DOI: https://doi.org/10.14256/JCE.1799.2016

Građevinar 10/2017

Primljen / Received: 5.8.2016.
Ispravljen / Corrected: 24.1.2017.
Prihvaćen / Accepted: 28.1.2017.
Dostupno online / Available online: 10.11.2017.

Experimental and numerical analysis of ferrocement RC composite

Authors:

Assoc.Prof. **Sridevi Kumarasamy**, PhD. CE
United Institute of Technology
Coimbatore, India
srisudhahar@gmail.com

A. Sudhahar, PhD. CE
DIMENSIONS, Structural Consultant
Coimbatore, India
constructeasy@yahoo.com

Prof. **D.L. Venkatesh Babu**, PhD. CE
JSS Academy of Technical Education, India
drdlvbabu@gmail.com

Prof. **R. Venatasubramani**, PhD. CE
DSD - Dr. Mahalingam College of Engineering
and Technology, India
rvs_vlb@yahoo.com

Preliminary note

Sridevi Kumarasamy, A. Sudhahar, D.L. Venkatesh Babu, R. Venatasubramani

Experimental and numerical analysis of ferrocement RC composite

The investigation of flexural behaviour of ferrocement elements that are used as permanent formwork in conventional reinforced concrete members is presented in the paper. Individual ferrocement panels are tested under two-point and midpoint load, and the load-deflection behaviour is then studied. The ferrocement panels are provided with shear connectors to investigate interaction between ferrocement and conventional RC members. The experimental results are compared with those obtained through finite element models using the ANSYS software, and a good correspondence of these results was established.

Key words:
ferrocement, composite action, tensile strength, ductility, shear connector

Prethodno priopćenje

Sridevi Kumarasamy, A. Sudhahar, D.L. Venkatesh Babu, R. Venatasubramani

Eksperimentalna i numerička analiza ferocementnog ab kompozita

U radu je prikazano ispitivanje savojne čvrstoće ferocementnih elemenata koji se u tradicionalnim ab elementima koriste kao trajna oplata. Pojedinačni ferocementni paneli ispitani su nanošenjem opterećenja u dvije točke i u sredini te je nakon toga određena njihova otpornost. Kako bi se ispitalo međudjelovanje ferocementnih i tradicionalnih ab elemenata, ferocementnim panelima dodani su moždanici. Eksperimentalni rezultati uspoređeni su s rezultatima proračuna pomoću programa ANSYS te je dobiveno dobro podudaranje rezultata.

Ključne riječi:
ferocement, kompozitno djelovanje, vlačna čvrstoća, duktilnost, moždanik

Vorherige Mitteilung

Sridevi Kumarasamy, A. Sudhahar, D.L. Venkatesh Babu, R. Venatasubramani

Experimentelle und numerische Analyse von Ferrozement- und Stahlbetonverbundwerkstoffen

In der Arbeit wird die Untersuchung der Biegefestigkeit von Ferrozementelementen dargestellt, die in gewöhnlichen Stahlbetonelementen als dauerhafte Verschalung verwendet werden. Einzelne Ferrozementpaneele wurden durch Belastung in zwei Punkten und in der Mitte untersucht, wonach ihre Beständigkeit bestimmt wurde. Um die Interaktion von Ferrozementelementen und traditionellen Stahlbetonelementen zu prüfen, wurden den Ferrozementpaneelen Dübel hinzugefügt. Die experimentellen Ergebnisse wurden anhand des Programms ANSYS mit den Bemessungsergebnissen verglichen und es wurde eine gute Übereinstimmung der Ergebnisse festgestellt.

Schlüsselwörter:
Ferrozement, Verbundwirkung, Zugfestigkeit, Duktilität, Dübel

1. Introduction

The present scenario of rapid development of building infrastructure in India places emphasis on cost effective systems with the focus on the speed of construction and structural soundness. The revised earthquake zones map of India requires most of the building infrastructure to have an appropriate ductility and robustness. The present development in infrastructure gives major importance to the affordable housing projects, which are usually low rise structures.

Ferrocement is a type of thin-wall reinforcement concrete commonly made of hydraulic cement mortar, reinforced with closely spaced relatively small diameter mesh in layers [1, 2]. The use of ferrocement as a building element in India has been restricted to either low cost applications or it is used as a structurally non-participating building element. The use of ferrocement as permanent formwork for regular RC elements helps in achieving a required ductility and robustness of structures, and aids fast track constructions [3-5]. Permanent ferrocement formworks [6-8] also exhibit partial to complete structural interaction with regular RC members and hence improve their efficiency in terms of earthquake resistance and serviceability.

Ferrocement is a composite material that exhibits non linear behaviour because of its material characteristics and the complexity of bond between wire mesh and concrete. In the last 25 years several approaches have been used for the analysis of ferrocement structures. The first use of the finite element technique to analyse ferrocement slabs using rectangular heterosis elements [9, 10] was made with a computational model based on the Timoshenko beam finite element formulation using quadratic isoparametric elements with three degrees of freedom. The analysis of flanged ferrocement beams [11] using ANSYS software with an eight-node solid isoparametric element to study the composite action between ferrocement slabs and steel sheeting was presented by earlier researchers. The validity and calibration of theoretical formulations and the program used was judged through comparison of analytical results with available experimental data. Although the need for experimental research to provide the basis for design equations continues, the development of powerful and reliable analytical techniques, such as the finite element method, reduces the time and cost of expensive experimental tests, and may better simulate the loading and support conditions of the actual structure. However, accurate finite element analysis results require adequate modelling of the actual behaviour of the materials, including nonlinearity. Ferrocement exhibits nonlinearity because of cracking, inelastic material behaviour, stiffening and softening phenomena, complexity of bond between wire mesh and concrete, and other factors.

Various investigations on ferrocement indicate that the use of ferrocement in conventional reinforced concrete members has improved its structural capacity. The present investigation is based on the preparation of a small scale ferrocement panel model to check the viability of its use as a replacement for formwork shutter in conventional RC slabs at the tension side cover zone.

2. Methodology

A good quality mortar or concrete is achieved by selecting good quality cementitious materials, aggregate, paste proportion, aggregate paste interaction, admixture type, dosage, and by taking meticulous care in mixing and handling. In any structural element, mechanical characteristics and durability are a major parameter in the design that can be obtained by proper selection of ingredients. Since ferrocement is a very thin element, corrosion may be a major cause of lower durability performance. To obtain a good quality ferrocement, materials must be selected taking

Table 1. Material properties

Material description	Properties	Characteristic values
Cement	Specific gravity	3.12
	Type	Portland Pozzolana Cement (PPC)
Fine aggregate	Specific gravity	2.56
	Fineness modulus	2.51
	Size	Passing through 2.36 mm sieve
Coarse aggregate	Specific gravity	2.71
	Maximum Size	20 mm
Wire mesh	Size	2 mm diameter, 12.5 mm x 12.5 mm square opening
	Yield strength	390 N/mm^2
Mix proportion for mortar	1:3, w/c ratio = 0.45	
M20 Concrete mix proportion	1:1.49:3.36 with w/c ratio = 0.5	

into account their physical and mechanical characteristics. To ensure better packing density and avoidance of voids due to interference of mesh and larger particles, fine aggregate passing through the 2.36 mm sieve is used in the preparation of mortar.

2.1.1. Mortar

Ferrocement mortar was prepared using the 1:3 mix proportion with the 0.45 water cement ratio. Portland Pozzolana Cement conforming to IS:1489 -1 (1991) was used, and river sand, with specifications as per IS 2386- Part 1& 3 (1963), conforming to zone III as shown in Table 1, was used.

2.1.2. Concrete

Using IS:10262 (2009) mix design procedure, M20 concrete was designed and the mix proportion of 1:1.49:3.36 with water cement ratio 0.5 was used. Well graded coarse aggregate with maximum normal grain size of 20mm was selected, with specifications as shown in Table 1. The 20 mm normal size of coarse aggregate was selected so as to make a reasonable comparison with conventional slabs.

2.1.3. Reinforcement

Reinforcing bars were tested in the universal testing machine under tension as per IS 1608:2005. The tensile strength testing of 8mm diameter bars for RC panel provided a yield strength of 388 N/mm^2. The 2 mm weld mesh with 12.5 mm x 12.5 mm square opening, and with the yield strength of 390 N/mm^2, was used.

2.2. Specimen preparation

The ferrocement panel measuring 330 mm x 200 mm, 24 mm in thickness, and Ferrocement RC composite panel measuring 330 mm x 200 mm x 1000 mm, 150 mm in overall thickness including the ferrocement panel, were cast. The percentage of reinforcement, span, w/c ratio and cuing period were kept identical for the conventional and composite systems. Ferrocement panels were cast with 2 bolt type shear connectors on top of each panel to enhance interaction between the ferrocement and the RC panel member. The main reinforcement of the RC composite was tied with shear connectors on the ferrocement panel using binding wires. The ferrocement and ferrocement RC composite panel details are shown in Figure 1, Figure 2, and Figure 3. Ferrocement panels were cast and water cured for three days. After that five ferrocement panels were arranged and main reinforcement was tied to shear connectors. M20 concrete was placed after roughing the surface and ferrocement RC composite panels were cured for 28 days using gunny bags and pond curing techniques.

Figure 1. Ferrocement panel

Figure 2. Arrangement of ferrocement panels for composite casting

Figure 3. Composite panel after RC element casting

2.3. Experimental setup

Ferrocement panels were tested under two point loading and midpoint loading using a universal testing machine, and deflections were measured using the 0.01 range 20 mm travel dial gauges. The Ferrocement RC composite panel was tested in the 50 kN loading frame with simply supported end condition as shown in Figure 4, with an effective span of 800 mm. The load was transmitted through the panel using a manually operated hydraulic jack. In addition, the real-time measurement of structural response was achieved using dial gauges at various points. The deflection measured by the dial gauge and load measured via the data logger were stored for further calculations. For monotonic loading, the load was applied in 5 kN load increments until the ultimate load was reached. At each increment of loading, the reading in dial gauge was noted.

Figure 4. Load setup: ferrocement RC composite panel

2.4. Finite element modelling using ANSYS

The finite element modelling was done using SOLID65 and link8 elements for concrete and reinforcing steel. SOLID65 element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions, used for the three-dimensional modelling of solids with or without reinforcing bars. The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modelling reinforcement behaviour. A schematic of the element is shown in Figure 5 [12]. A Link8 element is used in a variety of engineering applications to model a truss element, a cable element, and steel reinforcement. The three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. The plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included. CONTA174 3-D 8-node element is used to represent the contact and sliding between 3-D surface and deformable surfaces. TARGE170 is an associated element that represents various 3-D "target" surfaces elements like CONTA173, CONTA174, CONTA175, CONTA176, and CONTA177. The contact elements themselves overlay the solid, shell, or line elements describing the boundary of a deformable body, and are potentially in contact with the target surface, defined by TARGE170. This target surface is discretized by a set of target segment elements (TARGE170) and is paired with its associated contact surface via a shared real constant set. Translational or rotational displacement, forces and moments, temperature, voltage, and magnetic potential can be imposed on the target segment element. Material description for the FEM is given and the meshed Ferrocement panel model is shown in Figure 6. Table 2 lists material characteristics used for modelling. The maximum size of meshing element used was 20mm. A total of 4030 elements with 19315 nodes were used for the composite model. The finite element model was developed by providing the weldmesh element in the Ferrocement mortar and developing it to the concrete infill on a shear connector. The numerical model loading was applied incrementally.

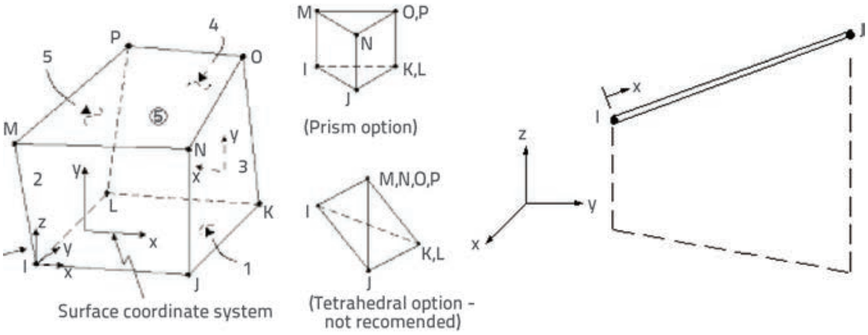

Figure 5. Elements used for Finite element modelling (SOLID65 Element & Link 8 Element)

Table 2. Material Properties (adopted for numerical modelling)

Property	Concrete	mortar	weld mesh
Compressive strength [N/mm^2] (experimental data)	24.03	29.01	2 mm diameter 12.5 mm · 12.5 mm
Young's modulus (E) [N/mm^2] (theoretical data)	24510	20000	$1.3 \cdot 10^5$ N/mm^2
Poisson's ratio μ (theoretical data)	0.2	0.11	0.3
Density [kg/m^3] (theoretical data)	2400	2080	7850
Thermal coefficient αm	$1 \cdot 10^{-5}$ / °K	$1.2 \cdot 10^{-5}$ / °K	$12 \cdot 10^{-6}$ °C
Yield tensile strength [N/mm^2] (experimental data)	-	-	
Tensile strength [N/mm^2] (experimental data)	3.13	2	390 (Yield)
Strain (Crushing)	0.0035	0.003	

TARGE170 and CONTA174 3-D 8 node elements were used as contact elements between the weld mesh, mortar and concrete.

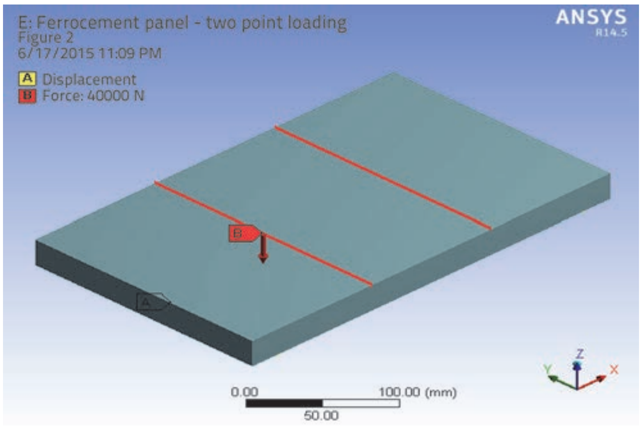

Figure 6. Ferrocement model with loading

3. Results and discussion

3.1. Compressive strength

Compressive strength values for mortar and concrete were tested as per IS: 516 – 1964 and IS: 2250 – 1981, respectively. Six concrete cubes measuring 150 mm x 150 mm x 150 mm, and six mortar cubes measuring 70.6 mm x 70.6 mm x 70.6 mm, were cast to check the compressive strength at 7 days and 28 days. Compressive strengths tests were conducted on cube specimens using the compressive strength testing machine 100 tonnes in capacity. Average compressive strengths values are listed in Table 3.

3.2. Ferrocement panel

Ferrocement panels were tested under flexure and the load deflection results were compared in ANSYS 14.5. The ultimate flexural strength of ferrocement panel under two point and midpoint loading amounted to 9.42 N/mm^2 and 6.89 N/mm^2, respectively. In all the cases, the failure state only depicted cracking and release of load. No delamination or separation of wire mesh was observed. Results shown in Figure 7 and Figure 8 indicate non linear behaviour of ferrocement elements.

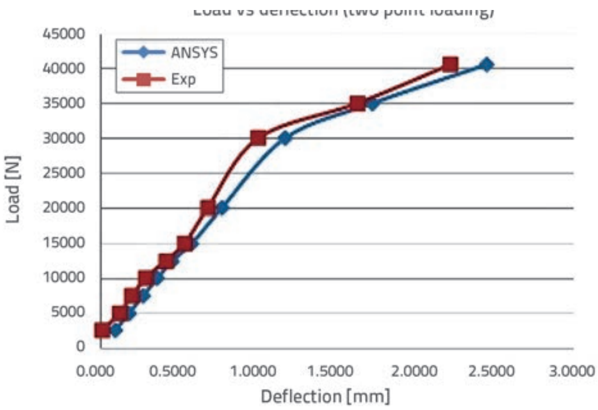

Figure 7. Load vs deflection under two point loading

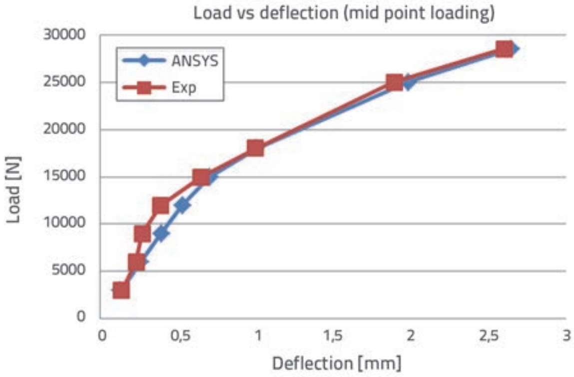

Figure 8. Load vs deflection under mid point loading

3.3. Ferrocement RC composite

The ferrocement RC composite panel 1000 mm in length was simply supported with two rollers at a distance of 100 mm from the edges, with a clear span of 800mm, and was placed in the loading frame. A multi-dial Indicator (range 0.01 – 20 mm) was used for deflection measurements. The specimen was then subjected to gradual loading by operating the lever of hydraulic jack at suitable intervals, and the deflectometers readings were

Table 3. Compressive strength of mortar and concrete

Specimen identification	Mortar compressive strength [N/mm^2]		Specimen identification	Concrete compressive strength [N/mm^2]	
	7 days	28 days		7 days	28 days
M1 *	19.79	29.42	C1*	15.11	24
M2	19.56	29.50	C2	15.37	24.17
M3	18.50	28.56	C3	16.04	23.55
Average strength	19.28	29.16	Average strength	15.50	24.08
*M – mortar, *C – concrete					

noted for different load values. The formation of the first crack was carefully noted. The deflectometers were removed when the deflection was at the maximum capacity of the dial gauge or when the specimens were about to collapse. The failure pattern of the controlled Reinforced concrete and Ferrocement RC composite panel is shown in Figure 9. The loading was continued till collapse of the specimens. Load deflection values are shown in Figure 10.

Figure 9. Composite panel after failure

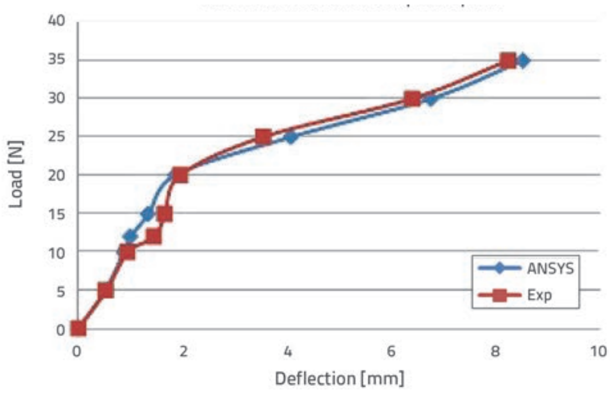

Figure 10. Load vs deflection under mid point loading

3.4. Numerical results

The variation between ANSYS and experimental results follows the same path without much difference. The loads near the ultimate points in the analysis using ANSYS have a slight increase in deflection, but the ductile plateau continues to be the same until the loading point. The total deformation variation of ferrocement panel under flexure loading is shown in Figure 11 and Figure 12.

4. Conclusion

The flexural strength of ferrocement RC composite panels was slightly higher compared to conventional RC beam. Although the flexural capacity improved, the first crack was developed near the second ferrocement panel, which was placed at the bottom. After the elastic curve and the first crack formation, an opening developed in between the ferrocement panels. This type of failure may be due to the lack of horizontal connection between the ferrocement panels. Though the flexural crack progressed and the width of the opening increased, it followed a clear ductile plateau with 10 % increase in ultimate flexural capacity. After a point of time, both conventional RC and Ferrocement RC composite panels behaved in the same manner. The ultimate capacity of the composite panels may be improved by providing a horizontal connection between individual ferrocement panels. Further research will be required to investigate the use of ferrocement cover for other applications, especially the use of deep covers, usually advocated in corrosive conditions, without giving rise to wide surface cracks.

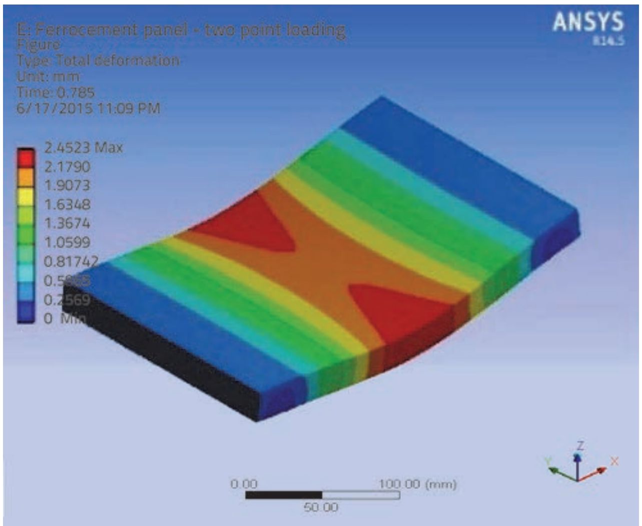

Figure 11. Total deformation under two point loading

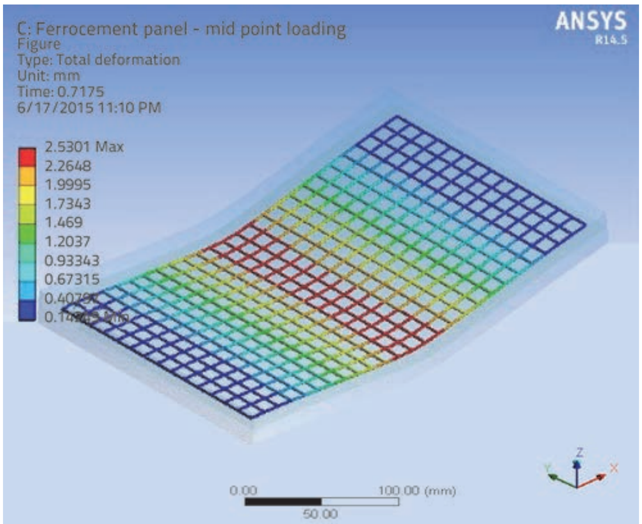

Figure 12. Total deformation under mid point loading

REFERENCES

[1] ACI Committee 549-1R-93, Guide for the Design, Construction, and Repair of Ferrocement, Manual of Concrete Practice, Farmington Hill, Michigan, USA. 27 pages, 2009.

[2] Naaman, A.E., Shah, S.P.: Tensile test of ferrocement, Journal of American concrete institute, September, pp. 693-698, 1971.

[3] Md. Zakaria Hossain, Md. Rokonuzzaman, Sohji Inoue.: Flexural Behaviour of Cement Composites Panels Reinforced With Different Types Of Meshes, 30th Conference On Our World In Concrete & Structures, MIE University, Japan, pp. 23 – 24, 2005.

[4] Parande, P.S., Gaidhankar, D.G.: Behaviour of ferrocement composite in direct tension by using welded square mesh, International Journal Of Research In Advent Technology, 2 (2014) 7, pp. 2321-9637.

[5] Phalke, R., Gaidhankar, D.G.: Flexural Behaviour of Ferrocement Slab panels using welded square mesh by incorporating steel fibers, International Journal Of Research In Advent Technology, pp. 756-763, 2014.

[6] Kadir, M.R.A., Saleh, J.M.Hj.: Ferrocement in Situ Permanent Formwork, Journal of Ferrocement, 23 (1993) 2, pp. 125-133.

[7] Barnes, R.A., Mays, G.C.: Strengthening of reinforced concrete beams in shear by the use of externally bonded steel plates: Part 1–Experimental programme, Construction and Building Materials, 20 (2006) 6, pp. 396-402, https://doi.org/10.1016/j.conbuildmat.2005.01.034

[8] Kadir, M.R.A., Samad, A.A.A., Muda, Z.C.H.E., Ali, A.A.A.: Flexural Behaviour of Composite Beam with ferrocement Permanent Formwork, Journal of Ferrocement, 27 (1997), pp. 209 – 214.

[9] Prakhya, K.V.G., Adidam, S.R.: Finite Element Analysis of Ferrocement Plates, Journal of Ferrocement, 17 (1998), pp. 313-320.

[10] Bin-Omar, A.R., Abdel-Rahman, H.H., Al-Sulaimani, G.J.: Nonlinear Finite Element Analysis of Flanged Ferrocement Beams, Computers & Structures, 31 (1989) 4, pp. 581-590, https://doi.org/10.1016/0045-7949(89)90335-0

[11] Boshra, A.A., El-Shafey, A., El-Shami, M.: Experimental and Analytical Model of Ferrocement Slabs, International Journal of Recent Trends in Engineering, 1 (2009) 6, , pp. 25-29.

[12] http://148.204.81.206/Ansys/readme.html