Experimental Study of Behavior of Reinforced Concrete One-Way Slabs Strengthened and Repaired by Ferrocement at Tension Zone

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Abstract

The principal objective of this paper is to investigation the experimental of the flexural behavior of strengthened and repaired reinforced concrete slabs with ferrocement tension zone. The result of tests on 10 simply supported one way slabs were presented, at which include 1control slab, 5strengthened slabs and 4repaired one way slabs. In the strengthened slabs, the cover of the control slab replacing with ferrocement cover, cold joint between ferrocement layer and the slab, connection type between the ferrocement layer and the slab, on the ultimate load, first crack load, the mid span-deflection, crack width and spacing were examined. In the repaired part the slabs were loaded to (55 %) of measured ultimate load of control slab, the effect of the thickness and number of wire mesh layers on crack pattern, mid span deflection and ultimate load was examined. In the repaired part the slabs were loaded to (55 %) of measured ultimate load of control slab, effect of the number of wire mesh layers of ferrocement on the mid span deflection, ultimate load and crack pattern was examined. The experimental results of strengthened and repaired slabs indicate that; the ultimate loads and mid span deflection were more effected by using ferrocement mortar at tension zone. The increase in ultimate load (8.2-18%) for strengthen slab and (9.1-17.3%) for repaired slab respect to the control slab.

Keywords: Concrete, ferrocement, repair, slab, strengthening

التقصي العملي لمقاومة الانثناء للبلاطات الخرسانية المسلحة ذات الاتجاه الواحد المقواة والمصلحة بغطاء من الفيروسمنت في منطقه الشد

دكتور مازن ديوان عبد الله

الخلاصة

ان الغرض من هذا البحث هو تقديم دراسة عملية عن مقاومة الانثناء للبلاطات المقواة والمصلحة باستخدام طبقة الفيروسمنت عند منطقه الشد.تعرض نتائج الاختبارات على 10 بلاطات بسيطه الاسناد تتضمن واحده منها كبلاطه مرجعيه وخمس منها مقواه اربع لدراسة فاعلية عملية الإصلاح. في عملية التقوية تم دراسة تأثير استبدال الغطاء الخرساني العادي من لوح التحكم بواسطة غطاء فيروسيمنت ، نوع الربط بين بلاطه وطبقه الفيروسمنت و تواجد المفصل البارد بين البلاطه وطبقه الفيروسمنت على الحمل الأقصى ,اول حمل تشقق,عرض التشقق و الحمل الأقصى والأود المقابل له. ، أما في حالة الإصلاح فقد تم تسليط (55 %) من الحمل الأقصى للبلاطات المرجعية على البلاطات المراد إصلاحها ودراسة تأثير عدد طبقات المشبكات السلكية وسمك طبقه الفروسمنت على الحمل الأقصى. والأود المقابل له بالإضافة إلى تأثيرها الشقوق.نتائج البلاطات المقواه والمصلحه ان الزياده بالحمل الاقصى قد ازدادت بمقدار (8.2-18%) و(9.1-17.3%) على التوالي (% مقارنة بالبلاطات الخرسانية غير المقواة باستخدام لفيروسمنت.

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[2]1. Introduction

Structural members are usually designed to keep the required load, However, it may require the upgrading or strengthening of this is due to several reasons including, human error, modifications in

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practicing design standards/codes, structural design and/or construction, structural deterioration due to environmental exposure and ageing, Misuse of buildings in the form of a change in the benefit of the structure, which led to an increase in the live load and stress concentration in structural members. Thus, not only linked to the term "strengthening" with existing structures but also the newly built structures (Khan et al, 2013).

2. Ferrocement

Ferrocement is a form of thin reinforced concrete structure in which a brittle cement-sand mortar matrix is reinforced with closely spaced multiple layers of thin wire mesh and /or small diameter rods, uniformly dispersed throughout the matrix of the composite(ACI Committee 549-97).

3. Test Specimens

The experimental program consists of preparing and testing 10 concrete one way slabs. These slabs were rectangular with 300 mm width, total depth (70-100) mm and 1800 mm total length. The specimens were divided in to five groups (**A**, **B**, **G**, **J**, **H** and **I**), see Figures 1 and 2. Table 1 show details of specimens.

Group A (Control)

This group consisted of one specimen. This specimen SA1 total thickness 70mm, the specimen was the control specimen. The cover of this specimen normal concrete cover.

Strengthened slabs: It consists of three groups (**B, G and J**) as shown below:

Group B (strengthened slab **SB1)**

One specimen strengthened with ferrocement cover with two layers of wire mesh and compressive strength (40 Mpa) for ferrocement mortar. This group is to study: The effect of using the ferrocement cover instade of normal concrete cover. One specimen (SB1) with a (70mm) total thickness, (20mm) of slab thickness replaced by ferrocement cover.

Group G (strengthened slabs **SG1**, **SG2** & **SG3**)

Three specimen strengthened with with ferrocement cover with two layers of wire mesh and compressive strength (40 Mpa) for ferrocement mortar. This group is to study the effect of shear connector between reinforced concrete slab and ferrocement cover. Three specimens were casted(**SG1, SG2** and **SG3**) with (2, 4 and 6) number of shear connector distributed in long direction of slab respectively , mild steel dowel bars 8mm in diameter and the spacing between these bars was 195 mm.

Group J (strengthened slab **SJ1**)

One specimen used in this group to study effect of cold joint connection between slab and the ferrocement cover. fires casted the ferrocement cover after 24h the reinforced concrete slab casting.

Repaired slabs: It consists of two groups (**H and I**) as shown below:

Group H (repaired slabs **SH1** & **SH2)**

Two specimens repaired after loaded to (55%) of failure load of control slab by ferrocement jacket thickness (20mm) connected by epoxy to bottom face of slab. Varying of the wire mesh layers numbers effect is to study in this group between two specimens (SH1 and SH2) from 2 to 5 layers.

Group I (repaired slabs **SI1** & **SI2)**

Two specimens repaired after loaded to (55%) of failure load of control slab by ferrocement jacket thickness (30mm) connected by epoxy to bottom face of slab. Varying of the wire mesh layers numbers effect is to study in this group between two specimen (SI1 and SI2) from 2 to 5 layers.

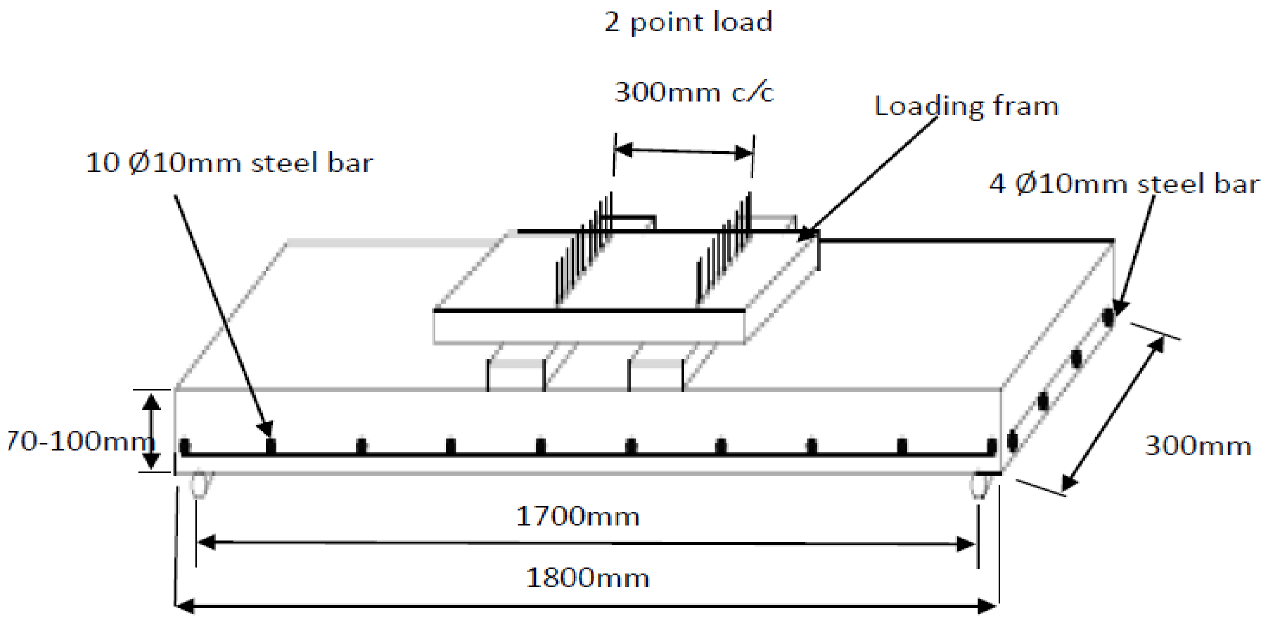
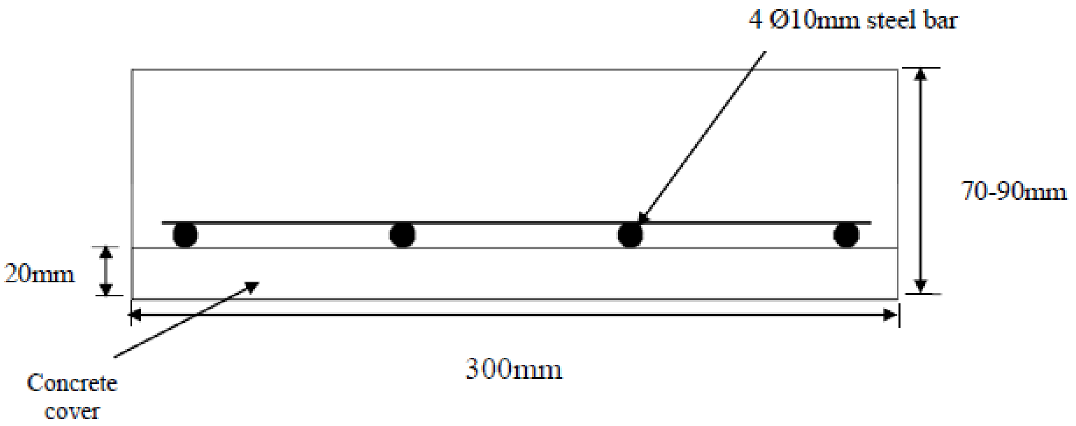
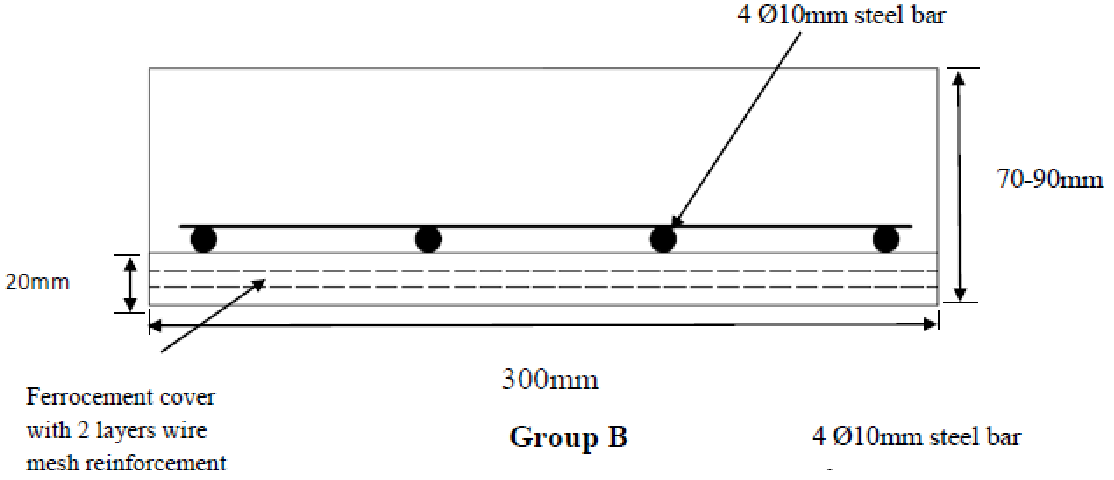


Figure.1: Geometry of Laboratory Specimens

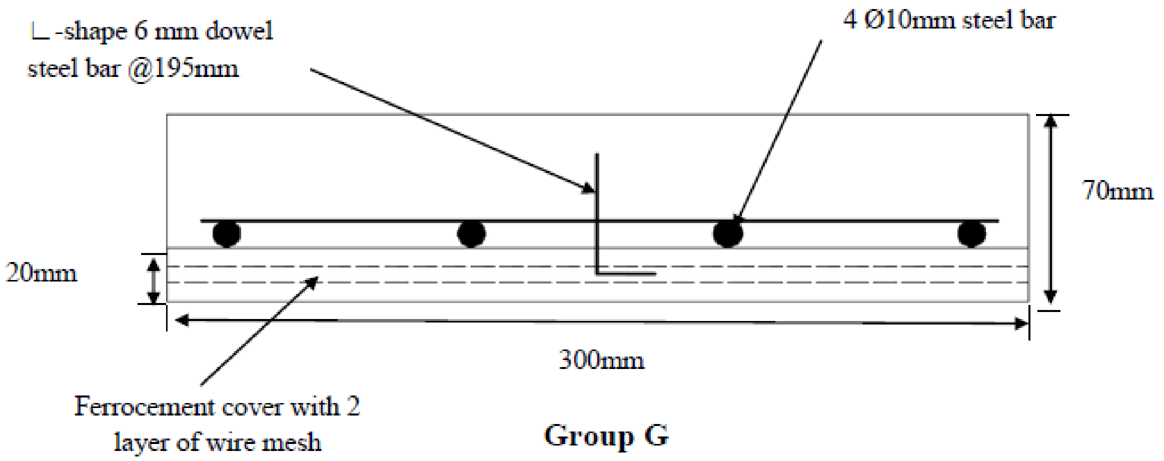


Group A

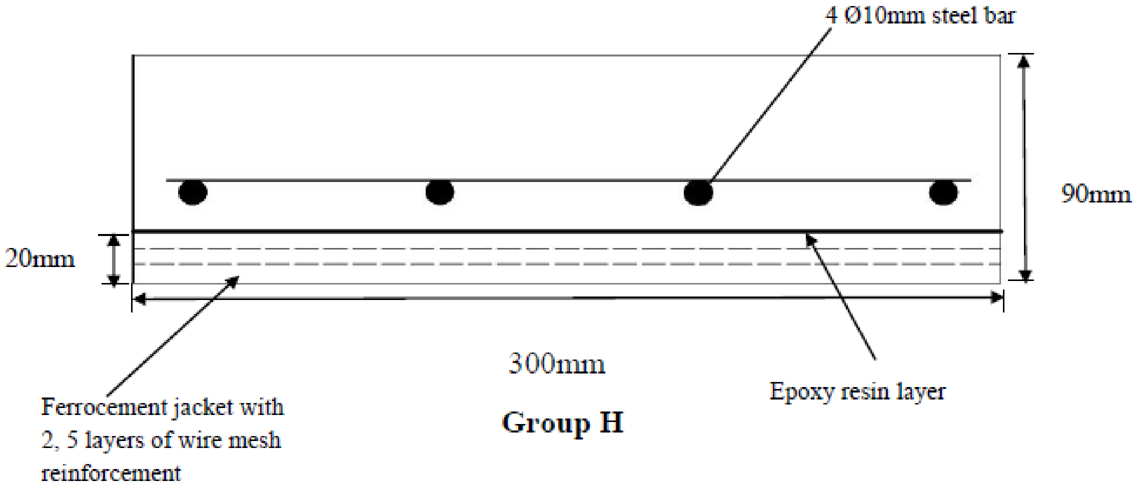


Group B

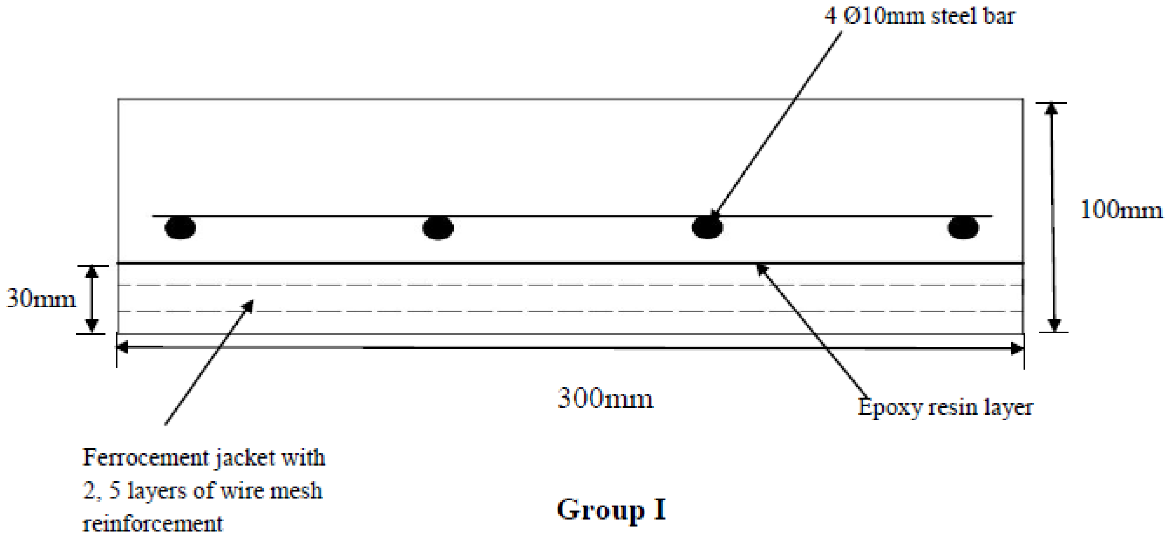
Figure.2: Continued



Group G



Group H



Group I

Figure.2: Continued

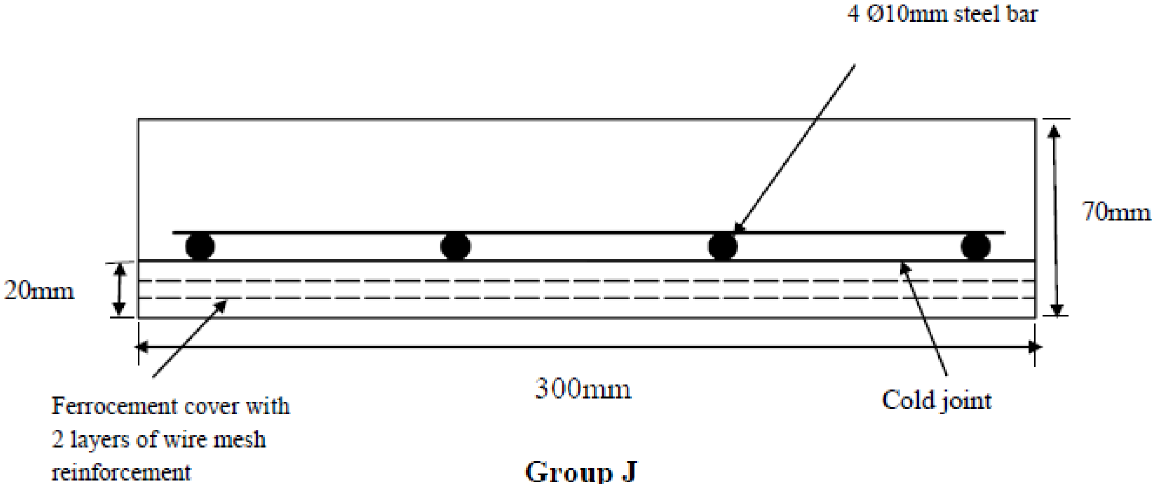


Figure.2: Test slabs details

Table 1: details of slab

purpose	Group	No. of specimens	Ferrocement thickness (mm)	Total thickness of slab (mm)	No. of wire mesh	Compressive strength of ferrocement mortar
Control	A	SA1	-----	70	----	-----
Strengthened	B	SB1	20	70	2	40
	G	SG1	20	70	1	40
		SG2	20	70	3	40
		SG3	20	70	4	40
	J	SF1	20	70	2	50
Repaired	H	SH1	20	90	2	40
		SH2	20	90	5	40
	I	SI1	30	110	2	40
		SI2	30	110	5	40

4. Materials

4.1 cement

In this study Maprok Portland cement was used. Physical properties and chemical compositions used in this study are presented in Tables 2 and Table 3. Properties conform to the Iraqi Specifications limits (I.O.S. 5/1984) for ordinary Portland cement.

4.2 Aggregate

Natural sand and aggregate from Al-Zubair region in Basrah that satisfied the specification (ASTM C33-03) (see table 4 and table 5) with the (10 mm) maximum aggregate size. Sand and aggregate then washed with water several times, spread out and left to dry in the air later, after which it was ready to use.

4.3 Steel Reinforcing Bar

Ukrainian deformed bars were used for main and shrinkage reinforcement. The longitudinal reinforcements are chosen as an 11 pieces of Ø10 with 4 pieces of Ø10 each 90 mm is used as transverse reinforcement along the short direction with yield strength of 420 MPa.

4.4 Steel Mesh Reinforcement

The ferrocement chicken wire of (1 mm) diameter was a galvanized welded square mesh of (11.5 mm) openings [7]. The yield strength was found to be 420 MPa.

5 .Concrete Mix and Ferrocement

25 MPa compressive strength of cylinder in 28-days by using (1:1.41:2.5/0.46 by weight) ratio of (cement: sand: gravel/water) was design according to [ACI 211]. The ferrocement mortar (cement: sand /water, super plasticizer), (ACI C 549R-97) were used in the ratio of 1:2.1/0.39 by weight, to give (40 MPa) compressive strength of mortar in 28-days with using super plasticizer (Daracem SP3) with a dosage of (1.3% of cement weight).

6. Preparation of Test Specimen and Casting

All reinforced concrete specimens were casted by using plywood molds. In strengthen specimen ferrocement cover first placed at the bottom of plywood molds with the specific number of layers of wire mesh after that steel reinforcement placing on the tope layers of the ferrocement and then the concrete placed instantaneously. Shear connectors(8 mm mild steel L-shaped dowel bars) were used in specimens SG1. SG2 and SG3. Before casting the ferrocement cover the shear connectors with 45 mm length and with 195 mm spacing between them in short direction were tied at the specific location to the main reinforcement. Then the ferrocement mortar and the concrete casting (see Figure 3). The effect of cold joint (between concrete slab and ferrocement cover) was studied in specimen SJ.The ferrocement cover was casted first, then after 24 h concrete slab casting. For the repaired reinforced concrete slabs (without ferrocement cover), after it was loaded up to (55%) of the failure load which was predicted by the control specimens, was then repaired by ferrocement layer which fixed to bottom face of the slab by epoxy resin because it has been found that roughening the face of slab was not enough to connect the ferrocement and slab tension face (Hani and Husam, 2003). With each specimen, to find the compressive the strength of concrete and ferrocement mortar three cylinders (150mm diameter and 300mm height) and three cubes (50×50×50mm) were casted to find the compressive strength of concrete and mortar respectively (ASTM C39M-99) (ASTM C109-99). Table (6) shown the compressive strength of mortar and concrete for all slabs.

Table 2: Chemical properties of cement Iq. (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 Iq (5/1984).

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

Table 4: specification of 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 gravel

Sieve size In.	Passing %	Standard %
2	100	100
1.5	95	95-100
3/4	64	35-70
3/8	16	10-30
3/16	3	0-5
Pan	0	
F.M.	7.3	
M.A.S	1.4 in	
Sp.gr.	2.64	

Table 6 Concrete and mortar Properties

Properties / Slabs	FC(concrete compressive strength)	Fcm(mortar compressive strength)
SA1	29.2	------
SB1	29.4	47
SG1	29.5	52.3
SG2	32.5	51.4
SG3	28.7	49.7
SH1	33.5	48.9
SH2	31.2	48.3
SI1	30.5	50.9
SI2	29.4	51.3
SJ	29.3	49.4

Figure.3.1: Steps of Casting Strengthened Slabs

Figure 3.2: Steps of Casting of Repaired Slabs

7. Test Set-up and Instruments:

Ten simply supported slabs with a clear span of 1700mm were tested under two-point flexural loading. The slab was loaded from top at the mid-span. Load was applied in increments, with approximately fifteen load steps to the failure. Mid-span deflection, total applied load and crack width were measured at each load increment. The total time to failure in a test was approximately 1 h. Figure (4) and Figure (5) show the position of loading point and dial gage on the slabs. An incremental loading procedure were used for all slabs. The dial gauge was used to measure mid span deflection. The control slab which is tested to find out the load carrying capacity, five strengthened slabs were tested to failure, rest of ten slabs are loaded up to 55 percent of the ultimate load obtained from testing the control slab.

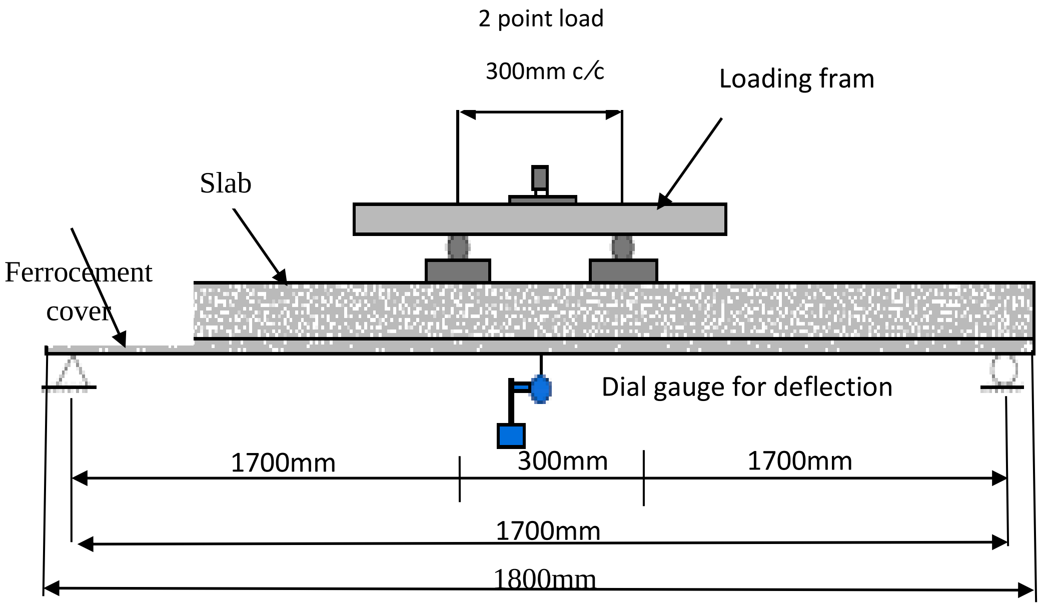


Figure 4: position of transducer, loading point

Figure 5: Test procedure

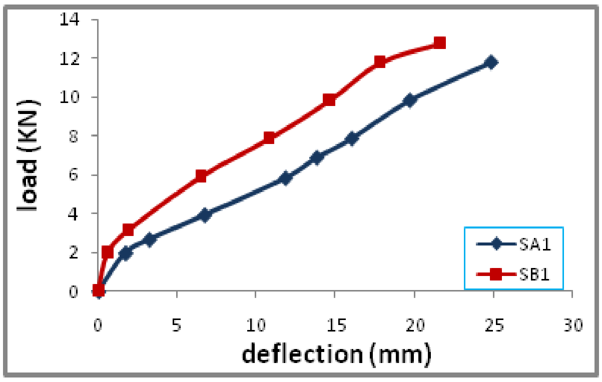
8. Results and discussion

8.1. Strengthened Slabs

Figures (6.1, 6.2 & 6.3) and Table (7) shows the load-deflection curves and the ultimate load for strengthened slabs. Slabs with ferrocement cover exhibited greater ductility stiffness, and ultimate load compered with the control specimens except specimen SJ. Table (8) It was noticed that increase the ultimate load and decreases deflection with replacement cover of each control specimens by ferrocement cover, from specimens (SG1,SG2 and SG3) it was noticed that the percentage of increase in ultimate load is largely decreases from (0.4%) to (0.1%) with increasing in the number of shear connector from (2) to(6), the ultimate load of specimen SJ1 provided cold joint less than the ultimate load of control specimen and a high deflection at ultimate load when compared with other strengthened specimens.

Table 7: Results of strengthened slabs

Specimen	Ultimate load(KN)	Deflection at ultimate
SA1	11.772	24.8
SB1	12.77	21.62
SG1	13.17	22.67
SG2	13.22	21.73
SG3	13.23	21.24
SJ	11.212	23.6



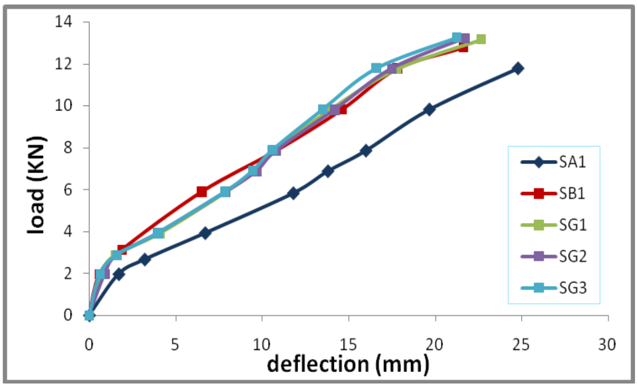


Figure 6.1: Load– midspan deflection for specimens (SA1:SB1)

Figure 6.2: Load– midspan deflection for specimens (SA1:SB1:SG1:SG2:SG3)

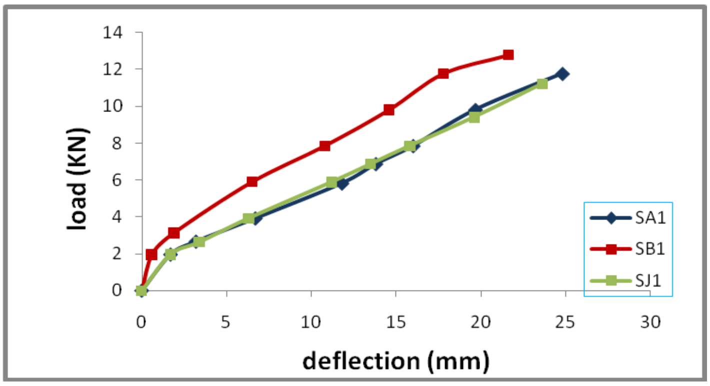


Figure 6.3: Load– midspan deflection for specimens (SA1:SB1:SJ1)

8.1.1Ultimate load

Figure (7) show the ultimate load of strengthen slabs.

Table8: Ultimate load of strengthened slab

group No.	Specimen	Ultimate load (KN)	% increase of ultimate load
A	SA1	11.772	------
	SB1	12.77	8.5
G	SG1	13.17	11.9
	SG2	13.22	12.3
	SG3	13.23	12.4
J	SJ1	11.212	-----

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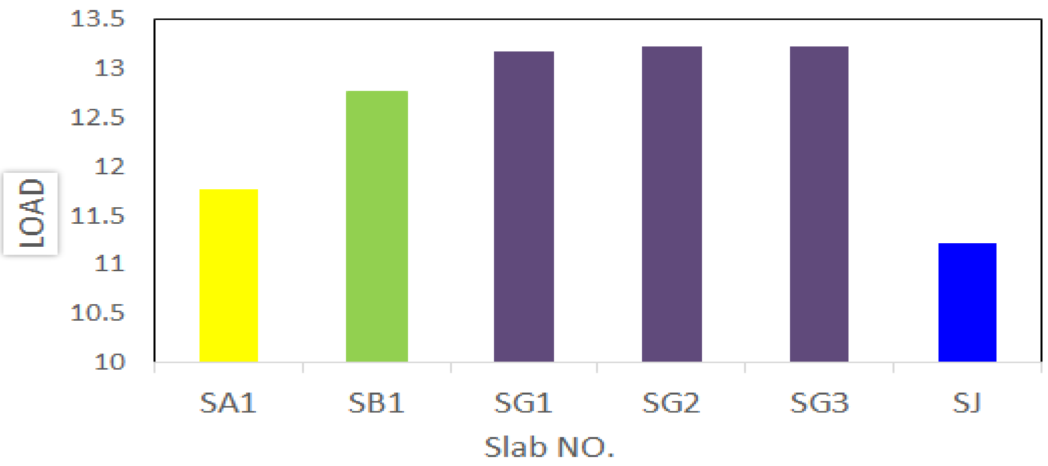


re7: Percentage increase in ultimate load of each slab compared to control slab

8.1.2Crack pattern

The cracks width reduce and the number of cracks increase by using ferrocement cover for reinforced concrete slabs as shown in figures (9.1) to (9.3) except specimen SJ. Noticed that the cracking characteristics improve in group B by replacing of the concrete cover by ferrocement cover. No noticeable improvement in the cracking characteristics in group G. From Figure (8.1) to Figure (8.6) show the crack pattern in control and strengthened slabs. The failure of specimen SJ was recorded due to debonding of ferrocement layer sheets from bottom face of slabs specimen as shown in figure (8.2). Table 9 show First cracking loads of the 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	2.67	-------
B	SB1	3.193	18
	SG1	2.87	8.2
G	SG2	2.87	8.2
	SG3	2.87	8.2
J	SJ	2.63	-------

Figure 8.1: Cracks Pattern of Specimen SA1

Figure 8.2: Cracks Pattern of Specimen SB1

Figure 8.3: Cracks Pattern of Specimen SG1

Figure 8.4: Cracks Pattern of Specimen SG2

Figure 8.5: Cracks Pattern of Specimen SG3

(a) Debonding failure

(b) Bottom Face

Figure 8.6 Cracks Pattern of Specimen SJ1

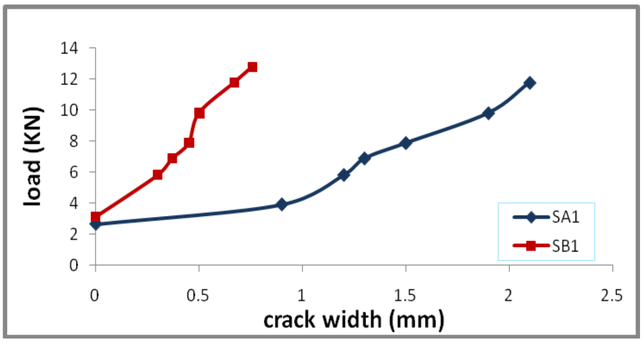


Figure (9.1) Crack Width – Applied Load for Effect of Using Ferrocement Layer on the Specimens of Avairable Depths

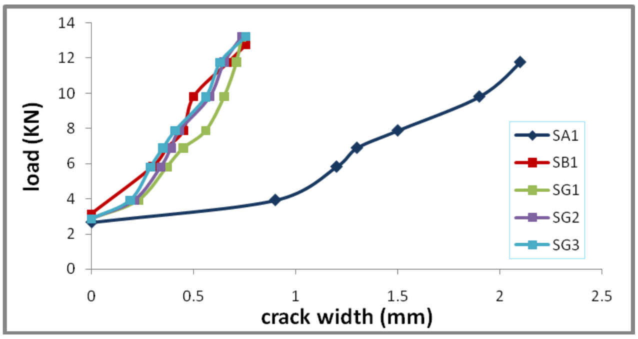


Figure (9.2) Crack Width – Applied Load for Effect of Shear Connector

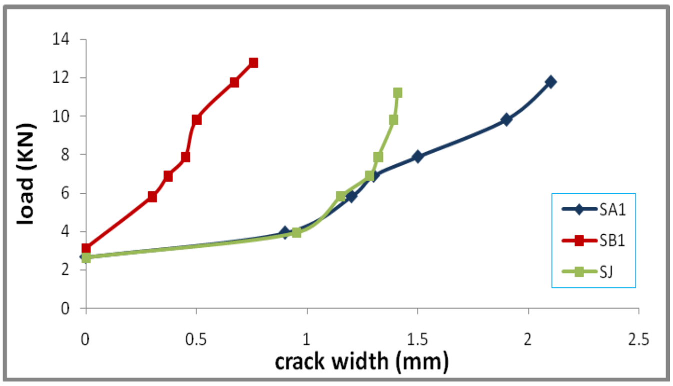


Figure (9.3) Crack Width – Applied Load for Effect of Cold Joint

9.2. Repaired Slabs

9.2.1Ultimate load

From Table (10) and Table (11) show that the addition of ferrocement resulted in an increase of the strength of the repaired slabs and restored the original capacity of the control slab (SA1) is mainly affected by the number of wire mesh layers. The effect of the thickness of ferrocement has only a marginal effect on the ultimate load. See Figure (10)

From Figures (11.1) and (11.4) show that the deflection at ultimate load decreases as the number of wire mesh layer and ferrocement layer thickness increase.

Table 10: Results of repaired slabs

Specimen	Ultimate load(KN)	Deflection at ultimate
SA1	11.774	24.8
SH1	12.84	21.3
SH 2	13.64	21.18
SI1	12.94	21.15
SI2	13.81	21.1

Table 11: Ultimate load of repaired slabs

group No.	Specimen	Ultimate load (kN)	% increase of ultimate load
A	SA1	11.772	------
H	SH1	12.84	9.1
	SH2	13.67	16.2
I	SI1	12.94	10
	SI2	13.18	17.3

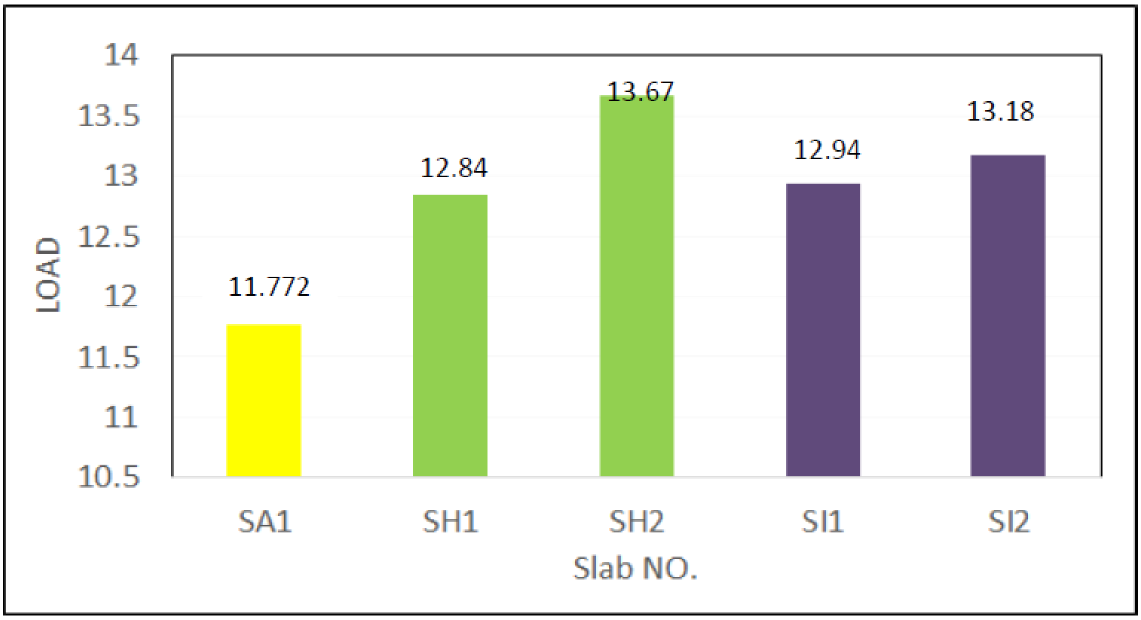


Figure 10: shows the percentage increase of ultimate load compared to control slab

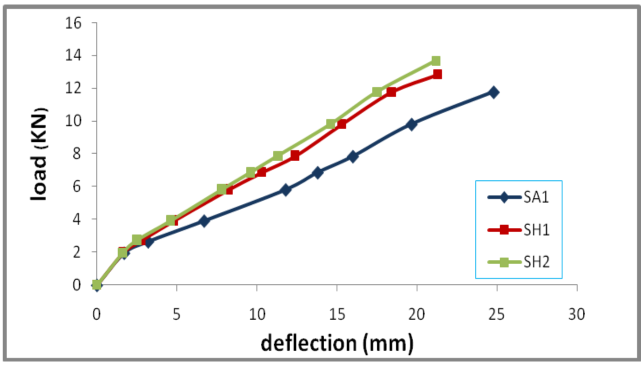


Figure 11. 1 Load- midspan deflection for specimens (SA1:SH1:SH2)

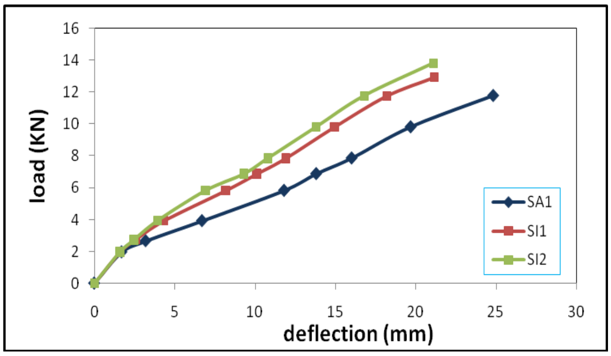


Figure 11.2 Load- midspan deflection for specimens (SA1:SI1:SI2)

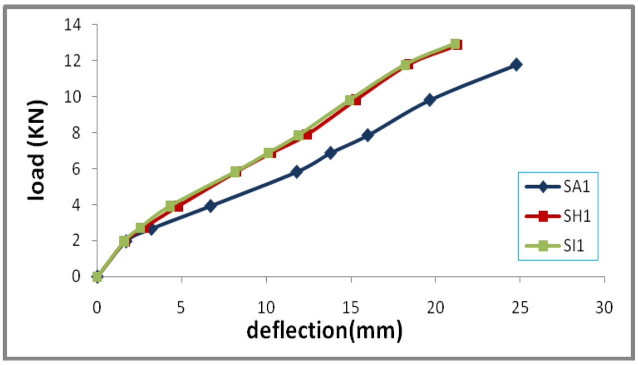


Figure 11. 3 Load- midspan deflection for specimens (SA1:SH1:SI1)

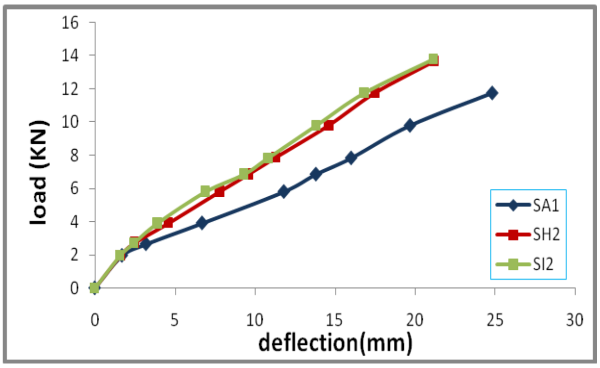


Figure 11. 4 Load- midspan deflection for specimens (SA1:SH2:SI2)

9.2.2 Crack pattern

Figures (13.1) to (13.2) showing the crack width developed and the ferrocement layer effect on the reduction of crack width for repaired test specimens. It noticed that in each group H, I, the percentage of reinforcement in ferrocement layer increases, the lower the crack width .Specimens SH2, SI2 with highest percentage of reinforcement in each group H, I respectively showed the lowest crack width. Figure (12) shows the crack pattern in repaired slabs. The failure was usually recorded due to debonding of ferrocement layer sheets from bottom face of slabs specimens which was very suddenly debonding happened as shown in Figures (12.2) and (12.3) when using epoxy. Table (12) show First cracking loads of the repaired slabs.

Table (12) First cracking loads of the repaired slabs

Croup	No. of specimens	First cracking load (kN)	Increase in cracking load (%)
A	SA1	2.66	-------
H	SH1	2.713	2
	SH2	2.74	3.2
I	SI1	2.73	2.7
	SI2	2.72	2.6

(a)Debonding failure

(b) Bottom Face

Figure 12.1: Cracks Pattern of Specimen SH1

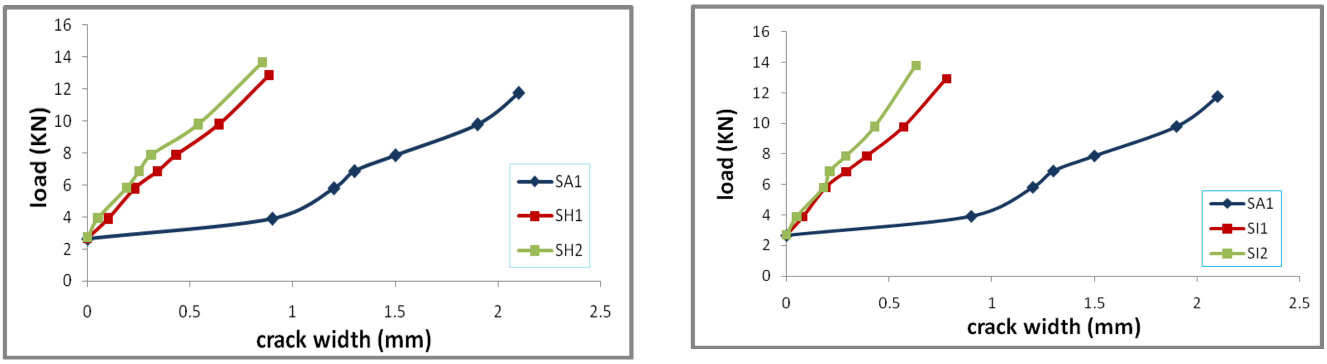
Figure 12.2: Cracks Pattern of Specimen SH2

(a)Debonding failure

(b) Bottom Face

Figure 12.3Cracks Pattern of Specimen SI2

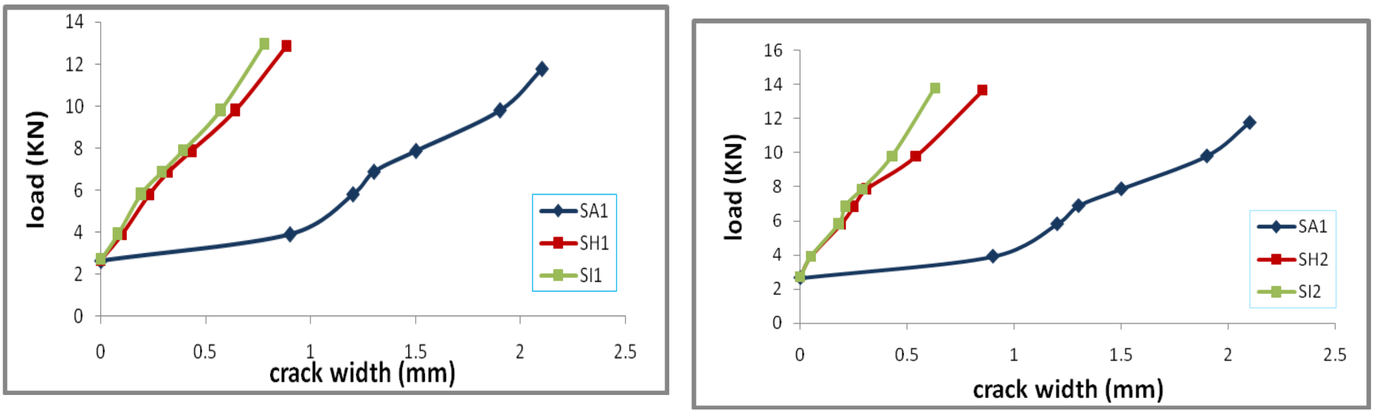
Figure 12.4: Cracks Pattern of Specimen SI2



(a)

(b)

Figure (13.1) Crack Width Versus Applied Load for Effect Number of Wire Mesh



(a)

(b)

Figure (13.2) Crack Width Versus Applied Load for Effect Ferrocement Thickness

10. Conclusion

- From this study could point out that for the reinforced concrete slab the ferrocement cover can be used successfully

- Slabs with ferrocement cover appeared greater stiffness, ductility and ultimate load than the control specimens.

-The ultimate load and first crack load increased slightly with use of ferrocement cover.

- Reduction in cracks width and spacing (33%-64%) and (58% -70%) as observed for strengthened and repaired specimens respectively by a ferrocement layer.

- The presence of shear connectors is effective in increasing the ultimate load capacity. From this study shows that the ultimate load capacity has little effect by increasing the number of shear connectors, (0.1%) was the increasing ratio due to increasing the shear connector from 4 to 6.

- The existence of a cold joint between slab and ferrocement cover lowered than the ultimate flexural load of unstrengthened (control) slab and a higher deflection when compared with specimens with ferrocement cover, (0.56 and 5.1%) were the reduction ratio in ultimate load and increasing ratio in deflection respectively due to presence of a cold joint.

- The number of wire mesh layers (volume fraction of wire mesh) is the major factor that affects the strength of repaired slabs.

10. Reference

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