Using Ferrocement Laminates in Strengthening Flexural Behavior of R.C. Slabs with Opening

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Abstract: This research presents a proposed method for strengthening reinforced concrete slabs with opening using ferrocement laminates. An experimental investigation was carried out to study the effectiveness of using ferrocement as external strengthening material to concrete slab with opening. The results of tests on nine simply supported slabs with overall dimensions of 1000 mm by 800 mm and 100 are presented. The effect of the following parameters: size of opening, strengthening length, volume fraction of reinforcement, and the type of connection between the ferrocement layer and the reinforced concrete slab on the ultimate flexural load, and the load–deflection relationship were examined. The test results clearly showed that ferrocement laminates strengthening leads to significant improvements in the flexural behavior of reinforced concrete with opening. The results indicate that the use of ferrocement cover slightly increases the ultimate flexural load, stiffness and energy absorption.
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Key Words: ferrocement, R.C. slab with opening, and strengthening.

1. Introduction

Suspended reinforced concrete R.C. solid slab has been widely used for the multi-storey building. For newly constructed slabs, the locations and sizes of the required openings are usually predetermined in the early stages of design and accommodated accordingly. In some cases; it is necessary to change the existing structural system due to change of usage rather than rebuilt a new structure. A common example is removing of slab sections to accommodate the mechanical and electrical services such as heating, plumbing and ventilating risers. Meanwhile, substantial size openings are required by lift, stairways and elevator shafts. The structural effect for small openings is often not considered due to the ability of the structure to redistributed stresses. However, for large openings, the static system may be altered when it involves a significant amount of concrete and reinforcement bar that need to be removed. This may lead to decrease in ability of the structure to withstand the imposed loads and the structure needs. The application of ferrocement laminates able to overcome this problem.

2. Experimental Program

The experimental program described in this paper consisted of nine reinforced concrete slabs. Seven among the nine slabs were strengthened with ferrocement laminates, and two reference specimens with and without opening.

2.1 Material properties

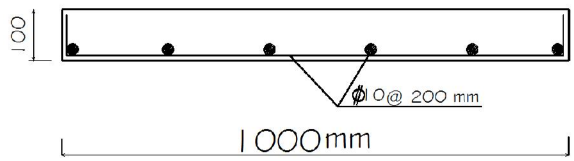
The slabs were constructed using ready-mixed concrete provided by a local supplier. The average 28-day compressive strength of concrete was 25 MPa based on testing standard concrete cubes. The mix proportions by weight were 0.4:0.8:1 for fine aggregate: coarse aggregate: Cement and the water cement ratio was 0.5. Deformed steel bars Ø 10 mm (db = 9.7 mm) were used in reinforcing the concrete slabs. The average yield strength of the steel bars was 46MPa obtained from unaxial tension tests. The ferrocement mortar consisted of sand, cement, and silica fume with the sand cement ratio of 18.5% of cement was replaced by silica fume to reach average 28-day mortar compressive strength of 46 MPa. The water cement ratio was 0.4. Super plasticizer with ratio of 2% of cement was used to improve workability. Expanded wire-meshes (diamond) of 1.50 mm diameter and 30 mm x 15 mm wire spacing were used as ferrocement reinforcement.

2.2 Test specimens

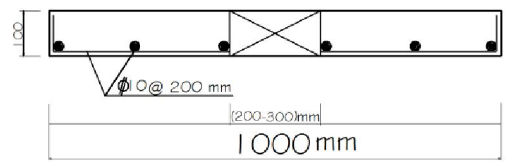
Nine reinforced concrete slabs were constructed with the same dimensions and steel reinforcement details. Seven among of the nine slabs were with central opening strengthened with ferrocement laminates, control slab with no opening, and a slab with a centrally-located opening and no strengthening. The overall slab dimensions were 1000 mm by 800 mm and 100 mm thick. 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. Figure 1 shows the typical dimensions and steel reinforcement layout of the test specimens, and Table 1 summarizes the overall dimensions and parametric studies of the two-way RC slabs. Methods of strengthening slabs with Ferrocement that were constructed for this experimental program was plotted in Figure 2.

2.3 Test Setup

The slabs were tested under simply supported conditions and subject to four symmetrical concentrated loads as shown in figure 3. The reaction frame used in the test program is 100 tons capacity and had a sufficiently large stroke of 300 mm. The deflections were measured using LVDT's connected to the data acquisition system. Two LVDT's were placed at the tension face of the slab, one at mid side of the opening, and the other at the corner of the cutout or at this equivalent position in the slab without opening.

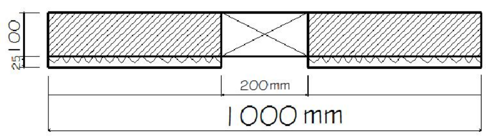


a) Details of control specimen without opening

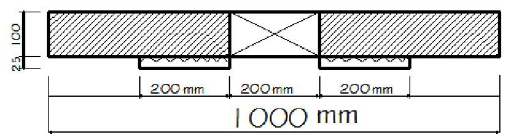


b) Details of Specimen with central opening (200-300)mm

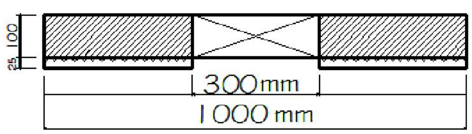
Figure 1. Dimensions and Reinforcement Details of specimens



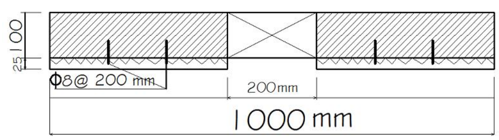
a) Applying ferrocement for specimen S3, S4



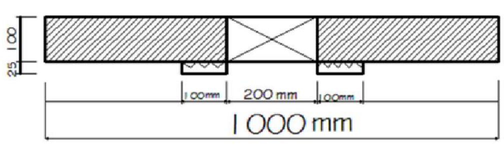
d)Applying ferrocement for specimen S7



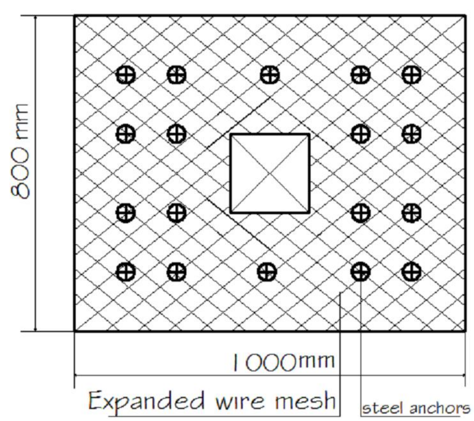
b) Applying ferrocement for specimen S5



e)Applying ferrocement for specimen S8,S9



c) Applying ferrocement for specimen S6



Plan

Figure 2. Methods of strengthening slabs with Ferrocement

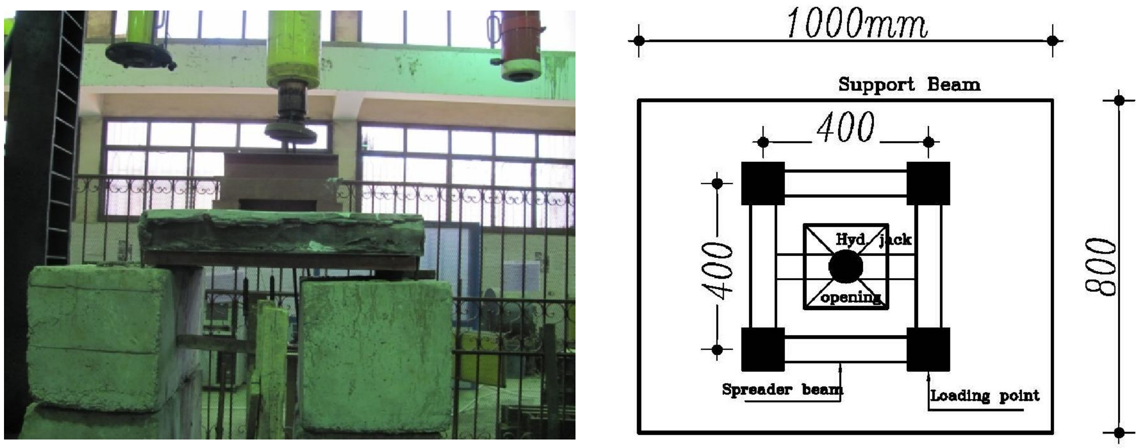


Figure 3. Test setup

Table 1. Specimens properties

Model	Size of opening	Strengthening length	volume fraction (%) per layer	Connection
S1 (control)	----	-----	------	------
S2 (control)	200x200	-----	-----	------
S3	200x200	Whole slab	1.48	Cast monolithically
S4	200x200	Whole slab	2.23	Cast monolithically
S5	300x300	Whole slab	2.23	Cast monolithically
S6	200x200	ts	2.23	Cast monolithically
S7	200x200	2ts	2.23	Cast monolithically
S8	200x200	Whole slab Using anchors	1.48	Ø8 mm bars
S9	200x200	Whole slab Using anchors	2.23	Ø8 mm bars

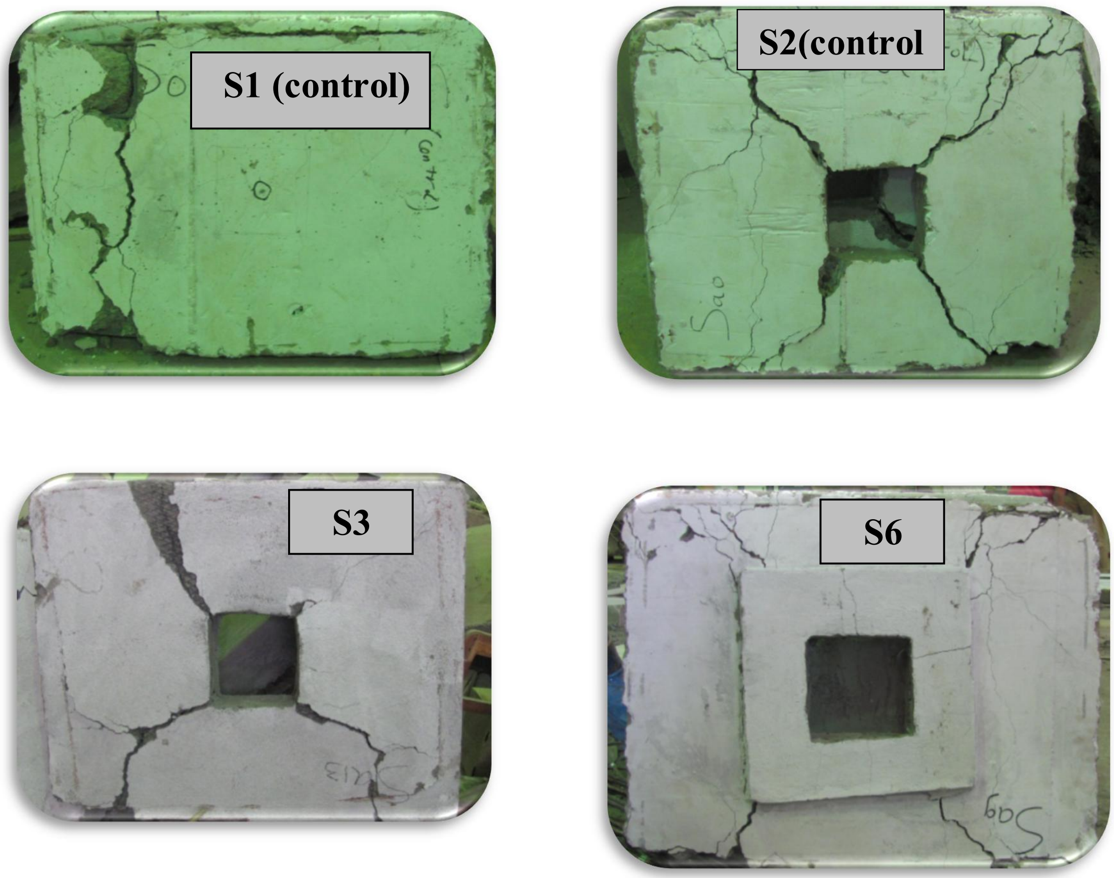
3. Test Results and Discussion

3.1. Cracking Pattern and Mode of Failure

For all specimens plane of failure were observed after completion of the test. It can be seen that all specimens failure are defined as flexure failure. First cracks were found at the bottom surface of the slab failure accompanied by vertical cracks and slight cracks appear in the whole slab for specimen control slab without opening. For other specimens first cracks were found at the bottom surface of the slab, cracks originated from the corners of the opening and propagated diagonally towards the specimen outer corners. Spalling of concrete was noticed on the surface of slab, starting gradually during the whole procedure and hearing of the cracking sound and increase gradually until the load approached almost its maximum, and after that point, crack width became wider. Figure 4 shows by photograph crack pattern on bottom of the slab.

3.2. Load deflection behavior

Figures from 5 to 7 show the load versus central deflection relationship for all tested specimens with the deflection measured at mid side of the opening in slabs with opening and at the same location in slab with no cutout. Comparing the load-deflection curve, it can be seen that all slabs failed under pure bending. The load deflection relationship of the tested specimens showed a non–linear behavior, it can be divided in to uncracked and cracked stages. The first part represents the behavior before cracking of concrete to reach the peak. At the second part there is a descending branch after the ultimate load is reached then decreased up to failure. All specimens showed the same behavior in the uncracked stage, while the post-cracking behavior appeared to be different. In general, slabs with ferrocement cover exhibited greater stiffness than the control specimens and greater ultimate load. It was found that Increase number of wire mesh layers lead to increase the ultimate load, and 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. From the figures it can be indicated that increasing strengthening length resulted in increasing ultimate loads, steel anchors presence in addition to steel washers and nuts as a fixation method increased the ultimate load.



Cracking Pattern for specimen S3

Cracking Pattern for specimen S6

Figure 4. Cracking Pattern for specimen

3.3. Ultimate Load Capacity

Figure 8 and table 2 give a summary of the test results. The control specimens experienced the lowest ultimate load of 174 and 111 KN for control specimens S1, and S2 respectively. The results indicate that R.C. slab with opening gave a reduction of 56% in capacity compared to R.C. slab without opening. All the strengthened specimens had higher ultimate loads than the control specimen without cutout. The increase in ultimate loads was compared with the reference specimen S1 and S2. The increase in ultimate strength for specimens S3, and S4 was 15%, and 44%; respectively with respect to control specimen S1 and 80%, and 126%; respectively with respect to S2, also it can be noted that specimen S5 had the greatest increase in ultimate load capacity with increasing size of opening to reach 129% with respect to control specimen S1 and 46%, with respect to S2, while the increase in strength for specimens S6, and S7 was 101%, and 102% with respect to control specimen S1 and 28%, and 29%; respectively with respect to S2, for specimen S8, and S9 resulted in increasing ultimate loads by 67%, and 120% with respect to control specimen S1 and 6%, and 40%; respectively with respect to S2. Comparing specimen S6 and S7 with specimen S4 it can be noted that strengthening with Ls = ts, and Ls = 2ts around the opening decreased the ultimate load by 25% and 24%; respectively than that obtained when the whole slab was strengthened. By comparing the ultimate load values of specimens S3 with specimen S4, it can be seen that with the increase in the volume of reinforcement ratio from 1.48% to 2.23%, the ultimate load values increase by 46%, comparing S3, and Sa4 with those of specimens Sa8, and Sa9 results indicated that using anchors in addition to steel washers and nuts as a fixation method decreased the ultimate load by 13% and 6%, and there was no sound effect at all for using anchors in addition to steel washers and nuts. From the test results, it can be concluded that strengthening with ferrocement is one of the most effective strengthening methods for R.C. slab with opening in terms of load carrying capacity, ductility, energy absorption, and crack pattern. Summary of test results are given in Table 2.

3.4. Ductility and Energy Absorption

The ductility is calculated as the ratio of the ultimate deflection to yield deflection, while the strain energy was calculated as the area under load deflection curve up to the peak (ultimate load). Figures 9 and 10 show calculated ductility and strain energy supported by specimens, it can be noticed that energy absorption increased by increasing volume of fraction, size of opening, and using anchors.

Table 2. Summary of test results

Model	Ultimate Load (kN)	Defl. at Ultimate Load (mm)	% increase above control S1	% increase above control S2	Ductility	Energy absorption (kN.mm)
S1	174	20.5	---	---	1.70	2404
S2	111	24	---	---	1.3	2137
S3	200	18.3	80	15%	1.26	1619
S4	251	20.75	126	44%	1.22	2427
S5	254	18.3	129	46%	2.60	3009
S6	223	13.5	101	28%	2.17	2057
S7	224	23.75	101.8	29%	1.25	2819
S8	185	63	67	6%	4.00	8155
S9	244	34.25	120	40%	2.44	5812

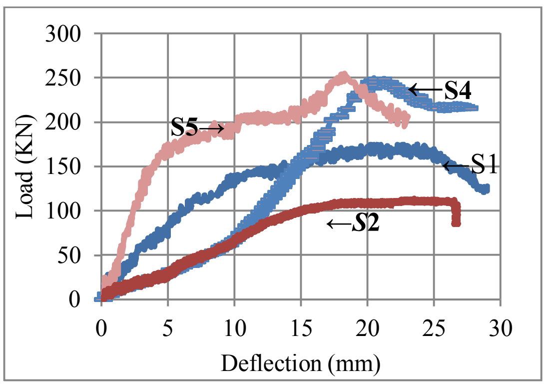


Figure 5. Load – deflection curves for effect of opening size

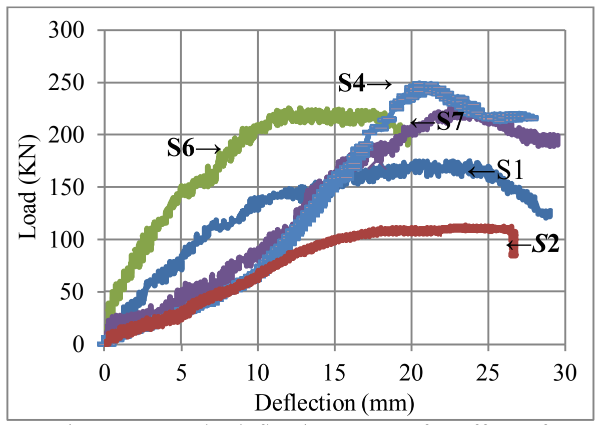


Figure 6. Load –deflection curves for effect of strengthening length

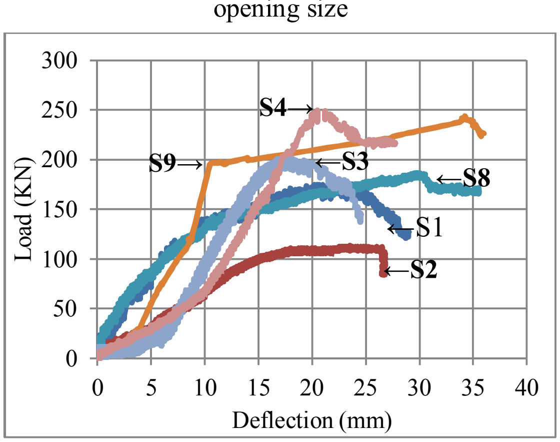


Figure 7. Load – deflection curves for effect of Volume fraction and fixation method

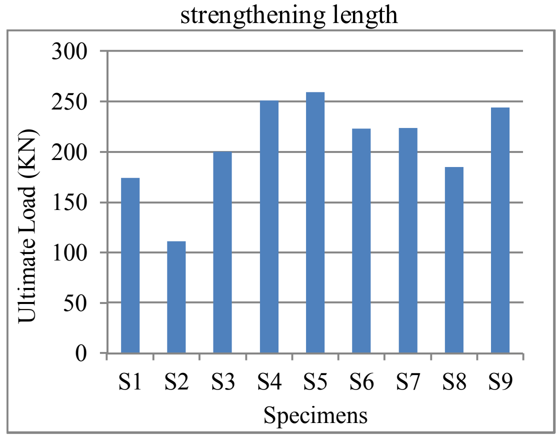


Figure 8. Measured Ultimate Load Supported by Specimens

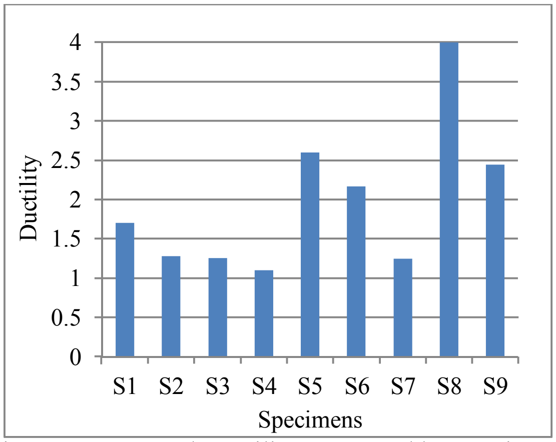


Figure 9. Measured Ductility Supported by Specimens

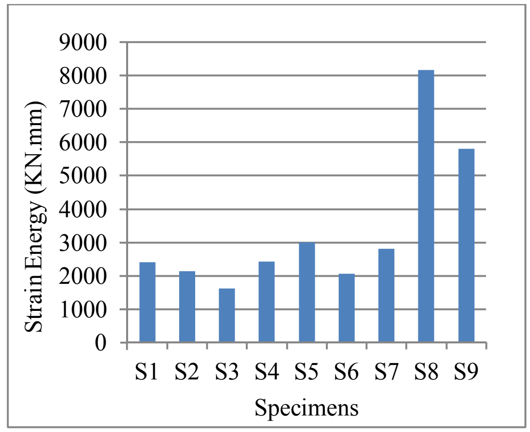


Figure 10. Measured Stain energy Supported by Specimens

4. Conclusion

The results of experimental investigation on the flexure behavior of slab with opening strengthened with ferrocement were presented. The main findings of this investigation can be summarized as follows:

1. The reduction of 5% area due to square opening located at the center of the R.C. slabs reduces 56.7% of flexural strength.
2. The ferrocement laminate can be successfully used for increasing ultimate load of slab with opening.
3. 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 129% with respect to control specimen S1 and 46% with respect S2 due to strengthening with ferrocement.
4. The cracking pattern found in the opening slabs show a high concentration stress occurred at the corner of the opening when vertical load is applied.
5. Increasing volume fraction of reinforcement (Vf) from 1.48%, and 2.23% disposed to increase the ultimate load by 80%, and 126% with respect to control specimen S1 and 15%, and 44% with respect to S2.
6. Using anchors in addition to steel washers and nuts as a fixation method has increased in ultimate strength, and strain energy.

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