Kufa Journal of Engineering
Vol. 8, No. 3, October 2017, P.P. 103-118
Received 14 April 2016, accepted 8 March 2017

FLEXURAL BEHAVIOR OF HIGH STRENGTH RC SLABS WITH OPENING STRENGTHENING WITH WIRE MISH AND STEEL FIBERS

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ABSTRACT

This paper consists of experimental study on ability of use of wire mish strengthening and steel fiber to recover the flexural strength of the slab after configuring openings cut out with different shapes. 15 slabs (800*800*95 mm) made of high strength concrete were prepared and tested, these slabs were divided to gropes, the first group was with square openings, the second group with was rectangular openings. For each group, two different strengthening techniques were used wire mish (with different layers and widths) strips around openings and steel fibers (with four contents of 0, 0.5, 1.0 and 1% by volume fraction). The results showed that the two strengthening techniques increased the load-carrying capacities of the slabs with openings compared with the slabs without strengthening. The wire mish was more effective than the steel fibers technique. Wire mish and steel fiber reduced the cracks at the inside faces of opening and also wire mish prevent it at the inside corners.

KEYWORDS: Fiber-reinforced concrete; Wire mish; High strength concrete; Slab with openings.

تصرف الانحناء للبلاطات الخرسانية عالية المقاومة المسلحة مع الفتحات والمقواة بالمشبكات السليكة والياف الصلب

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الخلاصة:

تتضمن هذا البحث دراسة التجريبية على قدرة استخدام التقوية بالمشبكات السلكية والياف الحديد لاستعادة مقاومة الانحناء لبلاطة بعد قطع فتحات فيها بأشكال مختلفة. تم إعداد 15 من ألبلاطات المربعة بابعاد (800 * 800 * 95) ملم مصنوعة من الخرسانة عالية المقاومة واختبارها، تم تقسيم هذه البلاطات إلى مجموعتين، وكانت المجموعة الأولى مع فتحات مربعة، وكانت المجموعة الثانية مع فتحات مستطيلة. في كل مجموعة، واستخدمت اثنين من التقنيات التقوية الاولى بالمشبكات السلكية (مع طبقات مختلفة وعرض) حول الفتحات والثانية بالألياف الفولاذية (مع أربعة محتويات 0، 0.5، 1.0 و 1٪ من حجم جزء). وأظهرت النتائج أن تقنياتي التقوية الاثنين ساهمت في زيادة قدرة تحمل البلاطات مع فتحات و كانت المشبكات السلكية أكثر فعالية من الألياف الفولاذية. المشبكات السلكية والياف الحديد قللت التشققات في الاوجهة الداخلية للفتحات والمشبكات السلكية منعت حدوث تشققات في داخل زوايا الفتحات.

1. INTRODUCTION

Due to changes in structural or functional requirements, it may become necessary to introduce sectional openings in existing slabs of buildings and industrial facilities. Requirements for elevators, escalators, staircases, or utility ducts for heating and air-conditioning result in the creation of cutouts and removal of the associated concrete and reinforcing steel bars. When part of a slab is removed, additional reinforcement is required to restore its ability to sustain imposed loads (Vasques and Karbhari, 2003).

The ACI 318 Building Code permits openings of any size in any new slab system, provided that an analysis is performed that demonstrates that both strength and serviceability requirements are satisfied (ACI 318-11 13.4.1). The analysis for slabs containing openings could be complex and time consuming, as an alternative the ACI 318 Code gives guidelines and limitations for opening location and size. If the designer satisfies those requirements the analysis could be waived. Few researchers have investigated the structural behavior of slabs with openings strengthened with steel fiber, wire mish strips.

Vasques and Karbhari (2003) investigated the effectiveness of externally bonded FRP strips for strengthening slabs with only one type of opening shape. They concluded that externally bonded FRP strips can be used to restore the original load carrying capacity of slabs weakened by cutouts.

Enochsson et al. (2007) studied the amount of carbon-fiber-reinforced polymer (CFRP) sheets needed to restore the load-carrying capacity of slabs with cutouts to equal that of corresponding slabs without openings.

Muhammed (2012) studied the effect of 1.0 % fraction by volume steel fiber and CFRP strips strengthening on flexural load capacity of normal strength self compacting concrete reinforced slabs 450*450*40 mm with and without square and rectangle opening. It was found that the CFRP is more effective than the steel fiber technique. Use of CFRP enable the slabs to restore its full load capacity and increased it by 30%, also the steel fiber hence enabled the slab to restore its full capacity and increased it by 20 %.CFRP and steel fiber reduced the cracks at the inside faces of opening and also CFRP prevent it at the inside corners.

Choi et al. (2013) conducted experimental testing of glass fiber reinforced plastic (GFRP) composite beam strengthened reinforced concrete (RC) slabs with two symmetrical openings. Test results showed that the strengthened slabs seems to increase the load-carrying capacity by 29%, 21% and 12% over that of the control specimen for diagonal, parallel and surround strengthening respectively. Furthermore, test results showed that the diagonal-strengthened system is one of the most effective methods for strengthening an RC slab with openings in terms of load-carrying capacity, stiffness and crack patterns.

YEE (2016) studied the effect of CFRP and anchors in shear zone on the behavior of slabs with openings. The results showed that, slab with opening strengthened with CFRP sheets had the highest ultimate load among all laboratory specimens. The ultimate load was about 10.79 % greater than unstrengthen slab with opening. In terms of crack patterns, for slab without opening, slab with opening and slab with opening strengthened with CFRP had exhibited similar crack pattern, with only a visible vertical crack at the mid-span. Meanwhile, for slab with opening strengthened with CFRP and anchors, two visible cracks were detected at the middle region of the slab.

2. RESEARCH SIGNIFICANCE

The purpose of this study is to give information on the results of a series of tests aimed at investigating the efficacy of internally contained steel fiber and wire mish and externally bonded CFRP composite laminates at strengthening slabs with opening. The failure mode, crack pattern and post-debonding response were also studied. Reinforced concrete slabs with opening both with and without the additional steel fiber and wire mish were tested to provide a thorough assessment of failure mode and overall response.

3. EXPERIMENTAL PROGRAM

The experimental program consists of preparing and testing 15 high strength concrete slabs. These slabs were divided into two groups, the first group consists of 7 slabs with square opening (150*150mm), and the second group consists of 7 slabs with square opening (150*300mm) as shown in Fig. 1. The slabs in each group were divided to 4 slabs made from concrete mixes containing steel fiber with contents of 0, 0.5, 1.0, 1.5 % of concrete volume and 3 slabs were strengthen internally with wire mish strips around openings with one layer of wire mish 5 mm width, two layer of wire mish 5 mm width and one layer of wire mish 10 mm width. In addition to the two groups, the control slab has been prepared and tested to comparison purposes. Table 1 presents all details of the tested slabs.

3.1. Specimens Description

All the slabs were 800*800*95 mm with the distance between the supports of 700mm and effective depth of 75mm and flexure reinforcement was Φ10 mm @175 mm in two directions to ensure flexural failure .Slabs were simply supported and a sand bag used to distributing the load on the slab as a uniform distributed load.

The specimen designation included a combination of letters and numbers, S or R indicate the shape of openings (square or rectangular); f or W indicate the type of strengthening (fibers or wir mish; and 0, 0.5, 1.0 or 1.5 to designate the percentage of fiber content as volume fraction of concrete volume, 5-1, 5-2, 10-1 indicate the width and number of layers of the wire mish (5-1 represents one layer of 5mm width wire mish) and Ref indicate to reference slab which without openings and strengthening.

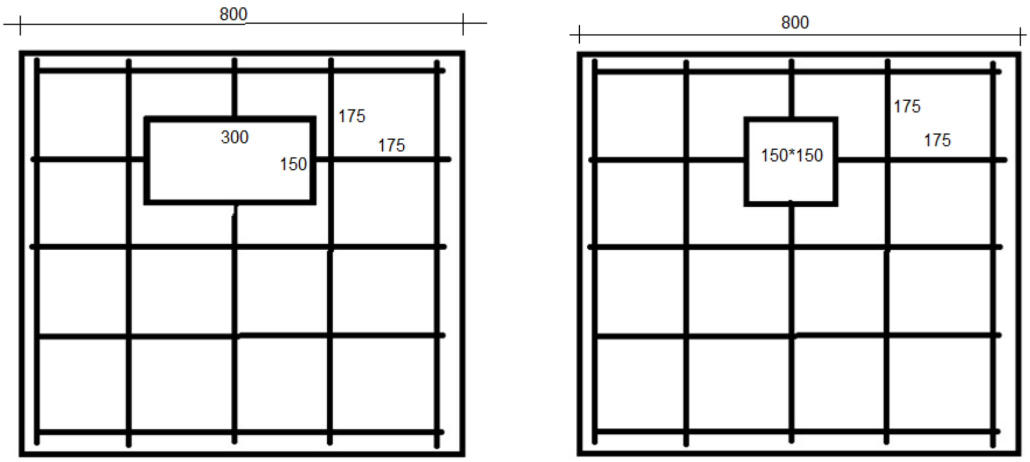

Fig. 1. Details of reinforced concrete slabs with openings.

3.2. Materials

1- Cement

Ordinary Portland cement was used throughout this study, which comply with Iraq Standard Specification I.Q.S. No.5, (1984) requirements.

2- Fine Aggregate

Natural sand from Al-Zubair region is used. The fine aggregate comply with limits of the Iraqi specification I.Q.S. No.45 (1984).

3- Coarse Aggregate

Gravel of maximum size of 10 mm from Al-Zubair region was used. The coarse aggregate conforms to the Iraqi specification I.Q.S. No.45 (1984).

4- Water

Ordinary potable water was used for casting and curing of concrete.

5- Superplasticizer

For the production of high strength concrete, superplasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. One of a new generation of copolymer-based superplasticizer is the Glenium 51. It complies with ASTM C494 (2004), type A and type F.

Table 1. Details of slabs.

Slab notation	Opening	Steel Fiber content %	Wire mish width(cm)
Ref	none	0	0
S000	square	0	0
S0.5f	square	0. 5	0
S1.0f	square	1.0	0
S1.5f	Square	1.5	0
S51W	square	0	5 one layer
S52W	square	0	5 two layers
S10W	square	0	10 one layer
R000	Rectangle	0	0
R0.5f	Rectangle	0. 5	0
R1.0f	Rectangle	1.0	0
R1.5f	Rectangle	1.5	0
R5-1W	Rectangle	0	5 one layer
R5-2W	Rectangle	0	5 two layers
R10-1W	Rectangle	0	10 one layer

6- **Silica Fume**

Silica fume has been used as a mineral admixture added to the high strength concrete mixes of this study. The percentage used was 10%, as partial replacement of cement weight.

7 -Steel Reinforcement

10 mm diameter steel bars was used as flexural reinforcement placed in the tension face of the slab with spacing of 175 mm. The yield strength was determined from tensile test was 490 N/mm^2 and the ultimate strength was 685 N/mm2.

9- Steel Fibers

High tensile steel fibers crimped type was used with different volume fractions of (0, 0.5, 1.0 and 1.5%). Table 2 shows the properties of the used steel fibers.

10-Wire mish

Expanded metal mesh of 8.4 mm square opening, 1 mm wire diameter and 314 MPa average yield strength was used.

3.3. Mix proportions and Properties of Concrete

Table 3 shows mix proportions and properties of all high strength concrete mixes used in this study depending on steel fiber fraction 0, 0.5, 1.0 and 1.5% by volume of concrete.

Table 2. Properties of steel fibers.

Property	Specifications
Density	7860 kg/m3
Ultimate strength	2000 MPa
Modulus of Elasticity	200x10^3MPa
Strain at proportion limit	5650 x10^{-6}
Poisson's ratio	0.28
Average length	30 mm
Nominal diameter	0.375 mm
Aspect ratio (Lf/Df)	80

Table 3. Mix proportions of all the used mixes.

mix		**Ref**	**0.5 %SF**	**1.0% SF**	**1.5% SF**
Mix proportion	**Unit**				
Cement	Kg/m^3	500	497	495	493
Sand	Kg/m^3	677	674	670	667
Gravel	Kg/m^3	1015	1010	1005	1000
Slica fume	Kg/m^3	50	49.7	49.5	49.3
Water	Kg/m^3	150	149	148.5	148
Superplasticizer	Kg/m^3	7.0	7.5	8.0	8.3
Steel fiber	Kg/m^3	0	39.2	78.5	117.7
W/cm		0.28	0.28	0.28	0.28
Steel fiber fraction (by volume)	**%**	0.0	0.5	1.0	1.5
Properties of fresh concrete					
slump	mm	150	150	150	145
Properties of Hardened concrete					
Compressive strength	MPa	85.4	88.0	91.0	93.5
Flexural strength	MPa	7.4	9.0	11.5	13.4

3.4. Specimen Preparation

Wooden moulds with clear dimensions of 800 x 800 x 95mm. The opening was made by using two wooden form with the size [150 mm×150 mm×150mm] for slabs with square opening, and [150 mm×300 mm×70mm] for slabs with rectangular opening, the forms were fixed in their correct positions. The cubes can be easily removed from the mold after casting. The wooden forms were oiled before casting, to prevent bonding between the wooden forms and the concrete. Fig. 2 shows the reinforcement details and the wooden moulds.

3.5. Test set up, loading procedure and instrumentation

The test was conducted by the hydraulic universal testing machine as shown in Fig. 3, with maximum capacity of 2000 kN. The load was applied in rate of 2 kN/min continued up to failure, under the plate of machine a sand bag used to distributing the load on the slab as a uniform distributed load. Deflection was recorded in each loading stage using dial gauge with accuracy 0.01 mm per division. The deflections presented in this study were measured at the center of slabs, these results represent the largest possible displacement of homogeneous slabs and for slabs with opening at the same location, and hence it's the nearest point to the opening that the deflection can be measured on it.

Fig. 2. Specimen preparation.

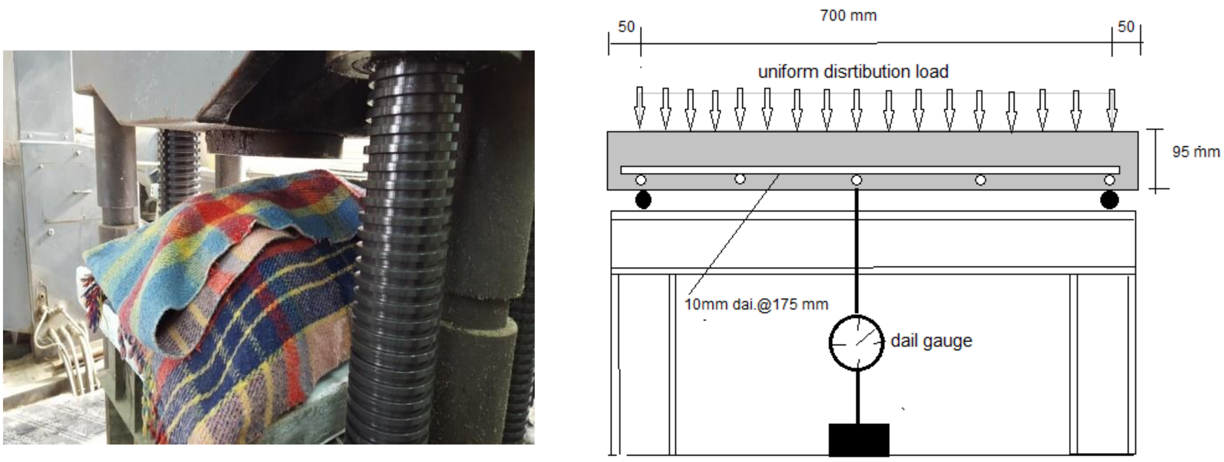

Fig. 3. Test setup.

4. TEST RESULTS AND DISCUSSION

Table 4 lists the main test results from the observations during the tests, which included the first cracking load and ultimate load. The results recorded during the experiments are presented and compared. The aim is to judge the used methods of strengthening considering the deflections and the load capacity. Furthermore, the results obtained from the tests of the slabs with opening show how the holes were decreasing the load capacity, so that strengthening is needed.

4.1. General behavior, Mode of failure and Cracks Pattern

In general, all slabs failed under pure bending. Flexural cracks started either at the center of the slab, first cracks began at load of 34.2 kN for solid slab Ref slab, while for slab with square and rectangular openings at 25.5kN, and 20.8 kN, its obviously clear that the opening effect and waked the slab from the first stage of loading, Table 4 shows the first cracks loads for all slabs,

Flexural cracks started either at the center of the slab (in slabs without opening) or along the edges of the cutouts (in slabs with opening) developing perpendicular to the adjacent line of support. Under increasing load, these cracks developed diagonally towards the four support corners, symmetrically located across the entire tension face as illustrated in Figs. 4 and 5.

Cracks inside the cutout also noticed, for the slabs with openings and without strengthening, the cracks started at the inside corners of opening and also appeared at the inside faces of opening, for the slabs with steel fiber the same case occurs, but less than that at slabs with openings and without strengthening. For the slabs with wire mish, few cracks appeared at the inside faces of opening, but disappeared at the inside corners, this pointed to the additional strength for opening corners provided by using wire mish around openings.

Table 4. The cracking and ultimate loads.

Slab notation	Opening shape	First crack load, Fcr kN	Ultimate load, Fu kN	Fcr/Fu ratio %	Fu with strengthening /Fu without strengthening ratio %	Fu with opening/Fu without opening ratio %
Ref	-----	34.2	110	31.1	----	100.0
S00	Square	25.5	78.2	32.6	100.0	71.1
S0.5f		27.2	88.9	30.6	113.7	80.8
S1.0f		28.4	89.4	31.8	114.3	81.3
S1.5f		30.8	91.5	33.7	117.0	83.2
S5-1W		31.5	93.4	33.7	119.4	84.9
S5-2W		33.7	97.5	34.6	124.7	88.6
S10-1W		32.4	98.1	33.0	125.4	89.2
R00	Rectangle	20.8	66.3	31.4	100.0	60.3
R0.5f		22.5	81	27.8	122.2	73.6
R1.0f		26.8	83.5	32.1	125.9	75.9
R1.5f		30.6	84.7	36.1	127.8	77.0
R5-1W		31.1	86.1	36.1	129.9	78.3
R5-2W		32	88.5	36.2	133.5	80.5
R10-1W		31.4	89.8	35.0	135.4	81.6

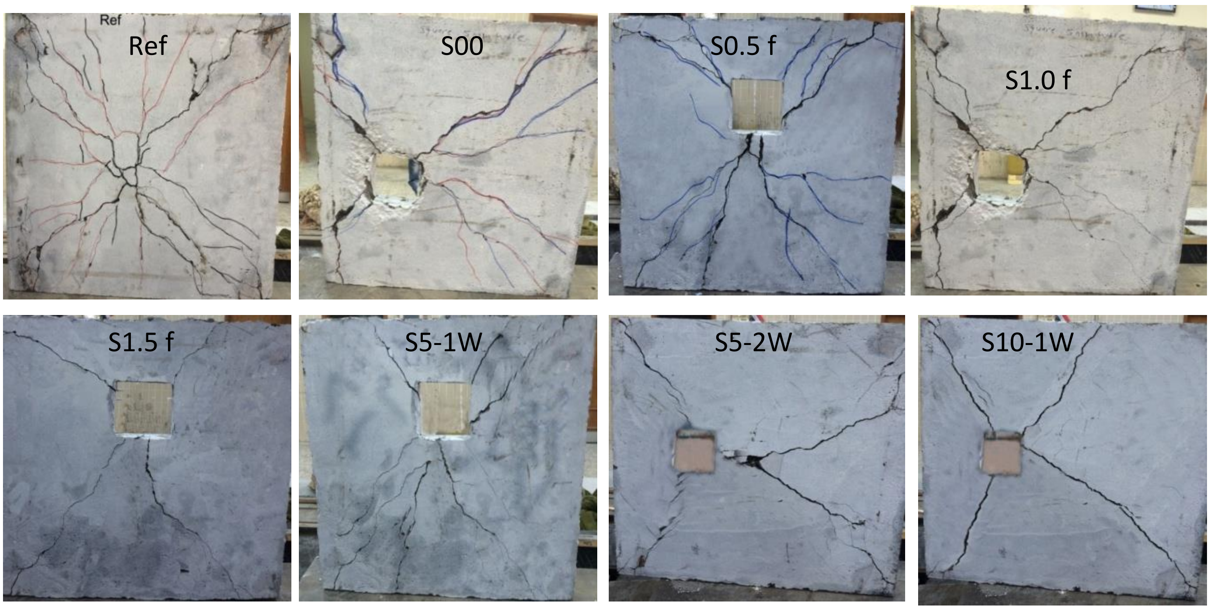

Fig. 4. Mode of failure and crack pattern of control slab and slabs with square openings.

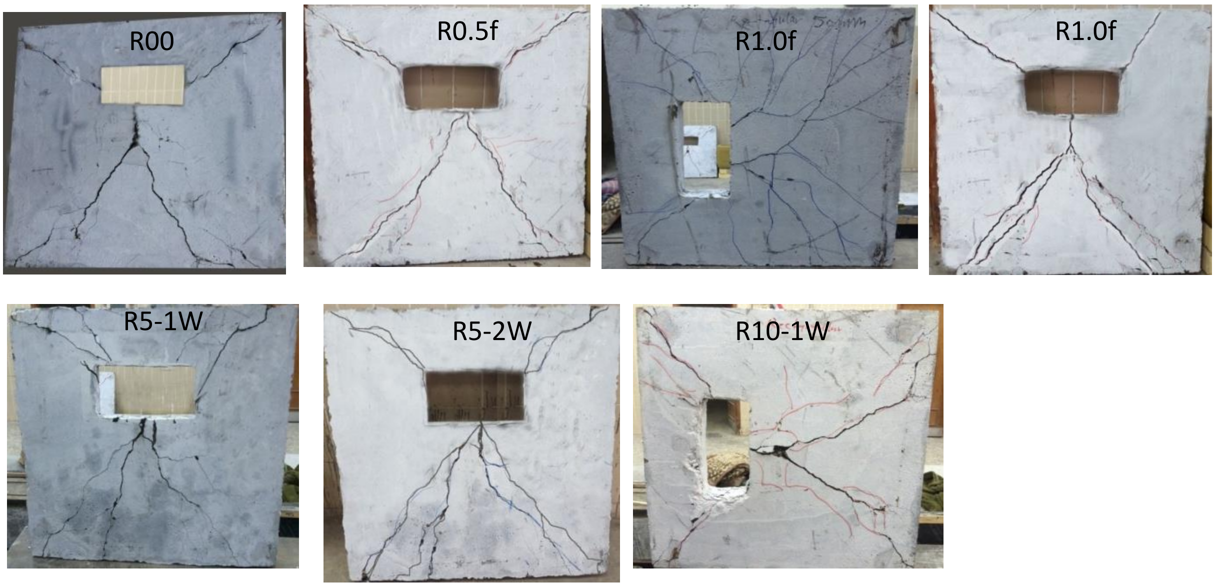

Fig. 5. Mode of failure and crack pattern of slabs with rectangular openings.

4.2. First crack and ultimate loads

The cracking and ultimate loads are presented in Table 4. From this table can be observed that, the first cracking load decreases for slabs with openings compared with Ref slab, where the first crack load of ref. slab was 34.2 kN and it reduced to 25.5 and 20.8 kN for slabs with square and rectangular openings(S00,R00) respectively. This is attributed to the cutouts causes cutting in steel reinforcement and concrete body and this is consider as the defect point in slab structure.

Table 4 shows that, for the slabs with square openings (S0.5f, S1.0f and S1.5f), the increase of in concrete from 0.5 to 1.5 % leaded to increase of the first cracking load from 7% to 21% more than that of slab without fibers (S00). This is due to that the tension strength of concrete increase with increasing the fibers content in concrete. For slabs with rectangular openings (R0.5f, R1.0f and R1.5f), the same case occurred, but increase was 8% to 36% more than that of slab (R00) respectively. That means the effect of fibers on the first crack load of slab with rectangular openings is very clear compared with the case of square openings.

From Table 4 it can be observed that, the crack load of slabs with square and rectangular opening strengthen with wire mish was higher than that of the slabs without strengthening and with strengthening by steel fibers. This is due to that the wire mish around the cutouts provided confinement for it and result in the distribution of stresses through wire mish and not concentration it in edges of openings.

For the ultimate load, Ref slab gave the ultimate load values 28.9% and 39.7% higher than that of S00 and R00 slabs respectively. This means that there is significant effect for cutout size on the ultimate strength of slabs failed in flexure.

From Table 4 it can be noted that the ultimate load increases with increasing the fibers content for both two types of slabs with openings , where slabs S0.5f, S1.0f and S1.5f showed 13.4% , 14.3% and 17.0% higher ultimate load than S00 slab, and slabs R0.5f, R1.0f and R1.5f exhibited 22.2 , 25.9 and 27.8% higher ultimate load than slab R00.

For the slabs with square openings (S0.5f, S1.0f and S1.5f), the increase of in concrete from 0.5 to 1.5 % leaded to increase of the ultimate load from 13.7 to 19.4 % more than that of slab without fibers (S00). This is due to that the tension strength of concrete increases with increasing the fibers content in concrete. For slabs with rectangular openings (R0.5f, R1.0f and R1.5f), the same case occurred, but increase was 22.2% to 27.8% more than that of slab (R00) respectively. That means the effect of fibers on the first crack load of slab with rectangular openings is very clear compared with the case of square openings.

For the slab with wire mish, the ultimate load of S5-1W, S5-2W andS10-1W slabs gave the ultimate load values 19.4%, 24.7% and 25.4% higher than that of S00 slabs respectively, and R5-1W, R5-2W and R10-1W slabs exhibited 29.9%, 33.5% and 35.4% ultimate load greater than that of S00 slabs respectively. This means that there is significant effect for wire mish size and distribution on the ultimate strength of slabs failed in flexure. The effect of wire mish on the ultimate load of slab with rectangular openings is very clear compared with the case of square openings. It is noted that two layers of 5mm wire mish give almost the same effect as that of one layer of 10 mm wire mish.

Test results presented in Table 4 showed that the two strengthening techniques increased the load-carrying capacities of the slabs with openings. The wire mish is more effective than the steel fiber technique. Use of wire mish enable the slabs with square and rectangular openings to restore 89.2 % and 81.6 % of full load capacity of slab without openings respectively, also the steel fibers hence enabled the slab to restore 83.2% and 77 % of its full capacity respectively after it was down because of the openings to 71.1% and 60% of full load capacity of slab without openings. The wire mish and steel fiber reduced the cracks at the inside faces of opening and also wire mish prevent it at the inside corners.

4.3. Deflections

The magnitude of the deflection is very important in the discussion of the load carrying capacity of the slabs. Figs. 6-9 show comparatives in load _deflection relationships for each group. From Figs. 6 and 8 it can be observed that, the proposed method of using the steel fiber in slab with square opening showed more stiff behavior than use it in slab with rectangular opening. It is found that at the same load, the deflection decreased as fiber content increases. From Figs. 7 and 9 it can be observed that, the proposed method of using the wire mish in slab with square opening showed more stiff behavior than use it in slab with rectangular opening. It is found that at the same load, the deflection decreased as wire mish length and number of layers increases. Also Figs. 7 and 9 shows that, the slabs with two layers wire mish of 5mm width exhibited almost same behavior of the slab with one layer wire mish of 10 mm width.

The effect of opening very clear on the load capacity and the maximum deflection occurs for slab with square opening. Fig. 7 for slabs with steel fiber, the worst case of opening effect was for slab with rectangular opening. Fig. 8 shows the effect of wire mish strengthening, the behavior was like that in Fig. 9 the square opening reduced the load capacity and increased the maximum deflection.

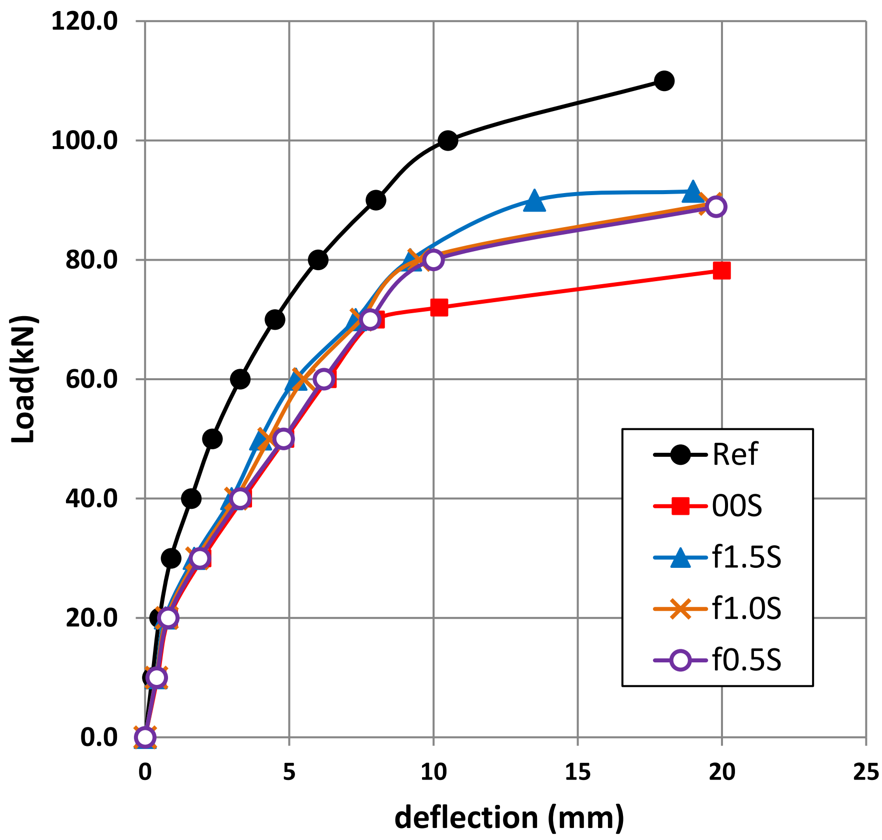

Fig. 6. Comparison load deflection curve for slabs with square openings strengthen with steel fibers.

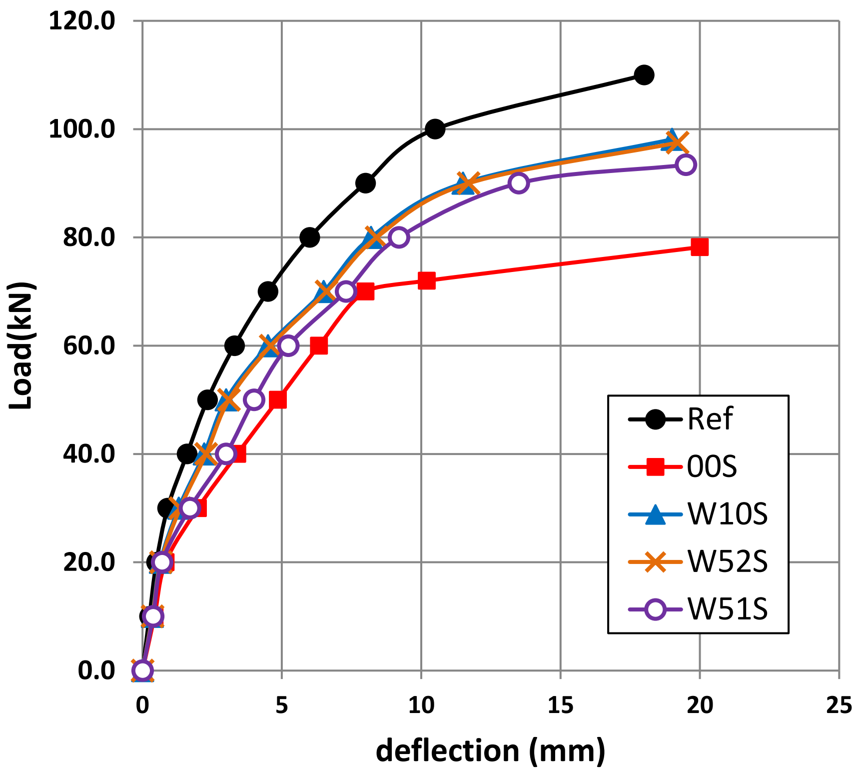

Fig. 7. Comparison load deflection curve for slabs with square openings strengthen with wire mesh.

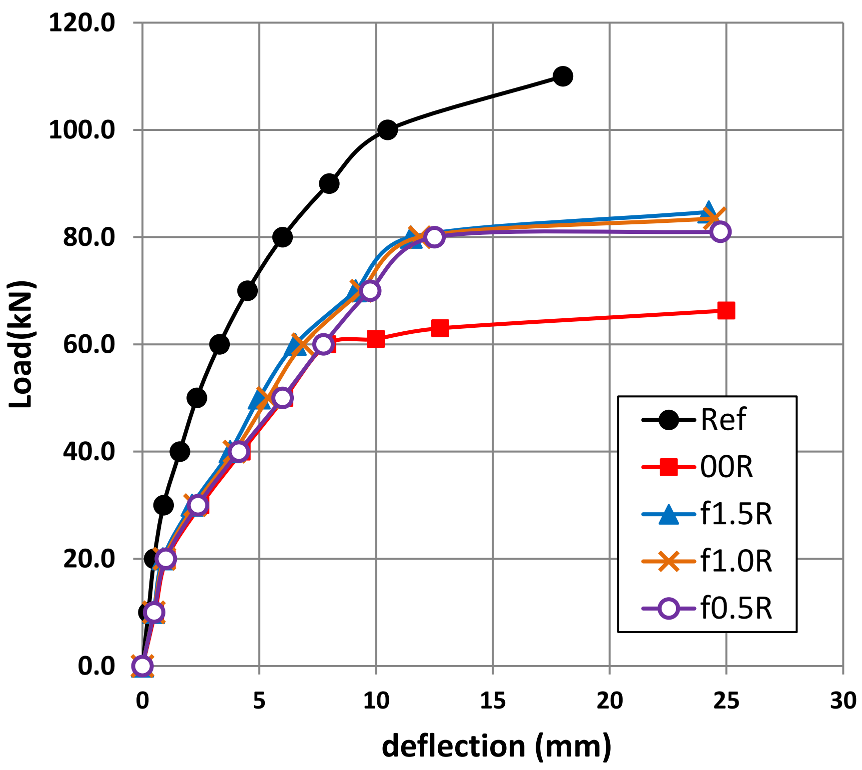

Fig. 8. Comparison load deflection curve for slabs with rectangular openings strengthen with steel fibers.

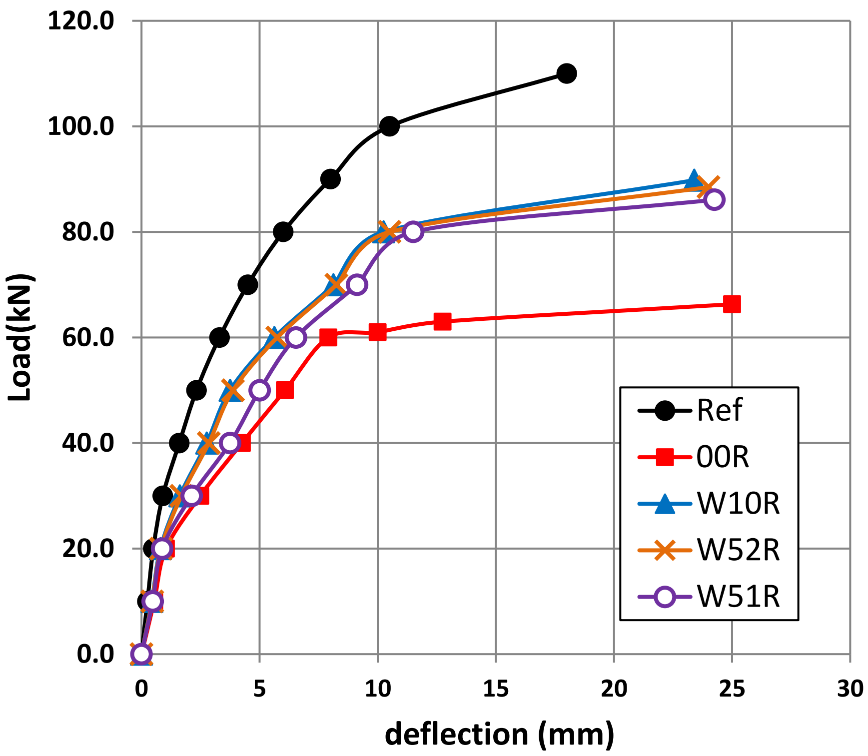

Fig. 9. Comparison load deflection curve for slabs with rectangular openings strengthen with wire mesh.

5. CONCLUSIONS

Based on the experimental results presented in this study, the following conclusions can be made:

1. Solid slab gave 28.9% and 39.7% ultimate load higher than that of slabs with square and rectangular openings respectively.
2. The two strengthening techniques (wire mish strips and steel fiber adding) enabled the slabs to recover some of full load capacity of solid slabs.
3. The use of wire mish strips around openings is more effective than the steel fiber distributed through a slab body.
4. The slabs with two layers wire mish of 5mm width exhibited almost same behavior of the slab with one layer wire mish of 10 mm width.
5. Wire mish and steel fiber reduced the cracks at the inside faces of the opening while wire mish prevent it at the inside corners of opening.

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