongskul (2011), in the beams constructions by B.P. Hughes, N.F.O. (1993), P. Paramasivam, B.I. Shaheen Yousry, Noha M. Soliman (2013) and E.H. Fahmy, M.N.A. Zeid, Y.B. Shaheen(2005) and in building elements such as doors as T. Baetens (2004) and walls as E.H. Fahmy, B.S. Yousry, Mohamed N. Abou AbouZeid, Hassan Gaafar (2004). The performance of ferrocement components like beams, slabs, and columns had been tested up to failure by experimentally such as Hago et al. and H.M. Ibrahim (2011) who applied experimentally the ultimate capacity of simply supported slab panels and ferrocement slabs. While the require for experimental study to present the starting point for design equations continues but by using the FEM, be able to decrease the time and cost of otherwise costly experimental tests, and may well enhanced to emulate the loading and support conditions of the real structure. So the FEM was applied by Nassif and Najm (2004) to survey the performance of ferrocement composite beams under a two-point

loading scheme. They applied a smeared crack model, which be capable of applying the constitutive equations separately at every integration point of the model to establish failure in concrete and as a result they explored that the ferrocement composite beams comprise superior ductility, cracking strength, and ultimate capacity parallel to reinforced concrete beams. The same Qasim Mohammad (2012) considered the FEM to examine the ferrocement slabs. Modeling of concrete compression and tensile cracking had been studied by a plasticity model and smeared cracking approach respectively. Furthermore, to explore the composite effect between the ferrocement slabs and steel sheeting, B. Aboul-Anen, A. El-Shafey, M. El-Shami, (2009) used ANSYS software with Eight-node solid isoperimetric elements.

2. Research Significant

The paper presents an experimental investigation of ferrocement panels reinforced with different kinds of reinforcement mesh (expanded and welded) connected with U profiles to exhibit composite behavior. The experimental results are then compared and validated by means of NLFE models. A comparison of the results is carried out, both between the two different specimens as well as between the experimental and numerical models, in an attempt to reach to some conclusions. This application of using the ferrocement technology in lightweight units and low-cost housing.

3. Experimental program

The experimental study was performed in the laboratory at the Shoubra Faculty of Engineering, Benha University, Egypt. The main objective was studying the ultimate load, ultimate deflection, and mode of failure of expanded wire mesh and welded wire mesh specimens.

3.1. Experimental Study: materials used are:

1. Fine aggregate: was of natural siliceous sand with a modulus of fineness 2.75.
2. Cement: Ordinary Portland type CEM I 42.5 N (El-Suez Cement Company).
3. Water: Tap water used for mixing and curing procedures.
4. Super plasticizer: with a density of 1.2kg/litre and an amount of 1.0% of the cement weight.
5. Reinforcing wire meshes: Fig. 1 showed expanded & welded wire mesh used as reinforcement for ferrocement. The mechanical properties of welded & welded wire mesh according to manufacturer are given in Table 1.

3.2. Mortar Matrix

The concrete mortar was designed to get a compressive strength (f_{cu}) of 25MPa at 28days. Mix properties based on "ACI committee 54, (2009)" are listed in Table 2.

a) Expanded wire mesh b) Welded wire mesh

Fig 1 Types of meshes

Table 1 mechanical properties of expanded and welded wire mesh

Expanded Wire Mesh		Welded Wire Mesh	
Diamond size	16.5 × 31 mm	Dimensions Size	12.5 × 12.5 mm
Weight	1660 gm /m^2	Weight	600 gm/m^2
Sheet ThickNess	1.25 mm	Wire Diameter	0.7 mm
Young's Modulus	12000(N/mm^2)	Young's Modulus	17000 (N/mm^2)
Yield Stress	250 (N/mm^2)	Yield Stress	400 (N/mm^2)
Yield Strain	9.7 × 10^{-3}	Yield Strain	1.17× 10^{-3}
Ultimate Strength	380 (N/mm^2)	Ultimate Strength	600 (N/mm^2)
Ultimate Strain	59.2 ×10^{-3}	Ultimate Strain	58.8× 10^{-3}

Table 2 Ferrocement mortar mix properties

Mix Design	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
M 1	700	1400	245	7

3.3. Samples Description

The experimental program consists of two ferrocement concrete slabs. All slabs were cross section of: 600 mm, 200mm and 1200 mm in width, depth and effective span length of the beam respectively. Composite ferrocement slabs consists of steel channels of dimension 200 x 50 x 20 mm and ferrocement layer cover of thickNess 30mm. The specimens were tested under two point-load loading 300mm load distance. The specimens were divided into expanded wire, and welded wire mesh. All the slabs were cast and cured for 28 days. The admixture used in this study was Super-plasticizer. Concrete dimensions details for slabs are shown in Fig. 2. The slabs specimens are summarized in Table 3.

Specimens ID	Wire mesh type	Specimen No.	Specimens description
S1	expanded	3	one-layer expanded wire mesh
S2	expanded	3	two-layer expanded wire mesh
S3	welded	3	one-layer welded wire mesh
S4	welded	3	two-layer welded wire mesh

Table 3: Slabs specimens' notation

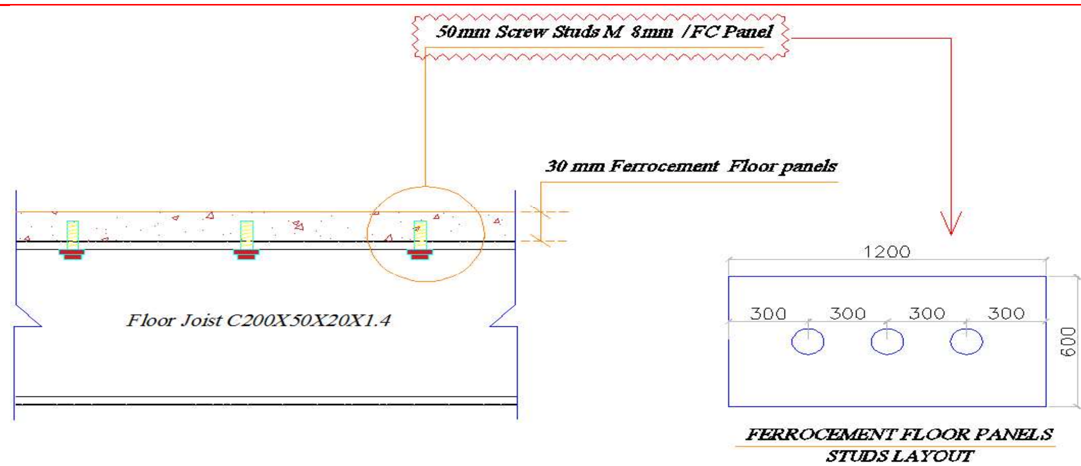


Fig. 2 Composite ferrocement slab geometry

3.4. Test setup

The slabs specimens were tested under two point-load loading on a universal testing machine of maximum capacity of 5000 kN with 1200mm effective span length and 300 mm load distance as shown in Fig. 3. Load was affect at 5 kN increments on the specimen. LVDT's with an accuracy of 0.01mm were placed in the bottom of the slab at the mid-point to find the deflection. The load was increased until the specimen reached to failure. Load & displacement were recorded.

Fig. 3 Test setup of ferrocement composite concrete slab

2.5. Test results and discussion

2.5.1. Ultimate loads

Table 4 & Fig. 4 show the ultimate loads of tested slabs. As shown in Table 4, ultimate load for expanded wire mesh slabs S1 & S2 was higher than ultimate load for welded wire mesh slabs S3 & S4. The ultimate load of the expanded wire mesh slabs was 33.95kN & 40.27kN for one & two layers expanded wire mesh slabs respectively. While, the ultimate load of the welded wire mesh slab was 29.88kN & 33.46kN for one & two layers welded wire mesh slabs respectively. The increase of the load carrying capacity of the expanded wire mesh slabs is due to increasing the volume fraction.

2.5.2. Ultimate deflection

Table 4 & Fig. 4 show the ultimate deflection of tested slabs. The deflection of slabs was 1.37mm for one layer & 1.46mm for one & two layers expanded wire mesh slabs with respect to 1.23mm &1.35mm for one & two layers welded wire mesh slabs. The decrease of the ultimate deflection of the expanded wire mesh slabs is mainly due to increasing the volume fraction

Table 4 Experimental test results (average of 3 specimens):

Slab Specimens ID	Failure load $P_{ult.}$ (kN)	Max. mid span deflection $\Delta_{ult.}$ (mm)
S1	33.95	1.37
S2	40.27	1.46
S3	29.88	1.23
S4	33.46	1.35

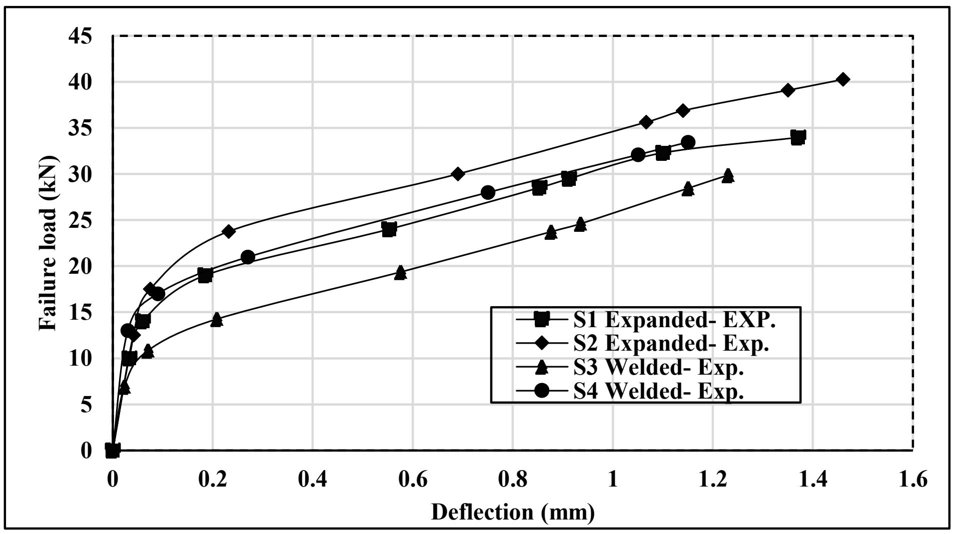


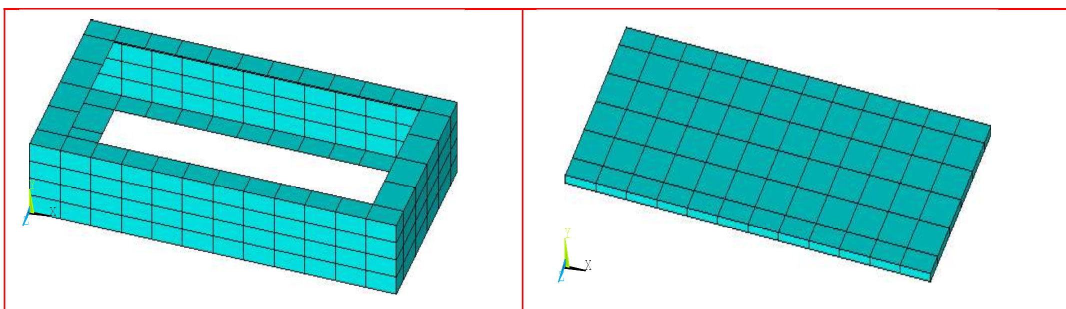
Fig. 4 Load –midspan displacement curves for tested slabs

4. Analytical Study

The analytical study was done to verify the results obtained from the experimental study. Slabs of dimension 300x 600 x 1200mm were modeled and analyzed by using ANSYS.

4.1. Modeling

Non-linear finite element analysis; (NLFEA) was carried out to investigate the flexural behavior of ferrocement composite slabs specimens using ANSYS 14.5 Software as indicated in Fig. 5. The ultimate carrying capacity, ultimate deflection and cracks pattern of the examined slabs were investigated.

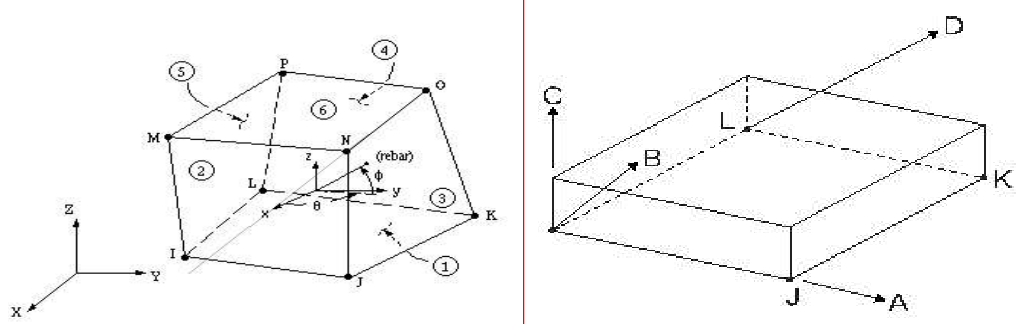


a) Steel channel | b) ferrocement concrete cover.

Fig. 5 NLFEA model of examined slabs

4.1.1. Element Types

In this research, SOLID 65 for the concrete as it is suitable for presentation of compression stress- strain curve for concrete other properties. The steel channels were modelled using SHELL63 element. Also, the other innovative composites materials were represented by calculating its volumetric ratio in concrete element using its special properties. The volumetric ratio refers to the ratio of steel to concrete in the element. ANSYS allows the user to enter three rebar materials in the concrete. Each material corresponds to x, y, and z. The orientation angles refer to the orientation of the reinforcement in the smeared model. Therefore, expanded & welded wire meshes were presented as smeared layers with volumetric ratio as it is referred below. The analytical solution scheme adopted for non-linear analysis was an incremental load procedure. The geometry and node locations for elements type solid65 and SHELL63 are shown in Fig. 6a, 6b respectively.



a) Solid65 | b) Shell 63

Fig. 6 Geometry and node locations for elements types

4.1.2. Material Properties

This part shows the material properties for concrete, reinforcing expanded & welded wire mesh.

- The material properties constants for concrete are input as follows:

Elastic modulus of elasticity (E_c = $4400\sqrt{f_{cu}}$=22000 N/mm^2) and Poisson's ratio (v=0.3) according to ECP' 203/2017.

- The material properties for expanded wire mesh are input as follows:
  - Yield stress (f_y=250 N/mm^2)
  - The diamond size is 16.5 x 31mm with thickness of 1.25mm
  - Volumetric ratio of one layer of expanded mesh (VI=0.0093).
  - Volumetric ratio of one layer of expanded mesh (VI=0.0186).
- The material properties for welded wire mesh are input as follows:
  - Yield stress (f_y=400 N/mm^2)
  - The size of opening is 12.5x12.5mm with wires of diameter 0.7mm
  - Volumetric ratio of one layer of expanded mesh (VI=0.0031).
  - Volumetric ratio of two layer of expanded mesh (VI=0.062).

4.2. Analytical results discussion (model verification)

The finite element analysis of the model in this study examines cracking, yielding of the steel and failure strength of the slab. The nonlinear response is computed by the Newton-Raphson method of analysis. Loading was incrementally increased until unconvergence which means failure. The finite element analysis predictions including the ultimate loads and deflection are summarized in Table 6.

4.2.1. Ultimate loads

Table 6 & Fig. 7 show the ultimate loads of all slabs. As shown in Table 4, ultimate load for expanded wire mesh slabs S1 & S2 was higher than ultimate load for welded wire mesh slabs S3 & S4. The ultimate load of the expanded wire mesh slabs was 32.93KN & 39.57KN for one & two layers expanded wire mesh slabs respectively. While, the ultimate load of the welded wire mesh slab was 27.67KN & 31.08KN for one & two layers welded wire mesh slabs respectively.

4.2.2. Ultimate displacement

Table 6 & Fig. 7 show the ultimate deflection of all slabs. The deflection of slabs was 1.34mm for one layer & 1.42mm for one & two layers expanded wire mesh slabs with respect to 1.21mm &1.31mm for one & two layers welded wire mesh slabs.

Table 6 Analytical results test results:

Slab Specimen ID	Failure load $P_{ult.}$ (kN)	Max. mid span deflection $\Delta_{ult.}$ (mm)
S1	32.93	1.34
S2	39.57	1.42
S3	27.67	1.21
S4	31.08	1.31

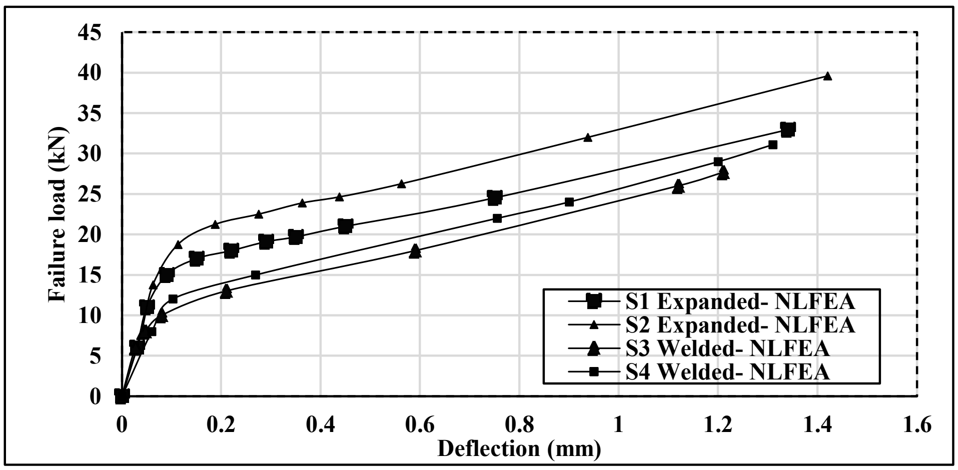


Fig. 7 NLFEA load –midspan displacement curves for slabs

5. Comparison between experimental results and NLFEA results

The goal of the comparison of experimental and non-linear results is to ensure that NLFE models are suitable to exhibit the behavior response of the ferrocement composite slabs.

The analytical models were compared with the experimental results in terms of ultimate load, ultimate deflection, and crack pattern.

5.1. Ultimate load

Table 7 and Fig. 8,9 showed a good agreement between the experimental & NLFEA load capacity. Pu NLFEA/Pu exp. ratio of the expanded wire mesh slabs was 0.970 & 0.983 for one & two layers expanded wire mesh slabs respectively. While Pu NLFEA/Pu exp. ratio of the welded wire mesh slabs was 0.926 & 0.929 for one & two layers welded wire mesh slabs respectively. The NLFE analysis showed the object of test parameters considered on the load carrying capacity.

5.2. Ultimate deflection

Table 7 showed comparison between deflection from experimental test & NLFEA. Fig. 8,9 showed the load displacement curves for all slabs for both experimental and analytical studies. The load displacement curves for tested specimens and analytical results showed a good agreement. Table 7 showed a deflection ratio $\Delta u_{NLFEA} / \Delta u_{exp.}$ of the expanded wire mesh slabs was 0.978 & 0.973 for one & two layers expanded wire mesh slabs respectively, and ratio $\Delta u_{NLFEA} / \Delta u_{exp.}$ of the welded wire mesh slabs was 0.984 & 0.970 for one & two layers welded wire mesh slabs respectively.

The analytical models provided an acceptable load deflection response. Fig. 10 showed the typical deformed shape of ferrocement slabs.

Table 7 Comparison between experimental & NLFE Analysis

Slab Specimen	Failure Load $P_{ult.}$ (kN)		Deflection $\Delta_{ult.}$ (mm)		$\frac{PuNLFEA}{Pu\ exp}$	$\frac{\Delta u\ NLFEA}{\Delta u\ exp}$
	NLFEA	EXP	NLFEA	EXP		
S1	32.93	33.95	1.34	1.37	0.970	0.978
S2	39.57	40.27	1.42	1.46	0.983	0.973
S3	27.67	29.88	1.21	1.23	0.926	0.984
S4	31.08	33.46	1.31	1.35	0.929	0.970

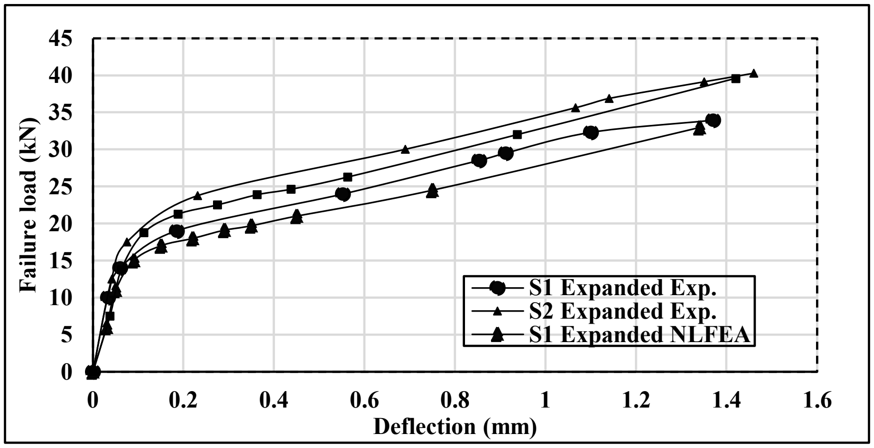


Fig. 8 Comparison between experimental and NLFEA load displacement curves for expanded wire mesh.

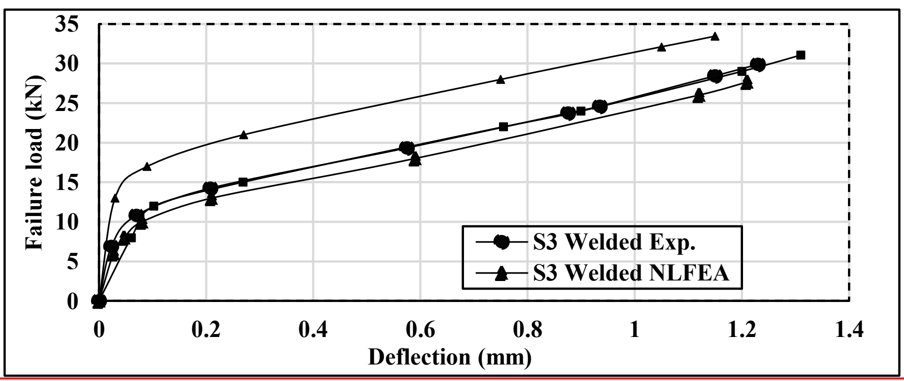


Fig. 9 Comparison between experimental and NLFEA load displacement curves for welded wire mesh

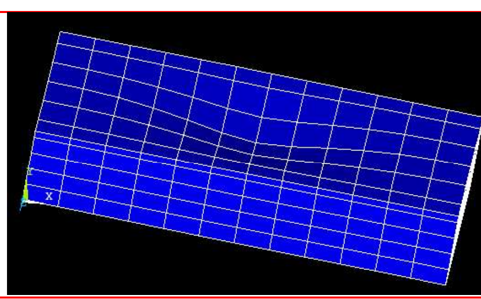
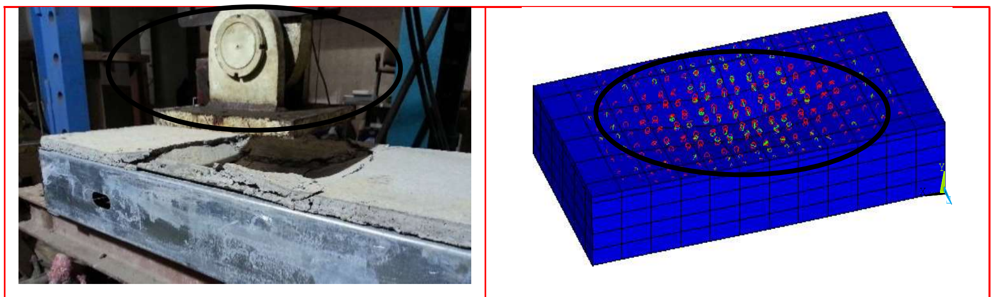


Fig. 10 Typical deformation shape of ferrocement composite slabs

5.3. Cracks Pattern

Fig. 10 indicate comparison between crack pattern obtained from experimental test & NLFEA. All slabs exhibited similar patterns of crack propagation as shown.



a)Experimental cracks	b) NLFEA crack pattern

Fig. 10: Crack pattern for composite slabs

- **Conclusions**

The main conclusions can be summarized as follows:

- Ferrocement concrete specimens reinforced by expanded or welded steel wire mesh exhibit superior ultimate loads under flexural loadings.
- Expanded wire mesh contributed to increase load carrying capacity and deflection higher than welded wire mesh.
- Cracks with greater number and narrower widths were observed for those slabs reinforced with expanded steel wire mesh compared with slabs reinforced with welded steel wire mesh.
- Good agreement between experimental results and analytical ones. Therefore, experimental program was carried out and can be helpful for further parametric studies including various parameters could be investigated.
- The presented work gives good prediction of flexural strength of expanded wire mesh ferrocement slabs where the average ratio (f_{NLFEA}/f_{exp}) was found to be 0.97.

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