Experimental and Theoretical Behavior of Reinforced Concrete One Way Slabs Strengthened by Ferrocement Cover at Tension Face

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Abstract:

This paper presents a study of the flexural behavior of strengthened reinforced concrete one slabs by ferrocement cover in tension. This study included testing 14 simply supported one way slabs, which include 3 control slabs,11 strengthened slabs. In the strengthened slabs, the effect of the using ferrocement cover on the specimens of avairable depth, the thickness of ferrocement cover, number of wire mesh layers on ferrocement and the compressive strength for mortar on the ultimate load, mid span deflection at ultimate load and cracks pattern were discussed. All reinforced concrete slab specimens were designed of dimensions (1800mm*300mm) with (70-100mm) thickness and reinforced identically to fail in flexure. All slabs have been tested in simply supported conditions subjected to two point loads. The experimental results show that the ultimate loads are increased by about (4.1-15.3%) for the slabs strengthened with ferrocement with respect to the unstrengthened reinforced concrete slab (control slab). Three-dimensional nonlinear finite element analysis has been used to conduct the analytical investigation, ANSYS (Version 14.0) computer program was used in this study. The analytical result from modeling in ANSYS program exhibited a good agreement with experimental results.

Keywords: Concrete, ferrocement, slab, strengthening.

الخلاصة

يتضمن البحث الحالي دراسة مقاومة الانثناء للبلاطات المقواة والمصلحة باستخدام طبقة الفيروسمنت في منطقه الشد تضمنت الدراسة تهيئة و فحص اربع عشر بلاطة، ثلاثه كبلاطة مرجعية واحدى عشر منها مقواة بالفيروسمنت، وبلاطة واحدة تم أخذهما كبلاطات مرجعية. إن المتغيرات التي تمت دراستها في عملية التقوية هي مدى فعالية الفيروسمنت في تقوية العينات ذات الاعماق المختلفة ، عدد طبقات المشبكات السلكية و مقاومة الانضغاط للفيرو سمنت على الحمل الأقصى والأود المقابل له بالإضافة إلى تأثيرها على انماط الشقوق.صممت جميع البلاطات الخرسانية المستخدمة في هذا البحث بالابعاد (1800*300 ملم)مع سمك(70-90ملم) وتم تسليحها بشكل يضمن فشلها بالانحناء. تم فحص جميع البلاطات في فضاء بسيط الاسناد وبتسليط نقطتين حمل . أظهرت النتائج العملية التي تم الحصول عليها من النتائج المختبرية أن عملية تقوية البلاطات الخرسانية باستخدام لفيروسمنت ادت الى زيادة في قيمة التحمل الاقصى للانحناء للبلاطات (Ultimate Loads) يصل مقدارها بين (4.1-15.3%) مقارنة بالبلاطات الخرسانية غير المقواة باستخدام لفيروسمنت. تم أستعمال التحليل اللاخطي بواسطة العناصر المحددة (Finite Elements) ثلاثية الأبعاد كوسيلة عددية للدراسة والتحري عن سلوك وتصرف هذه البلاطات باستخدام البرنامج (ANSYS الاصدار الرابع عشر). النتائج النظريه من البرنامج(ANSYS) اعطت نتائج جيده مع النتائج العملي .

كلمات مفتاحية: الخرسانة، الفيروسمنت، السقوف، التقوية.

1.Introduction

Sometimes there are structural components of reinforced concrete exposed to distress. Even before their periods of service through due to several reasons .Defects, failure and general distress in the structure could be the result of the structural diminution caused by falser design, poor workmanship or overloading of the structure. It could be due to impact of explosive loading during the construction or service life of the structures. Another source of damage could be the physical damage due to the misuse of the structure. Also individual member or integrated structural unit may be over stressed and may need elaborate strengthening measures. Moreover, structure may suffer deterioration of concrete as a result of inadequate cover to the reinforcement, presence of chloride or poor quality concrete.Fire damage may also weaken the structure as a whole as well as individual concrete member. A damaged or distressed structure can be repaired or renovated to a satisfactory level of performance at a reasonable cost by different methods.

In recent years repair and rehabilitation of existing structures have become one of the most challenging problem in Civil Engineering. Ferrocement is an ideal material for a rehabilitation and strengthening of the structure, because it improves crack resistance combined with high toughness, the ability to be cast in to any shape, rapid construction with no heavy machinery, small additional weight it imposes and low cost of construction (Rahman 2002).

2.Ferrocement

Ferrocement was invented by a Frenchman, Joseph Louis Lambot, in 1848. It was a form of reinforced concrete, and it was used for the first time in making boats. Since the 1940's its application in the civil engineering field has widened. In this regard the American Concrete Institute (ACI) Committee 549 put forward the definition of ferroccment as follows:

" Ferrocement is a type of thin wall reinforced concrete construction where usually a cement morter is reinforced with layers of continuous and relatively small diameter mesh. Mesh may be made of metallic or other material."**(**Naaman 2000).

3.Test Specimens

Fourteen simply supported slabs were tested .The specimens were rectangular with 300mm width ,(70-90)mm total depth and a total length of 1800 mm. Every reinforced concrete slab is reinforced with 4Ø10mm steel bar as a main reinforcement and 10Ø10mm steel bar as secondary reinforcement . Two support were placed at 50 mm from the slab edges, so the effective span of the slab was 1700mm.All specimens subjected to a two point loads and the five group were casted, (A-F) as follow:-

Group A (Control):

This group consisted of three specimens. These specimens (**SA1, SA2 and SA3**) with total thickness (70, 80 and 90mm) respectively, were the control specimens with normal concrete cover and test up to failure.

Group B (strengthened slabs SB1, SB2 and SB3)

This group consisted of three reinforced concrete slab strengthened with ferrocement cover. The purpose of this group is to investigate the effect of replacing normal concrete cover of each slab by ferrocement cover .For this purpose three specimens (**SB1,SB2 and SB3**) with a total thickness (70mm,80mm and 90mm) respectively in which the (20mm) of reinforced concrete slab replaced by ferrocement layer.

Group D (strengthened slabs SD1 and SD2)

This group consisted of two reinforced concrete slabs strengthened with ferrocement cover. The compressive strength of ferrocement (40MPa) and two layer of wire mesh for ferrocement were used .The purpose of this group is to investigate the effect of varing the thickness of ferrocement . For this purpose the specimens of this group (**SD1 and SD2**) with ferrocement thickness (30mm and 40mm) respectively**.**

Group E (strengthened slabs SE1, SE2, SE3 and SE4)

This group consisted of four reinforced concrete slabs strengthened with ferrocement cover (20mm) thickness and 40 Mpa compressive strength for ferrocement. This is to investigate the effect of varing the number of layers of wire mesh .For this purpose four specimens (**SE1,SE2,SE3 and SE4**) with (1,3,4 and 5) layers of wire mesh respectively.(Mohammed and Thanoon, 2013) used 4 layers of wire mesh in ferrocement thickness is 20mm

Group F (strengthened slabs SF1 and SF2)

This group consisted of two reinforced concrete slab strengthened with two layers of wire mesh and (20mm) thickness for ferrocement cover . The purpose of this group is to investigate the effect of varing the compressive strength of ferrocement (50MPa and 60MPa) for specimens (**SF1 and SF2**) respectively. Table (1) & Fig.(1) shows all the details of specimen.

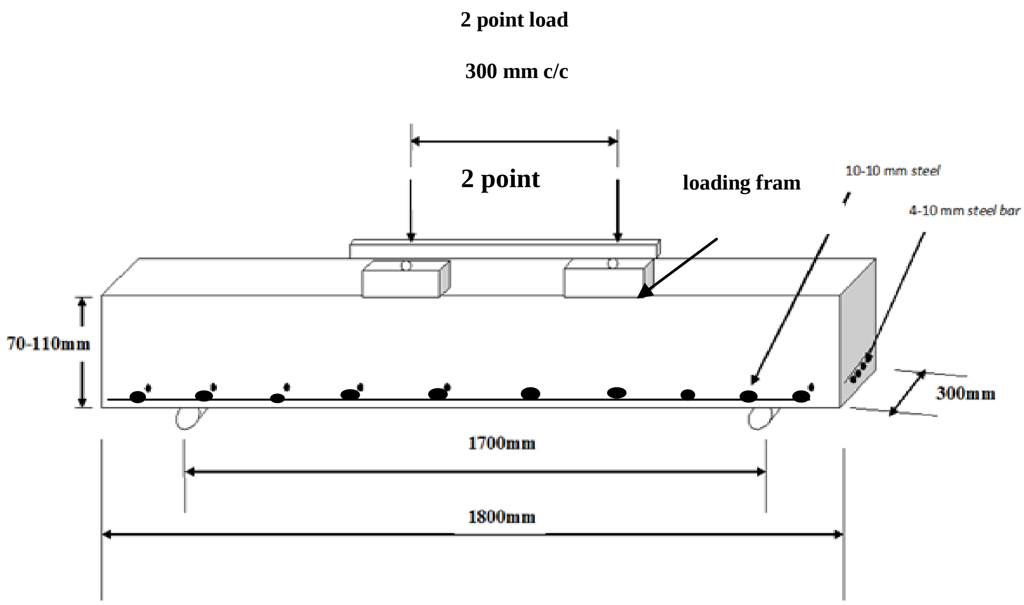
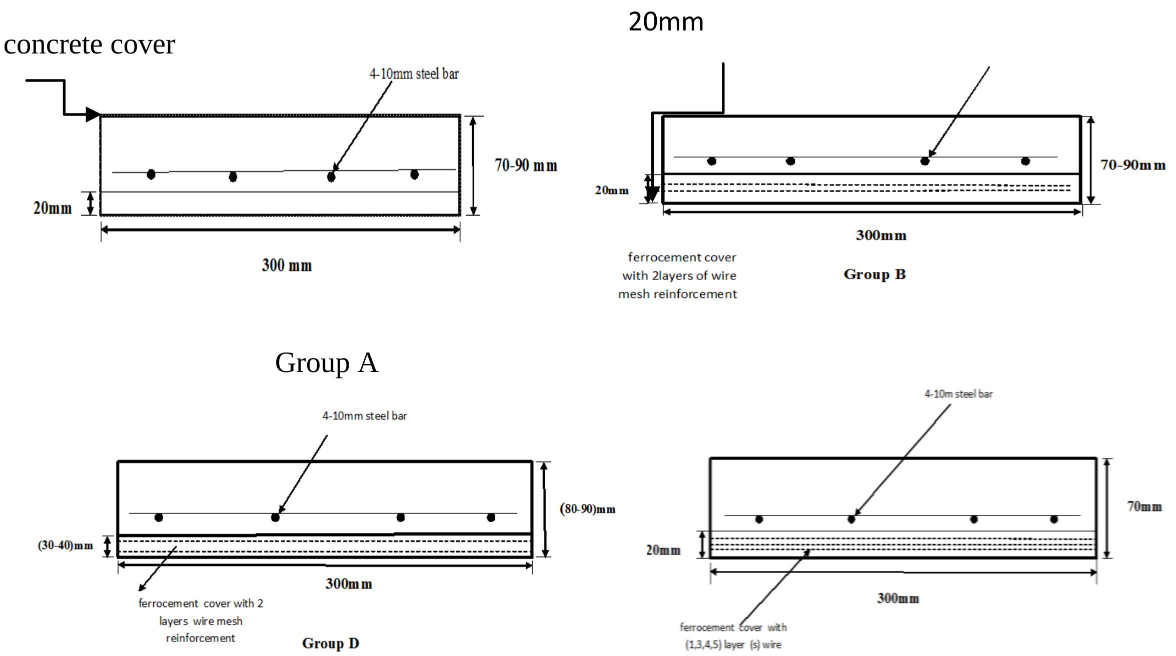


Figure (1-1): Geometry of Laboratory Specimens



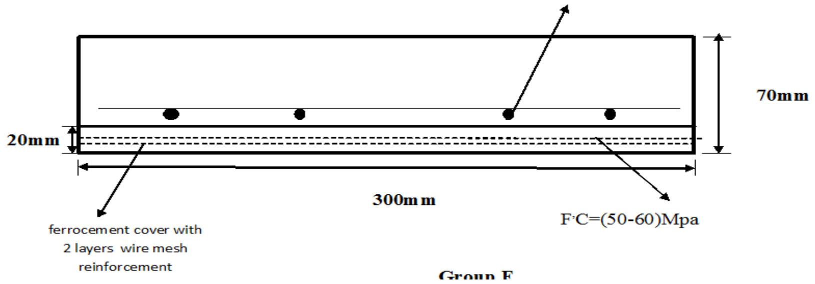


Figure (1-2) Continued

Figure: 1 Details of test specimens

Table 1: details of specimen

purpose	Group	No. of specimens	Ferrocement thickness (mm)	Total slab thickness (mm)	No. of wire mesh	Compressive strength of ferrocement mortar (MPa)
Control	A	SA1	-----	70	----	-----
		SA2	------	80	-----	-----
		SA3	------	90	----	-------
Strengthened	B	SB1	20	70	2	40
		SB2	20	80	2	40
		SB3	20	90	2	40
	D	SD1	30	80	2	40
		SD2	40	90	2	40
	E	SE1	20	70	1	40
		SE2	20	70	3	40
		SE3	20	70	4	40
		SE4	20	70	5	40
	F	SF1	20	70	2	50
		SF2	20	70	2	60

4.Materials

Maprok Portland cement satisfied the specification (IQS:5/1984)[3IQS (5)] (Table 2 and Table 3 contain the chemical and physical properties of cement respectively), natural sand and aggregate with the (10 mm) maximum aggregate size that satisfied the specification [ASTM C33-03](see Table 4 and Table 5)are used for the concrete (cement: sand: gravel/water) in the ratio of (1:1.94:2.94/0.46 by weight). The concrete mix was design to give 28-days cylinder strength of 25 MPa [ACI 211.2]. All slabs were reinforced with four (10mm diameter) tensile steel bars in longutindal direction and ten (10mm diammter) in transverse direction and with yield strength of 420 MPa. For ferrocement mortar (cement: sand /water, super plasticizer), Portland cement and natural sand [ACI Committee 549R-97] were used in the ratio of 1:2.2/0.4,1:2.2/0.35and 1:1.5/0.3by weight. This mortar gives 28-days strength of (40

MPa),(50MPa) and (60MPa) with the aid of using super plasticizer (Daracem SP3) with a dosage of (1.4% ,1.5% and 1.6% of cement weight). The ferrocement chicken wire of (0.6 mm) diameter was a galvanized welded square mesh of (12.5 mm) openings, the choice square mesh was related to many studies stated that the type of mesh with square opening is better than any other types of mesh [Alniaeeme2006]. The mesh tested according to the method described in reference (Naaman,2000) to get its yield strength and it was found to be 420 MPa.

5. Preparation of Test Specimen and Casting

The molds made of plywood were used for casting slabs specimens. For strengthened slabs the ferrocement cover was first placed at the bottom with the required layers of wire mesh followed by placing steel reinforcement on the top layers of the ferrocement and then concrete instantaneously placed (see Fig 2). With each specimen, three cylinders (150mm diameter and 300mm height) casted to fined compressive strength of concrete [BS-1881-116- 1983] and three (50×50×50mm) cubes casted to fined the compressive strength of mortar[ASTM C109-99], Table (6) includes the concrete compressive strength and mortar for all slabs. The specimens, were kept covered with wet sacks for 28-day. All of these tests are conducted in the structure laboratories for the college of engineering in Basrah University.

Table 2: Chemical properties of cement Iraqi specification number (5/1984) .

Composition of cement	(%)	Specification limit (IQS,5/1984)[23]
(CaO)	62.28	
(AL_2O_3)	5.5	
(SiO_2)	22.54	
(Fe_2O_3)	2.67	
(SO_3)	2.44	2.8%
(MgO)	3.24	5%
(L.O.I)	0.98	4.00 (Max.)
(I.R)	1.47	1.50 (Max.)
(L.S.F)	84	
compound of cement		
(C_3S)	38.51	31.03- 41.05
(C_2S)	33.65	28.61 – 37.9

Table 3: physical properties of cement Finesse Iraqi specification number

Physical property	Test results	Limit of I.Q.S No. 5/1984
Setting time (apparature)(minute)		
Initial	86	≥45
Final	234	≤ 600
Compressive strength (70.7mm cube) (MPa)		
3-day	19.9	≥ 16 MPa
7-day	25	≥ 21 MPa

Table 4: specification of used sand

Sieve size	Passing %	Standard
No. 8	100	100
No. 4	96	95-100
No. 8	85	80-100
No.16	62	50-85
No. 30	46	25-60
No. 50	18	5-30
No. 100	8	2-10
F.M.	2.7	
M.A.S	No.4	
A.S.S.	No.30	
Sp. gr.	2.61	

Table 5: specification of used gravel

Sieve size In.	Passing %	Standard %
2	100	100
1.5	97	95-100
3/4	66	35-70
3/8	13	10-30
3/16	2	0-5
Pan	0	
F.M.	7.1	
M.A.S	1.5 in	
Sp.gr.	2.64	

Table 6: Properties of concrete and mortar

Properties / Slabs	F'_C(concrete compressive strength)	F_{cm}(mortar compressive strength)
SA1	29.2	------
SA2	28.1	-------
SA3	28.2	------
SB1	29.4	47
SB2	30.1	49.5
SB3	32.8	50.1
SD1	28.6	50.1
SD2	32.5	52.3
SE1	35.8	49.3
SE2	35.7	48.7
SE3	33.7	47.6
SE4	34.1	52.3
SF1	35.8	63.7
SF2	32.1	74.3

Fig 2: Placing the wire mesh and casting the slabs

6. Test Set-up and Instruments:

Fourteen slabs were tested under two-point flexural loading over a clear span of 1700mm. The machine of 2000 kN capacity was used. Load was applied in increments. At each load increment, the total applied load on the slab, mid-span deflection, and crack width were measured. The cracks were plotted and marked. A test was terminated when the total load on the specimen started to drop off. Figure (3) and Figure(4) show the position of dial guage and loading point on the slabs. All the slabs were tested using an incremental loading procedure. The mid span deflection of the slab was measured by using dial gauge. The initial values for deflections, loads were zeroed on the measuring device and the loading system was the assembled in position. These conditions were then considered to represent the initial state of the slabs. Out of these fourteen slabs three are control slabs which are tested after 28 days of curing to find out the load carrying capacity, eleven strengthened slabs were tested to failure.

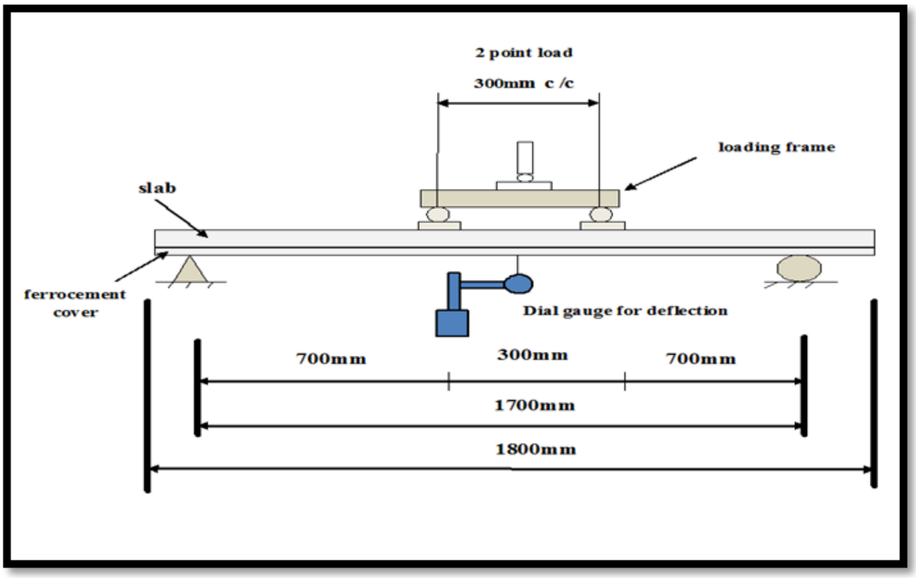


Fig. 3: position of transducer, loading point

Fig.4: Test procedure

7. Results and discussion

7.1. Strengthened One Way Slabs

From Fig.(5.1) to Fig.(5.4) shows the load-deflection curves for strengthened slabs and Table (7) shows the results of the ultimate load for strengthened slabs. In general, slabs with ferrocement morter exhibited greater stiffness, ductility and ultimate load than the control specimens**.** This ultimate load increased with: increasing the thickness of specimen (8.5 ,6.3 and 4.7%) when using (70, 80and 90mm) , the ferrocement thickness (8.5, 8.7 and 8.9%) when using (20, 30 and 40mm) ferrocement thickness, the wire mesh layers (4.1, 8.5,11.2,14.6 and 15.3 %)when using (one layer, two layers, three layers,four layers and five layers of wire mesh), the increase of compressive strength of ferrocement (8.5, 13.1and 13.13%) when using (40, 50 and 60MPa) compressive strength of ferrocement**.** Increase of ferrocement thickness has a little effect on the reducing the total deflection as shown in Fig.(5.2) and deflection at ultimate load increase due to increase the number of wire mesh layers but it was still less than the deflection at ultimate load in control slab**.** The ferrocement compressive strength did a significantly reduce the total deflection .The use of the number of wire mesh layers tend to large increase in ultimate load but the ratio of increasing in ultimate load is reduced as the number of wire mesh is increased and become very little between specimens SE3 and SE4 for wire mesh layer 4,5 respectively . The effect of ferrocement covers decreases with increasing the depth of specimens.

Table 7: Results of strengthened slabs

Specimen	Ultimate load(KN)	Deflection at ultimate load(mm)
SA1	11.772	24.8
SA2	12.77	20.8
SA3	14.3	18.78
SB1	12.77	21.62
SB2	15.2	18.2
SB3	20.54	16.49
SD1	12.8	20.93
SD2	12.82	20.51
SE1	12.25	21.41
SE2	13.08	21.79
SE3	13.4	22.26
SE4	13.57	23.2
SF1	13.1	21.14
SF2	13.13	20.8

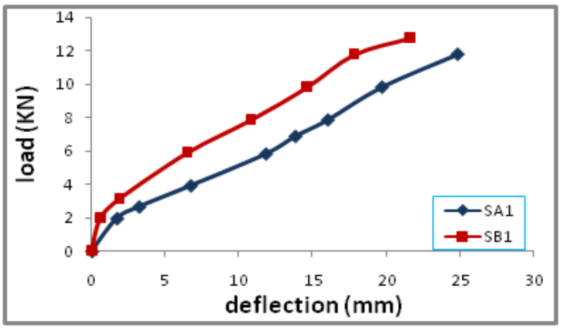


Fig 5.1(a) Load- midspan deflection for specimens (SA1:SB1)

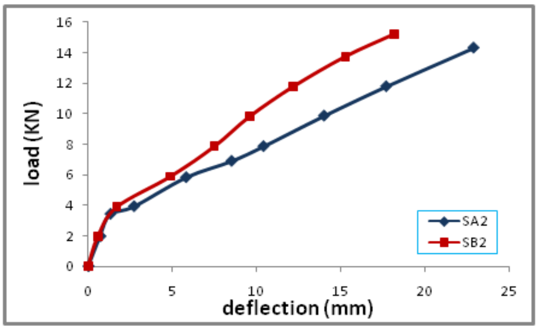


Fig 5.1(b) Load- midspan deflection for Specimens (SA2:SB2)

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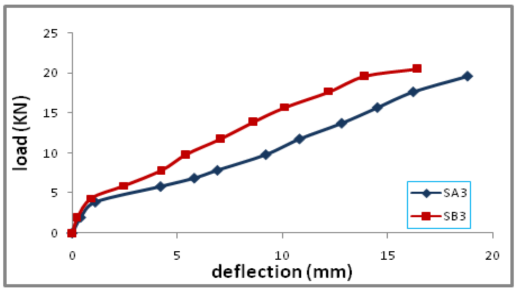


Fig.5.1.(c) Load- midspan deflection for specimens (SA3:SB3)

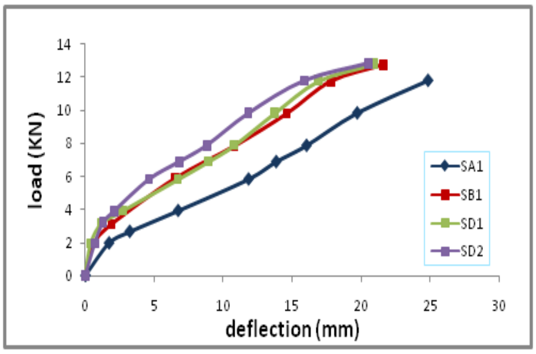


Fig.5.2 Load- midspan deflection for specimens (SA1:SB1:SD1:SD2)

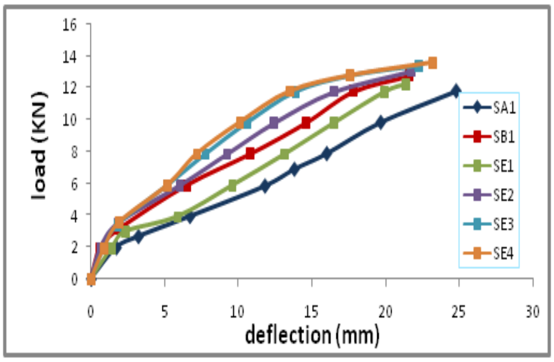


Fig.5.3 Load- midspan deflection for specimens (SA1:SB1:SE1:SE2:SE3:SE4)

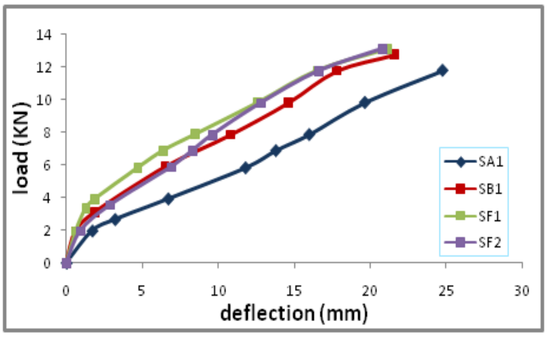


Fig.5.4 Load mid-span deflection for specimens

(SA1:SB1:SF1:SF2)

7.1.1Ultimate load

The ultimate load of strengthen slabs are given in Table (8).

Table8: Ultimate load of strengthened slabs

group No.	Specimen	Ultimate load (KN)	% increase of ultimate load
A	SA1	11.772	3 as reference specimen
	SA2	14.3	
	SA3	19.62	
B	SB1	12.77	8.5
	SB2	15.2	6.3
	SB3	20.54	4.7
D	SD1	12.8	8.7
	SD2	12.82	8.9
E	SE1	12.25	4.1
	SE2	13.08	11.2
	SE3	13.4	14.6
	SE4	13.57	15.3
F	SF1	13.1	11.3
	SF2	13.13	11.6

The results above show that the addition of ferrocement increases the ultimate load as shown in Fig. (6). The table shows that the increase of ultimate load compared with the control specimens (SA) is mainly affected by the using ferrocement cover on the specimens of avairable depth , the number of wire mesh layers, , compressive strength of ferrocement mortar and the thickness of ferrocement. By comparing the results of groups B, D, E and F it may be noted that the increasing the number of wire mesh layers a r e more effective than other factors for increasing the ultimate load.

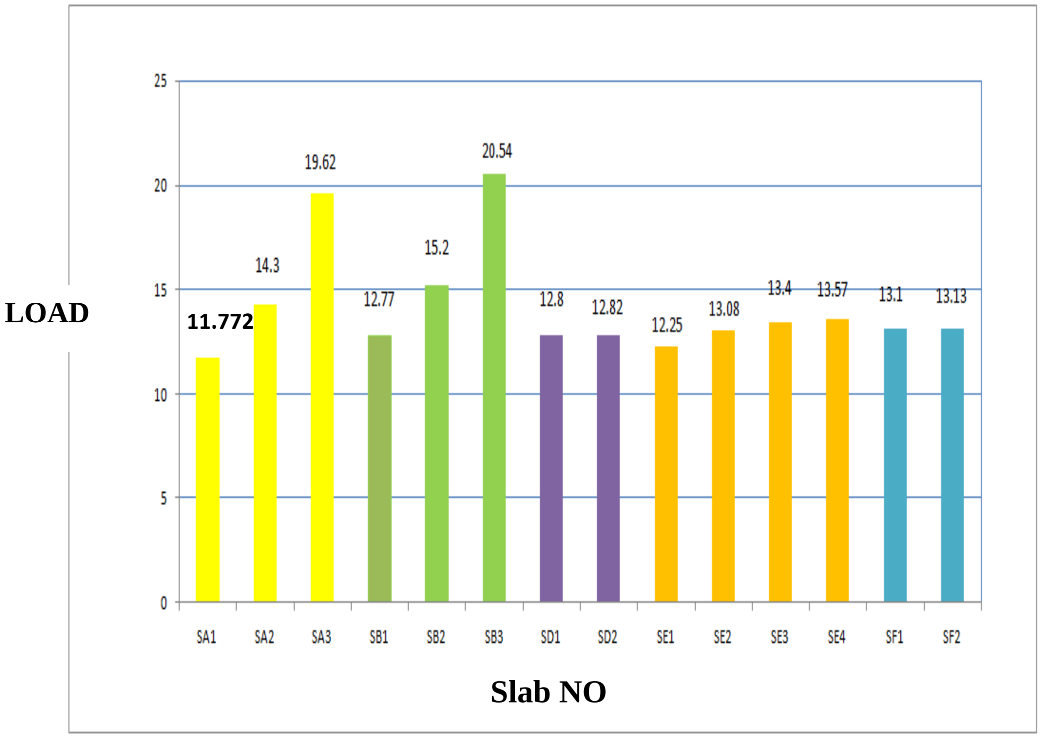


Fig.(6): the percentage increase of ultimate load compared to control slab

7.1.2 Crack pattern

From Figure (7) shows that the use of ferrocement cover for reinforced concrete slabs resulted in aconsiderable reduction in the crack width and a consequent increase in the number of cracks.From Fig.(7.1) to Fig (7.3), it is noticed the group D, increasing the cover thickness from 30 to 40mm didnot result in any further improvement in the crack value. The group E indicate that the higher percentage of reinforcement in the ferrocement cover, the lower the crack width. Specimen SE4 with the highest percentage of longitudinal reinforcement (3.14%) showed the lowest crack width. In the group F increasing compressive strength of ferrocement mortar caused a significant reduce in the cracks width**.**.

It is clear from Table (9) that the thickness of ferrocement, mesh layers number, compressive strength of ferrocement mortar caused a significant reduce in the cracks width**,** due to the increase in specific surface of ferrocement reinforcement (specific surface is the total bonded area of reinforcement (interface area) per unit volume of composite) and the increase of compressive strength of ferrocement led to increase in the stiffness of ferrocement. Figure.(8) shows the crack pattern in control and strengthened slabs.

Table (9) First cracking loads of the strengthened slabs

Croup	No. of specimens	First cracking load (KN)	Increase in cracking load(%)
A	SA1	2.66	3 as reference specimen
	SA2	3.42	
	SA3	3.87	
B	SB1	3.139	18
	SB2	3.89	14
	SB3	4.33	12
D	SD1	3.192	20
	SD2	3.24	22
E	SE1	2.98	12
	SE2	3.218	21
	SE3	3.4	28
	SE4	3.54	33
F	SF1	3.378	27
	SF2	3.56	34

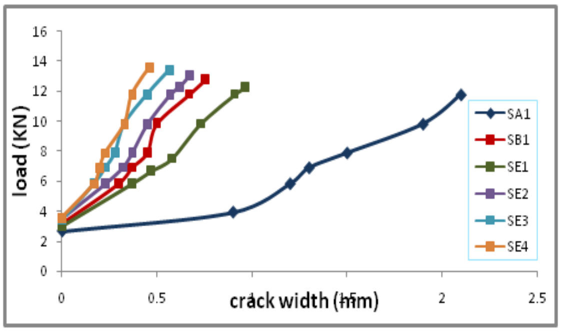


Figure (7.1) Crack Width Versus Applied Load for Effect of Ferrocement Thickness

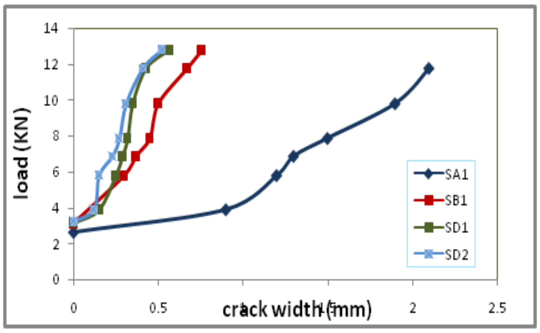


Figure (7.2) Crack Width Versus Applied Load for Effect of Number of Wire Mesh

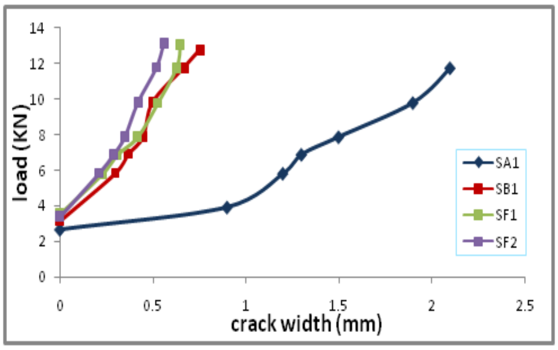


Figure (7.3) Crack Width Versus Applied Load for Effect of Compressive Strength of Ferrocement

Figure 8: Cracks Pattern of Slabs

8. Numerical Application

In parallel with the experimental work, finite element (FE) models were constructed in the ANSYS Version 14.0 program for each of the tested slabs. Material properties which have been used in experimental work for all slabs are adopted in this analysis. The support and loading condition of experimental slabs were simulated in the analytical model by restraining the appropriate degrees of freedom. The displacement in y direction are equated to zero for single line of nodes on support plate. The concrete of slab was modeled using SOLD 65 element, which is defined by eight nodes with three degrees of freedom at each node –translation in the nodal x,y and z directions and the isotropic material properties . A LINK180 element is used to model the steel reinforcement two nodes. A solid element, SOLID45 is used to model the loading and support plates. Fig.(9.1) to Fig.(9.3) shows a typical model for one of the analyzed slabs .

A summary of experimental and the finite element is presented in Table (10). Fig 10 shows crack patterns for slab specimen and Fig (11.1) to Fig.(11.5) represents the load –deflection curves from finite element analysis and experimental results for all slabs**.**

In general, the load-deflection plots for all eleven slabs from finite element analyses agree quite well with the experimental data, for the eleven slabs .The first cracking loads for all eleven models from the finit element analyses are lesser than those from the experimental results by (1%-7%).After first cracking, the stiffness of the finite element models is again higher than that of the experimental slabs by (2%-23%).

There are several factors that may cause the higher stiffness in the finite element models. Microcracks produced by drying shrinkage and handling are presented in the concrete to some degree. These would reduced the stiffness of the actual slabs while finite element models do not include microcracks. Perfect bond between the concrete and steel reinforcing is assumed in the finite element analysis.and this is not actually accurate (Kachlakev, Miller and Yim. 2001).

Table (10) : The ultimate load of strength

Series	Specimens designation	P_{ult} Numerical KN	P_{ult} Experimental KN	P_{ult} Numerical/ P_{ult} Experimental
A	SA1	11.99	11.772	1.02
	SA2	16.49	14.3	1.15
	SA3	20.93	19.62	1.07
B	SB1	15.35	12.77	1.2
	SB2	18.64	15.2	1.23
	SB3	24.18	20.54	1.18
D	SD1	14.55	12.8	1.14
	SD2	14.88	12.82	1.16
E	SE1	13.8	12.25	1.13
	SE2	15.47	13.08	1.18
	SE3	16.2	13.4	1.21
	SE4	17.2	13.96	1.23
F	SF1	14.96	13.1	1.14
	SF2	15.13	13.13	1.15

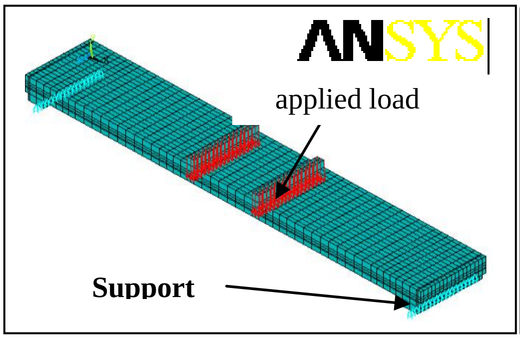


Fig 9.1. Applied loads and Supports

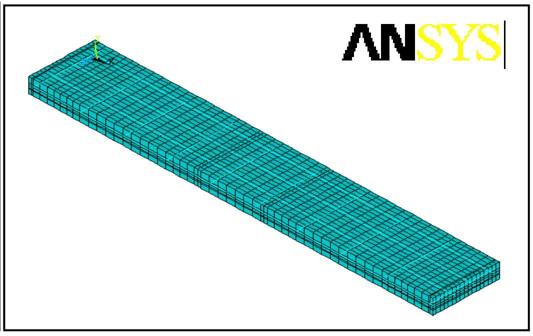


Fig 9.2. : Mesh modeling of tested concrete slab (SB1)

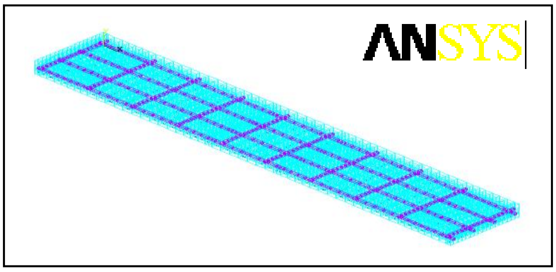
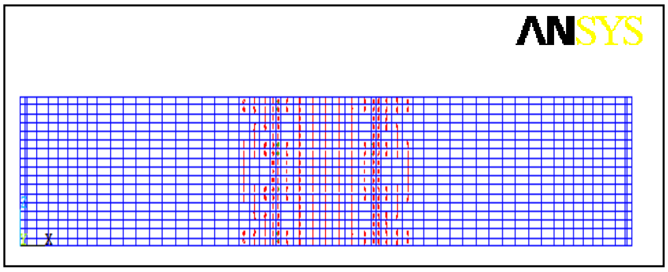
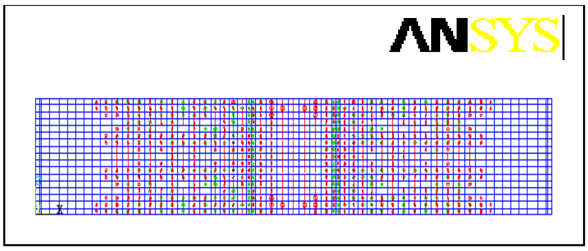


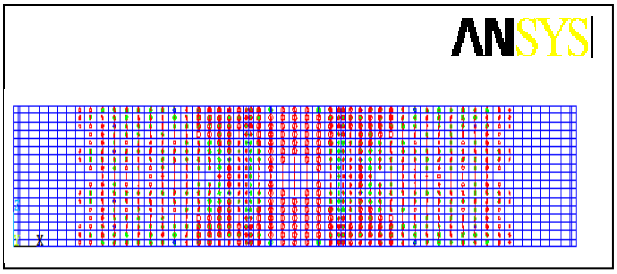
Fig 9.3.: Internal reinforcement arrangement of tested concrete slabs



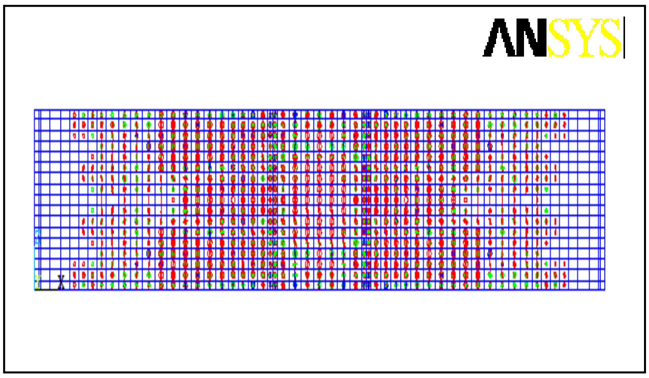
a) At load =0.19 Pu (first crack)



b) At load =0.56 Pu



c) At load =0.71 Pu



d) At load =0.88 Pu

Fig 10: Crack patterns for slab specimen (SA)

(bottom view)

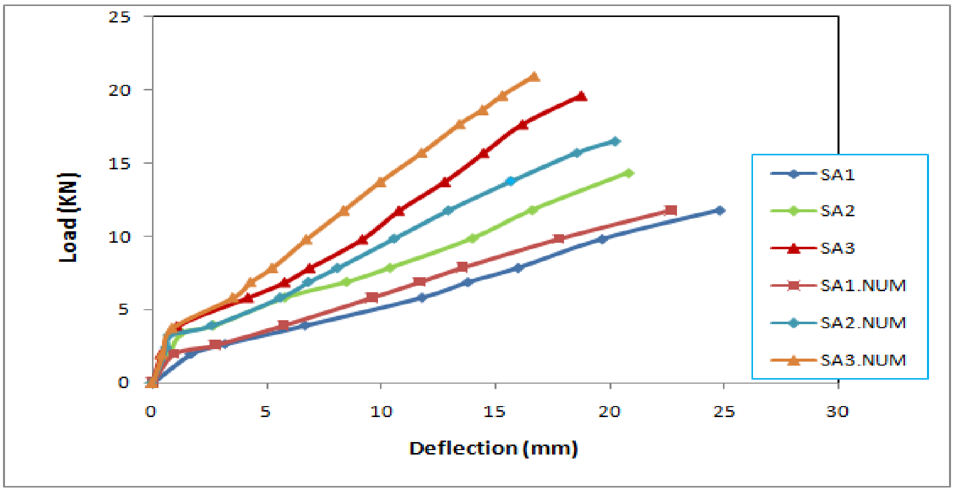


Fig 11.1. Load mid-span deflection for specimens (SA1:SA2:SA3)

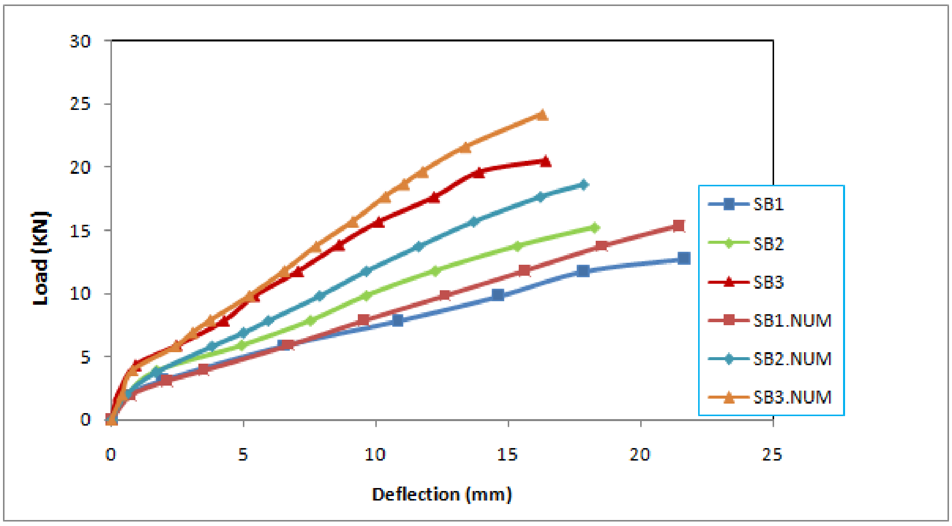


Fig 11.2. Load mid-span deflection for specimens (SB1:SB2:SB3)

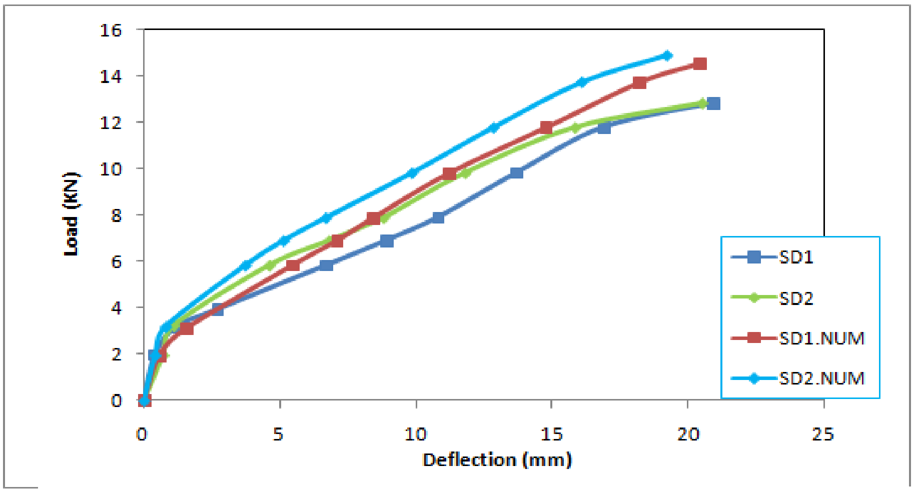


Fig 11.3 Load mid-span deflection for specimens (SD1:SD2)

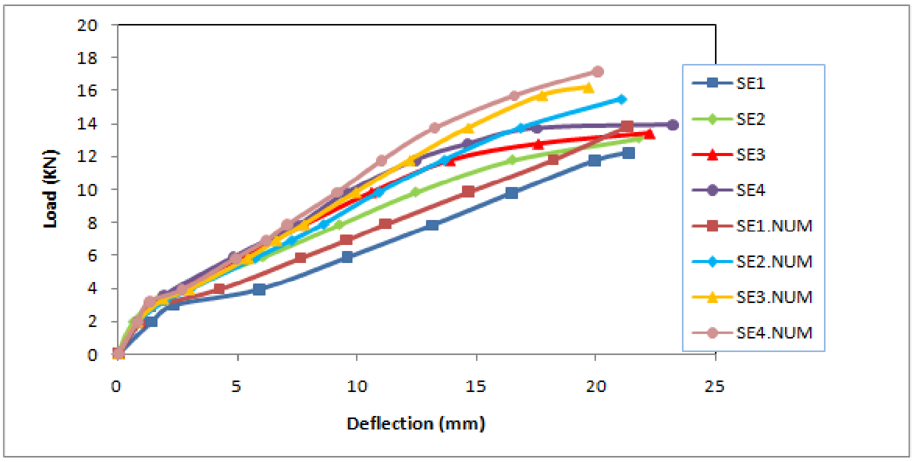


Fig11.4. Load mid-span deflection for specimens (SE1:SE2:SE3:SE4)

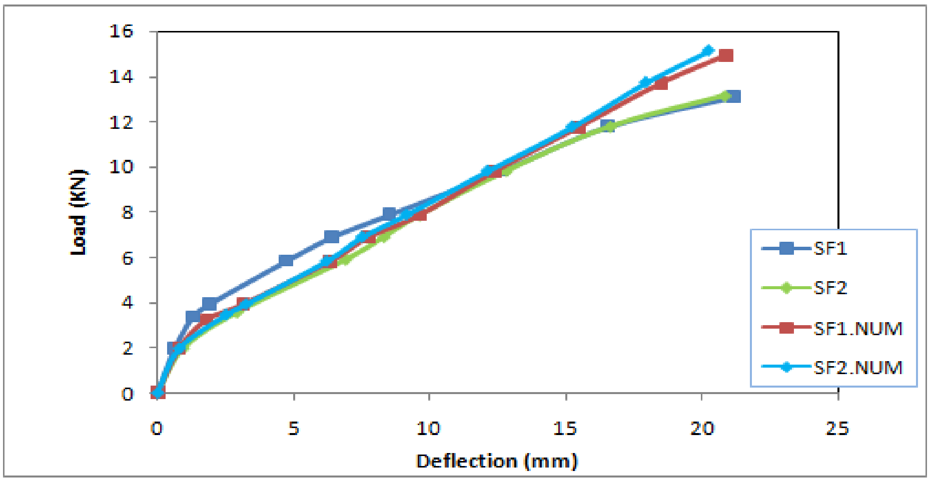


Fig 11.5 Load mid-span deflection for specimens (SF1:SF2)

9. Conclusion

Based on the test results obtained from the experimental Numerical study, the following conclusions may be drawn :-

1- Ferrocement cover can be used successfully for the reinforced concrete slab
2- One way slabs with ferrocement cover show greater stiffness, ductility and ultimate load than the control specimens
3- It was noticed that the effect of ferrocement cover decreases as the depth of specimens increase
4- Increase thickness of ferrocement cover tend to slightly increase the ultimate load.
5- It is noticed that the use of the number of wire mesh layers tend to large increase in ultimate load but the ratio of increasing in ultimate load reduces as the number of wire mesh is increased.
6- Deflection at ultimate load increases due to increase the number of wire mesh but it was still less than the deflection at ultimate load in control slab .
7- The main factor affecting the strength of strengthened slabs is the number of wire mesh layers of ferrocement and the compressive strength of ferrocement.
8- Crack width of the examined reinforced concrete slab was quite narrowed by the use of ferrocement.
9- The analytical results from modeling in ANSYS program exhibited a good agreement with experimental results(Ultimate load, deflection)

10.Reference

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