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Numerical Analysis of Strengthening R.C Slabs with Opening using Ferrocement Laminates

Mahmoud Elsayed
Assistant Professor,
Civil Engineering Department, Faculty of Engineering
Fayoum University
Fayoum, Egypt

***Abstract*—in this paper the structural behavior of reinforced concrete slab with a centered square opening strengthened with ferrocement laminates were investigated with nonlinear finite element analysis. The 3-dimensional feature available in the commercial analysis package ANSYS was used to model the specimens. The model accommodates the material non-linearities cracking and crushing of concrete and yielding of steel. Verification of study was calibrated with strengthened and unstrengthened numerical model by available experimental data. The studied parameters were; thickness of ferrocement layer, percentage of expanded wire mesh reinforcement in the ferrocement cover layer, compressive strength of mortar. Based on the results and observations of the numerical investigations presented in this research regarding the effectiveness of ferrocement laminates in strengthening slab with opening, it can be seen that ferrocement laminates can be successfully used for increasing the ultimate carrying capacity, strength, and energy absorption. The results showed that use of ferrocement enable the slabs to restore its full load capacity and increased its ultimate load carrying capacity up to 2 times.**

Keywords— Ferrocement, R.C. slab, Opening, Finite Element and strengthening.

I. INTRODUCTION

Reinforced concrete (RC) solid slab are quite common structural systems, and has been widely used for the multi-story building. Openings in floor slabs of buildings are required for many purposes like stairs, air conditioning ducts and elevators. Introducing openings in slabs can severely weaken the slabs due to the cut-out of both concrete and reinforcing steel. Several strengthening techniques have been developed in the past and used with some popularity including steel plate bonding, and non-corrosive innovative strengthening systems, such as fiber-reinforced polymers (FRPs), that have the potential for extending service lives of RC structures and reducing maintenance costs, are required to replace old strengthening systems. Ferrocement is one of the strengthening techniques, which is widely used in the last years to increase the structural capacity of the structural members or in case of damaged slabs, to restore the original capacity of the section. Hence, the aim of this study was to investigate the effect of using ferrocement laminates strengthening alternatives to restore the flexural capacity of the RC slabs with cut out at middle. The ferrocement laminates was externally bonded to the tension face of the slabs to strengthen reinforced concrete slabs with cut-out against flexural failure. Strengthening by ferrocement laminates is a popular method due to its availability, cheapness, and easy to work.

II. FINITE ELEMENT ANALYSIS

A. Finite Element Modeling

The general-purpose finite element program ANSYS is used in the present study to investigate the flexural behavior of strengthened RC slabs with opening previously studied experimentally. An extensive use of the finite element method for the numerical modelling for all R.C. slabs with cut-out. The three-dimensional, eight-node solid element (SOLID65), available in the ANSYS library, was used to model both concrete and ferrocement mortar. SOLID65 element is an eight-node solid element used to model the concrete with or without reinforcing bars, as shown in Figure 1. The element has capability to model the concrete while the rebar capability is available for modelling the reinforcement behavior. The solid element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The most important feature of this element is that it can represent both linear and nonlinear behavior of concert. The rebar reinforcement feature of this element was used to model the mesh reinforcement of ferrocement while 2-noded element was used to model the descrete steel bars used to reinforce the original specimens. The reinforcing steel bars were adopted using (LINK8) element.

B. Numerical Modeling of Slab

The test specimens were simply supported along the four edges. The dimensions of slab specimens were 1000x800x100 mm with (200*200 mm) square central opening. Each slab was reinforced with Φ10 @200mm in two directions, to simulate the actual case in nature all slabs has no additional reinforcement along the opening sides. A displacement control incremental loading was applied at four symmetrical points at 200 mm from corner of opening in two directions. Small initial load steps were used for detecting the first crack in the connections. Then, automatic time stepping (deltim=0.01) was used to control the load step.

C. Boundary Conditions

In this study, making advantage of the symmetry in geometry and loading, the simulated model is constructed in the form of one quarter of the slabs due to the two axes of symmetry (500*400*100 mm). Thus, the boundary condition of these two edges is defined as the symmetry of displacement, which is shown in Figure 2. Because the specimens are simply supported on four edges that are free to lift during the tests, the proper simulation of the boundary condition as taken into account.

D. Finite Element Discretization

After constructed a model with volumes, areas, lines and key points, a finite element analysis requires meshing of the model. The model is then divided into a number of small elements, and after loading, stress and strain are calculated at integration points of these small elements. In the current study, the dimensions of the finite element meshing are 50x50 mm and thicknesses are 15-85mm; respectively. This means that the slab thickness was divided into two layers, but the thickness of ferrocement laminate layer is divided into only one layer as shown in Figure 3.

III. MATERIALS MODELING

A. Concrete

Material properties of the concrete and mortar used for the model are modeled using the concrete smeared cracking model available in ANSYS program. For good correlation with experimental results, the plastic material properties of the concrete were assigned according to the results from the experimental test. Table I summary ANSYS requires input data for material properties of Solid65 element.

B. steel reinforcement

A 3-D link element (ANSYS-Link 8) is used to model the steel reinforcement. The finite element model for steel-bar was assumed to be elastic-perfectly plastic material and identical in tension and compression. The properties used to define this model are the elastic modules Es, yield strength fy, and Poisson's ratio υ. These parameters are listed in Table II.

C. Steel Wire-Meshes (Ferrocement Reinforcement)

In this study, expanded wire mesh (diamond) of 0.8 mm diameter and 40 mm x 15 mm wire spacing were used as ferrocement reinforcement, and arranged in different layer. The 3-D model element Solid 65 was used to model ferrocement. The rebar reinforcement feature of this element was used to model the mesh reinforcement of ferrocement. Table III shows properties of steel wire mesh.

TABLE I. CONCRETE PROPERTIES

Elastic modulus	Ec =$4700\sqrt{fc`}$ N/mm2
Poisson's ratio	υc = 0.2
Compressive Strength of concrete	(fc`) = 25 N/mm^2
Ultimate tensile strength (modulus of rupture)	ft = 2.85 N/mm^2
Shear transfer coefficient for an open crack	ßt; varied between 0.05 and 0.25
Shear transfer coefficient for a closed crack	ßc; widely within 0.8 to 1.0 therefore, taken 0.8 in this study

TABLE II. PROPERTIES OF STEEL REINFORCEMENT

Elastic modulus	Es =$2.1x10^5$ N/mm2
Bar diameter	Φ =10 mm
Poisson's ratio	υ = 0.3
yield strength,	fy = 420 MPa

TABLE III. MECHANICAL PROPERTIES OF STEEL WIRE MESH

Elastic modulus	Es =$1.38x10^5$ Mpa
Poisson's ratio	υ = 0.3
yield strength,	fy =290 MPa
Ultimate strength,	fu= 425 MPa

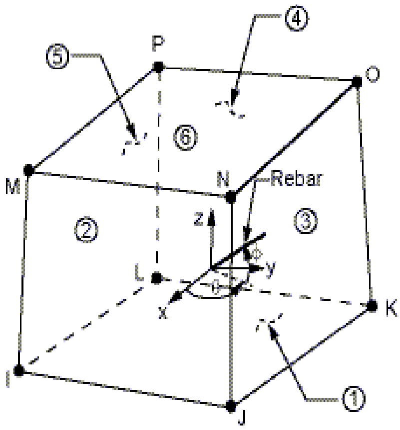


Figure 1 SOLID65 3-D reinforced concrete solid

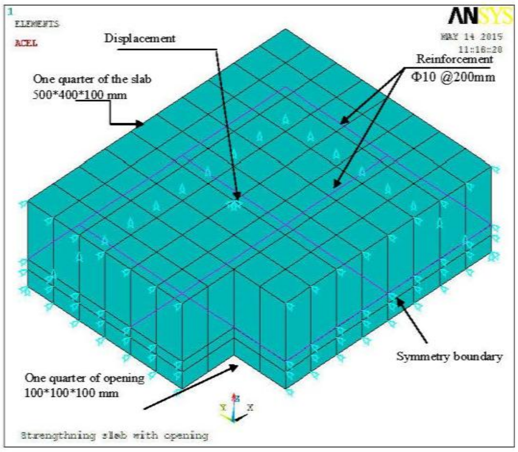
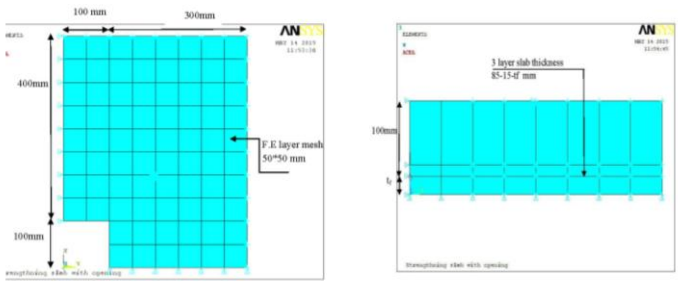


Figure 2 ANSYS numerical model



a) Top View b) Side view

Figure 3 Numerical model of strengthened slab

IV. PARAMETRIC STUDY

The analysis of using ANSYS program was developed to the four main groups and control slab, each group consists of four specimens. A total of 17 models were analyzed to investigate the efficiency of using ferrocement laminates for strengthening reinforced concrete slabs with opening. In this study three parameters were investigated; thickness of ferrocement laminates, volume fraction of reinforcement, and compressive strength of mortar matrix. The calculation only changes one parameter while keeping other parameters unchanged. Details of the numerical parameters and description of strengthened model is given in table IV.

TABLE IV. DESCRIPTION OF STRENGTHENED MODEL

Group	model	T_f (mm)	Vf %	fcu (MPa)
Control	S0	--	--	---
Group 1	S1	20	1.5	25
	S2	25	1.5	25
	S3	30	1.5	25
	S4	35	1.5	25
Group 2	S5	20	2.25	25
	S6	25	2.25	25
	S7	30	2.25	25
	S8	35	2.25	25
Group 3	S9	20	1.5	35
	S10	25	1.5	35
	S11	30	1.5	35
	S12	35	1.5	35
Group 4	S13	20	2.25	35
	S14	25	2.25	35
	S15	30	2.25	35
	S16	35	2.25	35

V. RESULTS AND DISCUSSION

A. Load deflection behavior

Figures 4 to 7 show a comparison between the load- deflection curves for all specimen groups. In general, all slabs failed under pure bending. On analyzing the graphs, it was found that all the strengthened specimens had higher ultimate loads than the control specimen with cut-out. From load deflection curve it can be seen that, the ultimate strength is significantly affected by increasing the thickness of ferrocement laminate, and not only restoring the original ultimate loads of strengthening slabs without opening but also caused to increase its ultimate strength. The results showed that increasing thickness of ferrocement layer and compressive strength of mortar causes a decrease in deflection values and increase in ultimate load capacity and exhibited a better performance. And it can be noticed that the Increase of wire mesh layers did not significantly reduce the total deflection and the deflection increase due to the increase of ultimate load but it was still less than the deflection at ultimate load in control slab.

Figures 8 and 9 represented the ultimate loads for all strengthened models due to change volume fraction of reinforming. It can be realized that all strengthened models had a higher ultimate loads than the control specimens. It was found that the increasing of percent of volume fraction from 1.5 to 2.25 for strengthened groups resulted in increasing the percentage of gain in ultimate capacity to 8 %.

B. Stiffness and Energy absorbation

Stiffness, ductility and energy absorption are calculated and tabulated in table V. Stiffness of all specimens was computed as the ratio between maximum failure load to corresponding deflection (at the ultimate load), while the strain energy was calculated as the area under load deflection curve up to the peak (ultimate load). It can be realized that the post-cracking stiffness increase as the compressive strength of mortar increased. From the results in Table V, all strengthened slabs have shown big values of stiffness than the reference slab with cut out, this lead to less ductile behavior has occurred due to Strengthening by ferrocement laminates. It is clear from the results summarized in table V that, energy increase has no significantly change with increase the percentage of steel wire mesh.

TABLE V. RESULTS OF SLAB SPECIMENS

Specimens	Ultimate Load Pu (kN)	Ultimate Deflection δu (mm)	$\frac{Pu}{Pucontrol}$ %	Stiffness (kN/mm)	Energy absorption (kN.mm)
Sc	110	19.4	100	5.67	1633
S1	181	18.9	165	9.58	2538
S2	187	17.2	170	10.87	2535
S3	206	18.1	187	11.38	2801
S4	217	18.7	197	11.60	3245
S5	186	16.92	169	10.99	2387
S6	193	17.6	175	10.97	2576
S7	209	17.9	190	11.67	2847
S8	219	18.1	199	12.1	3065
S9	194	17.9	176	10.84	2483
S10	205	15.83	186	12.95	2364
S11	227	14.99	206	15.14	2513
S12	236	14.94	215	15.80	2505
S13	210	16.07	191	13.07	2536
S14	212	15.31	193	13.85	2757
S15	229	13.45	208	17.03	2313
S16	245	14.11	223	17.38	2567

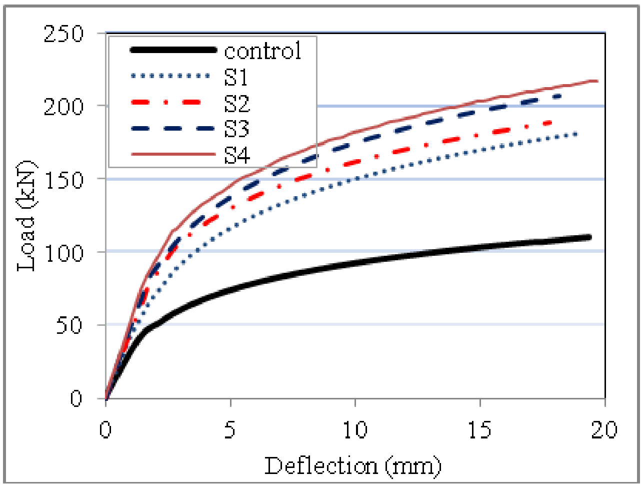


Figure 4 Load –deflection curves for group 1

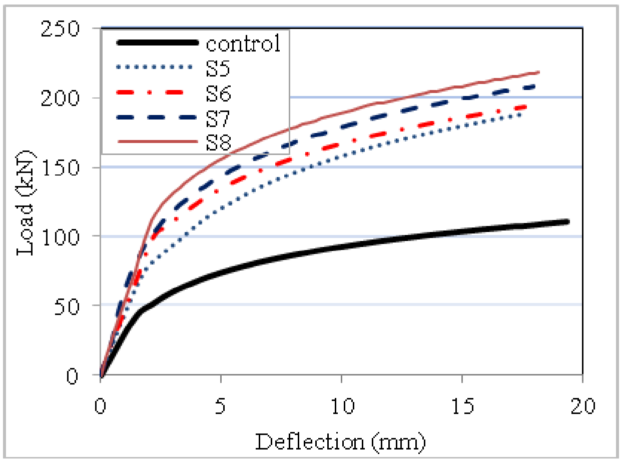


Figure 5 Load –deflection curves for group 2

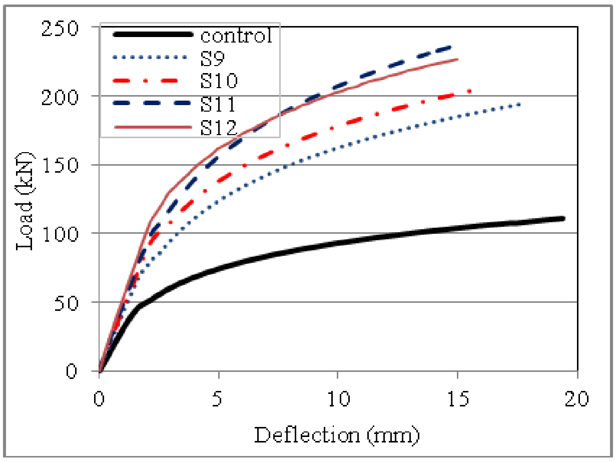


Figure 6 Load –deflection curves for group 3

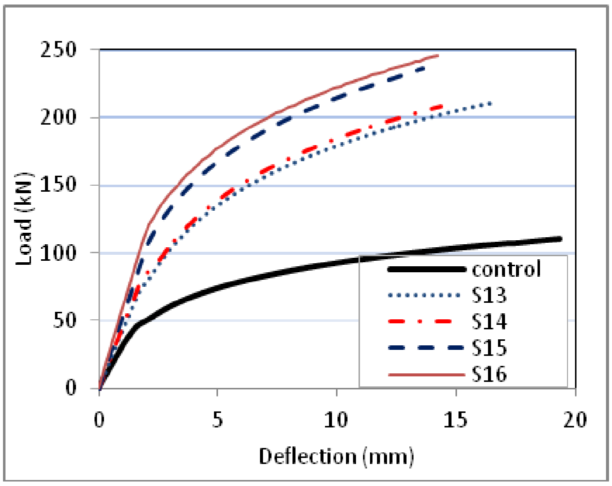


Figure 7 Load –deflection curves for group 4

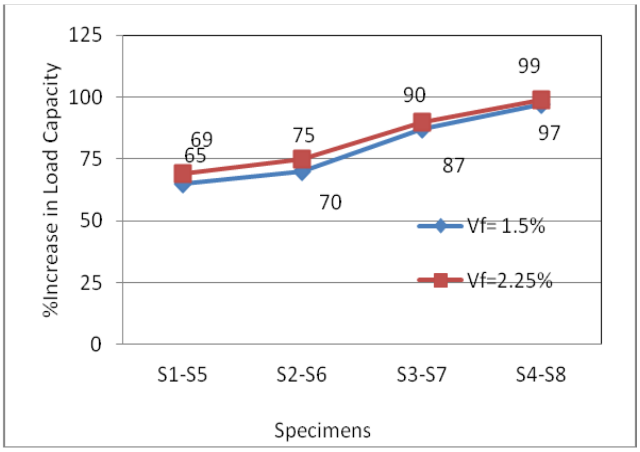


Figure 8 Gain percent in Load with variable steel wire mesh for group 1and 2

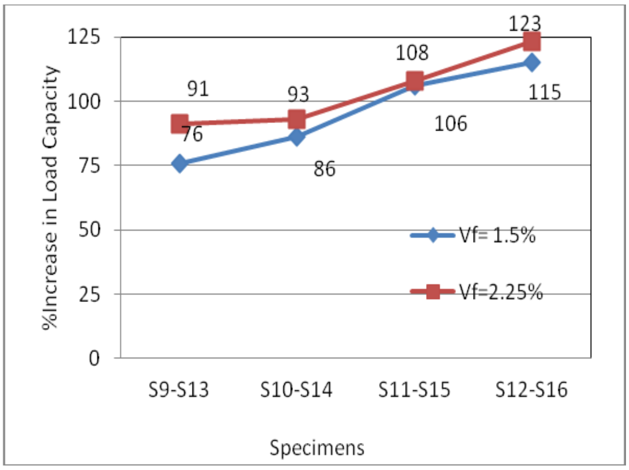


Figure 9 Gain percent in Load with variable steel wire mesh for group 3and 4

VI. CONCLUSIONS

A computer program (ANSYS) suitable for nonlinear analysis of three dimensional reinforced concrete members under monotonic increasing loads has been used to simulate the behavior of slabs with opening strengthened with ferrocement laminates. The following conclusions may be drawn from the present research:

1) Nonlinear finite element method based on 3D models created by ANSYS is a powerful and relatively economical tool which can be effectively used to simulate the real behavior of strengthened reinforced concrete slabs.
2) In general, it can be seen that, the ferrocement laminate can be successfully used for increasing ultimate load of slab with opening.
3) Using ferrocement laminate to strengthen RC slabs with opening is simple and easy to install, and it effectively improves the overall properties of these members.
4) All specimens failed under pure bending. The strengthened slabs experienced higher ultimate load compared with the control slab. The increase in ultimate load was up to 220% with respect to control specimen with opening.
5) The ferrocement thickness has a great influence on the amount of gain in ultimate punching capacity, stiffness, and energy absorption.
6) The strengthened specimens exhibit much stiffer responses and lower deflections than the corresponding unstrengthened (control) specimens.
7) RC slabs strengthened with ferrocement laminate exhibited more stiffness and lesser ductility than the non strengthened one. The greater thickness, the more stiff of the slab against excessive deflection.
8) Parametric study showed, increasing the compressive strength of mortar matrix (from 25 to 35 Mpa) caused remarkable growth in both stiffness and ultimate capacity of slabs and decrease in deflection.

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