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STUDY OF THE EFFECT OF STRENGTHENING OF OPENINGS ON THE LOADED REINFORCED CONCRETE SLABS

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الملخص

يعتبر نظام البلاطات المسطحه (اللاكمريه) هو الأكثر إستخداماً فى مجال صناعة البناء نظراً لما تتميز به من مرونه فى التعديلات المعماريه كما أنها تعطى إرتفاع أكبر للدور لعدم وجود كمرات ساقطه علاوه على سهولة وسرعة تنفيذها .

ونتيجه لشيوع إستخدام هذا النوع من البلاطات فى الكثير من المبانى والتى تتطلب عمل فتحات للعديد من الإستخدامات العامه مثل صواعد الكهرباء والسلالم والمصاعد وغيرها من الإستخدامات , لذلك فإن دراسة تأثير الفتحات فى البلاطات المسطحه يعتبر من أهم مجالات الدراسه خاصة وأن الفتحه تقلل من مقاومة البلاطه فى مواجهة الأحمال الواقعه عليها وخاصة القص الثاقب .

ولقد ركزت معظم الدراسات السابقه على متطلبات الأكواد وحدود أبعاد الفتحات , لذا فإن تلك الدراسات كانت مناسبه فقط للفتحات الصغيره ولم تركز على تأثير وجود الفتحات الكبيره على البلاطات .

وفى العقد الأخير ظهرت العديد من الأبحاث التى تناولت تدعيم وتقوية البلاطات ذات الفتحات لزيادة قدرتها على مقاومة الأحمال التى تتعرض لها , ولذلك أصبح مجال التدعيم من أهم مجالات الهندسه المدنيه . وهذه الأبحاث فى التدعيم لم يقتصر إستخدامها على المواد التقليديه , ولكنها أيضا تركز على إستخدام المواد الحديثه مثل البوليمرات المسلحه بالألياف الزجاجيه وألياف الكربون وغيره من المواد الحديثه الأخرى .

وهذه الرساله تدرس إستخدام أسياخ مسلحه بألياف البازلت فى تدعيم الفتحات فى البلاطات المسلحه من خلال إختبار أحد عشرة بلاطه بها فتحات بأماكن مختلفه ومرتكزه على أعمده مربعه فى مركز البلاطه , وتنقسم هذه البلاطات إلى خمس مجموعات , الأولى بلا تدعيم تتكون من ثلاث بلاطات , والمجموعات الثانيه والثالثه والرابعه تم تدعيمها بأعداد مختلفه من صفوف البازلت , أما المجموعه الخامسه فقد تم تدعيمها بحديد تسليح تقليدى للمقارنه وقد تم تحميل جميع البلاطات بحمل رأسى مركزى حتى الوصول لحمل الإنهيار .

وقد تناولت هذه الدراسه عدداً من المتغيرات مثل تأثير وجود الفتحه فى البلاطه , وتأثير موضع الفتحه , وتأثير التدعيم بأسياخ البازلت , والمقارنه بين إستخدام البازلت والحديد التقليدى فى عملية التدعيم .

ABSTRACT

The flat slab system is currently widely used in construction. It permits architectural flexibility, more clear space, less building height, easier formwork and shorter construction time. As a result of that the buildings which consist of flat slab must to be devoted to requirements of connecting to public utilities that required opening to be placed in the system. This thesis study using of Basalt fiber rebars BFRP in the strengthening of flat slabs, it presents tests to failure of nine full-scale slabs with openings with various locations of openings and supported on square columns under vertical load. The control three slabs did not have any shear reinforcement, but the rest slabs were strengthened with Basalt and traditional steel for comparison. All tested specimens were subjected to concentric vertical load. The parameters included in the investigation are different opening locations of opening near column, the effect of existing of opening in tested slabs, the effect of using different Basalt systems for strengthening and the effect of using traditional steel . Opening with different distance from column corner or column face, are the parameters taken in the parametric study.

1. Introduction

Reinforced concrete (RC) slabs have been widely used for the multi-story buildings, Small openings are required in the slab 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 redistribute 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 increasing use of fiber-reinforced polymer (FRP) bars encourages utilizing new fiber types , such as basalt fibers , rather than the commonly used fibers such as glass , aramid and carbon . However, extensive investigations are needed to evaluate the short and long term characteristics of these new developed rebar's . One of the benefits of using Basalt Fiber Reinforced Polymer (BFRP) as a strengthening material in concrete is that it is non-corrosive. In places where concrete structures are close to the sea, like houses or bridges, the maintenance of the concrete is needed on regular basis. In such conditions the common rebar is in constant danger of corrosion and therefore could become weak and hazardous in a short period of time.

Basalt rock can be used to make not only basalt bars but also basalt fabrics, chopped basalt fiber strands, continuous basalt filament wires and basalt mesh. Some of the potential applications of these basalt composites are: plastic polymer reinforcement, soil strengthening, bridges and highways, industrial floors, heat and sound insulation for residential and industrial buildings, bullet proof vests and retrofitting and rehabilitation of structures .

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Marek, et al [2] has done preliminary studies on BFRP rebars by testing its tensile test by unique testing equipment and analyzing the type of failure of BFRP strands and incorporating it to the failure modes in structures. Studies on stress-strain behavior was studied which was noted to be linear and completely different from steel reinforced structures which is considered to be a major disadvantage as structures involving large plastic deformations cannot be made by this kind of reinforcement.

Pouya and Anil [4] carried out tests on progressive deformation in concrete due to sustained loading is analyzed along with exposure to alkaline solution at high temperatures and the results were compared with the acceptable standard values as per American Concrete Institute (ACI). It has been analyzed that the creep rupture strength of BFRP rebars are comparatively lesser than their tensile strength, when compared to that of steel bars. The creep nature of BFRP rebars depends on its own fiber properties, resin and their bonding with each other.

Ahmed, et al [5] studied the factors of bonding strength and behavior of BFRP rebars in concrete. The test was based on pull out mechanism and the test results were incorporated with that of GFRP rebars. The bonding nature was compared with many parameters like, Embedded length into concrete surface; Material of bars and elasticity & Diameter of bars. Although BFRP and GFRP showed almost the same bond-slip curves, BFRP rebars showed an average of 75% increased bonding capacity than GFRP. The bonding behavior of BFRP rebars were studied based on (a) embedded length (b) modulus of elasticity (c) bar diameter, and was concluded by experimental verification that the bonding nature varied inversely in all the three parameters considered.

2. Experimental Work

2.1 Test specimens

Current experimental work includes nine RC square flat slab specimens have 1650 length and 150 mm thickness , which were designed so as the bending capacity prevail over the punching shear strength in order for slabs to fail in shear. The ordinary reinforcement ratio remained unchanged for all the tested slabs. Full details of specimens'geometry are presented in Figure (1) and summarized in Table 1

Table (1) Experimental program

Group	Sample	Dimensions (mm)	Thickness (mm)	Opening dims (mm)	RFT of slab	Description
1	S_{1a}	1650×1650	150	—	Top mesh 4Ø10/m Bottom mesh 10Ø12/m	Control (without strengthening)
	S_{1b}			300×300		
	S_{1c}			300×300		
2	S_{2a}	1650×1650	150	300×300		with one row of Basalt studs beside the column and the opening at distance d/2.
	S_{2b}			300×300		
3	S_{3a}	1650×1650	150	300×300		with two rows of Basalt studs beside the column and the opening at distance d/2 and d
	S_{3b}			300×300		
4	S_{4a}	1650×1650	150	300×300		with three rows of Basalt studs beside the column and longitudinal Basalt bars around the opening .
	S_{4b}			300×300		

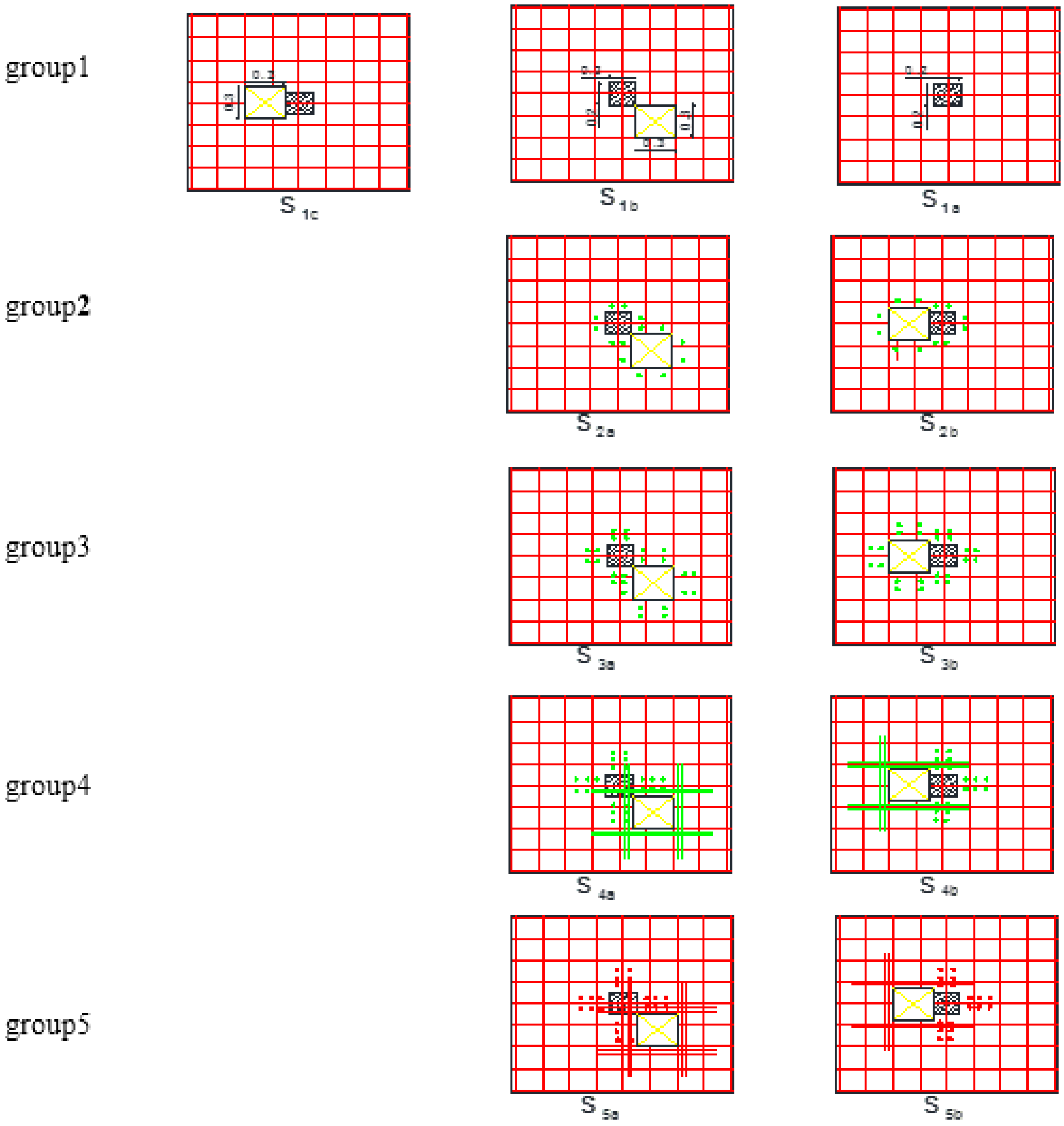

Fig (1) Details of typical specimens

2.2 Test setup

The testing frame was consisted of four steel I-beams rested on four steel columns. All tested slab specimens were supported on the testing frame during loading. The hydraulic jack is used for loading causing central load on the column as shown in Figure (2).

Fig. (2) Test setup

2.3 Test parameters

The following parameters were studied:-

1. Effect of the openings without strengthening.
2. Effect of the strengthening with one row of Basalt studs in the case of opening in different positions.
3. Effect of the strengthening with two rows of Basalt studs in the case of opening in different positions.
4. Effect of the strengthening with three rows of Basalt studs in the case of opening in different positions.

3. Analysis of Test Results

In this Chapter, the effect of openings, the effect of strengthening of openings using basalt fiber rebars with different positions. The crack patterns, modes of failure, load deflection curves, deflection profiles, area under load-deflection Curve, load strain curves, the ultimate loads and the maximum deflections at centroid of the slab for each tested specimen are analyzed as follows.

3.1 Effect of the openings without strengthening

This section illustrates the effect of existence of openings in tested specimens without any strengthening, the results were analyzed and a comparison among the tested specimens S_{1a} , S_{1b} and S_{1c} was done .

3.1.1 Cracks pattern and mode of failure

The cracks patterns and modes of failures for the tested specimens taking the effect of existence of openings are analyzed and comparing between them as follows. The effect of existence of openings on the cracks pattern and mode of failure was shown in Figure (3). The number of cracks increased, while the square shape of the punching failure increased. It is noted that, the tested specimens without openings failing in a similar manner that the tested specimens with opening , where the mode of failure for the tested specimens without openings was punching failure, but it was flexural punching for the tested specimens with opening when applying the concentric vertical load on the tested specimens.

Sa1 Sb1 Sc1

Fig (3) The effect of opening on crack patterns and modes of failure

3.1.2 Cracking load and ultimate load with corresponding deflection

The effect of existence of openings in tested slabs (S_{1b} , S_{1c}) comparing to a slab without opening (S_{1a}) on the values of cracking loads, ultimate loads and corresponding maximum deflections was summarized in Table (2). The ultimate load decreased from (307.5 kN to 190.5 kN) in specimen S_{1b} and from (307.5 kN to 190.2 kN) in specimen S_{1c} , and the deflection corresponding to the ultimate load decreased from (32.123 mm to 14.101 mm) in specimen S_{1b} and decreased from (32.123 mm to 16.784 mm) in specimen S_{1c} .

Table (2) Comparing between tested specimens where, Ultimate Load, Max Deflection and Energy Absorption Capacity for specimens S_{1a} , S_{1b} and S_{1c} .

Specimen	**Cracking Load (KN)**	**Ultimate Load (KN)**	**Max Deflection (mm)**	**Strain**	**Energy Absorption Capacity (KN.mm)**	**Failure Type**
S1a	76.4	307.5	32.123	3410	4938.911	Punching
S1b	59.2	190.5	14.101	2741	1343.12	Flexural Punching
S1c	55.9	190.2	16.784	2657	1596.16	Flexural
S2a	63.8	223.5	20.26	2520	2264	Flexural Punching
S2b	53.7	219	15.435	2460	1690	Flexural
S3a	59.4	204.5	17.05	2158	1734	Flexural
S3b	70	220.5	15.783	2160	1740	Flexural
S4a	54.3	197.5	19.129	2450	1889	Flexural
S4b	62.5	193	14.75	2320	1423.38	Flexural Punching

3.1.3 Load-deflection curve

Figure (4) shows the effect of opening on the behavior of tested specimens. When applying concentric load on the tested specimens , that the stiffness of RC flat slab with opening (S_{1b} , S_{1c}) was lower than RC flat slab without opening (S_{1a}) but it was no noticeable change in stiffness for the tested specimen S_{1b} and S_{1c} due to change of positions of openings. The area under this load-deflection curve which express the energy absorption capacity decreased with percentage 72.8% and 67.7% for tested specimens S_{1b} and S_{1c} respectively, it is shown clearly in Table (2).

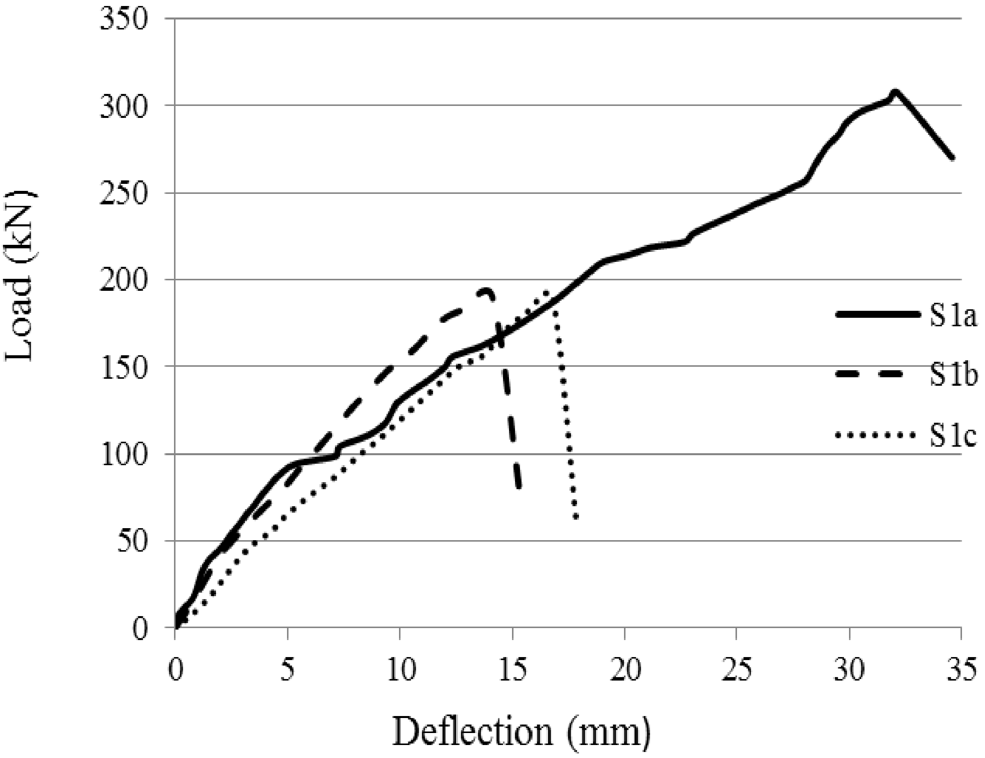

Fig (4) The effect of opening in different positions on the load-deflection curves.

3.2 Effect of the strengthening with one row of Basalt studs in the case of opening in different positions

This section illustrates the effect of strengthening with one row of Basalt studs around both column and opening in tested specimens with different positions, the results were analyzed and a comparison among the tested specimens S_{1b} , S_{1c} , S_{2a} and S_{2b} was done.

3.2.1 Cracks pattern and mode of failure

The cracks patterns and modes of failures for the tested specimens taking the effect of strengthening are analyzed and comparing between them as follows. The effect of strengthening with one row of Basalt on the cracks pattern and mode of failure was shown in Figure (5). The tested specimens without strengthening failing in a similar manner that the tested specimens with strengthening , where the mode of failure for the tested specimens S_{1b} and S_{2a} was flexural punching failure, but it was flexural for the tested specimens S_{1c} and S_{2b}

Fig. (5): The crack pattern of tested specimens s2a and s2b

3.2.2 Cracking load and ultimate load with corresponding deflection

The effect of strengthening with one row of Basalt studs in tested slabs (S_{2a} , S_{2b}) comparing to tested slabs without strengthening (S_{1b} , S_{1c}) on the values of cracking loads, ultimate loads and corresponding maximum deflections was summarized in Table (2), and the ultimate load increased from 190.5 kN to 223.5 kN in specimen S_{1b} and from 190.2 kN to 219 kN in specimen S_{1c} , and the maximum deflection corresponding to the ultimate load increased from 14.1 mm to 20.26 mm in specimen S_{1b} and decreased from 16.784 mm to 15.435 mm) in specimen S_{1c} .

3.2.3 Load-deflection curve

Figure (6) show the effect of strengthening with one row of Basalt studs on the behavior of tested specimens. The stiffness of the tested specimens without strengthening (S_{1b} , S_{1c}) was lower than the specimens with strengthening (S_{2a} , S_{2b}). The area under this load-deflection curve which express the energy absorption capacity increased with percentage 68.5 % and 6 % for tested specimens S_{1b} and S_{1c} respectively, it is shown clearly in Table (2).

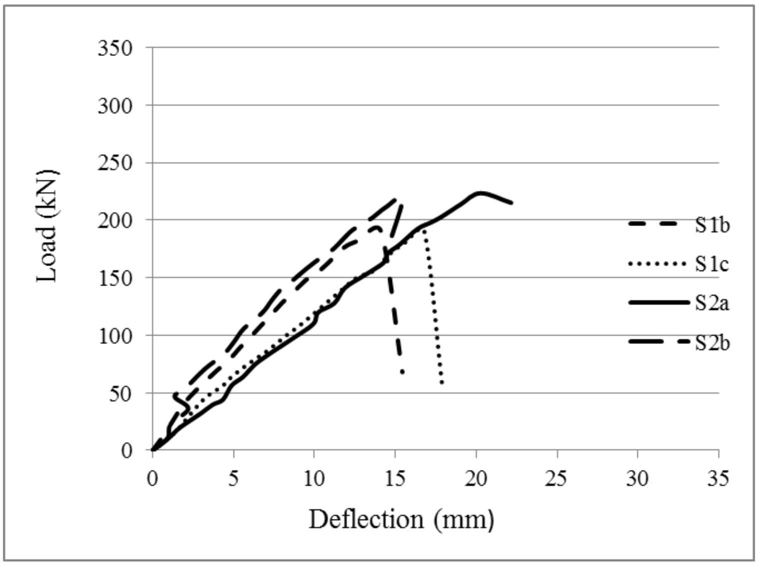

Fig (6) The effect of strengthening with one row of Basalt on the load-deflection curves.

3.3 Effect of the strengthening with two rows of Basalt studs in the case of opening in different positions

This section illustrates the effect of strengthening with two rows of Basalt studs around both column and opening in tested specimens with different positions, the results were analyzed and a comparison among the tested specimens S_{1b} , S_{1c} , S_{3a} and S_{3b} was done.

3.3.1 Cracks pattern and mode of failure

The cracks patterns and modes of failures for the tested specimens taking the effect of strengthening are analyzed and comparing between them as follows. The effect of strengthening with two rows of Basalt on the cracks pattern and mode of failure was shown in Figure (7). The tested specimens without strengthening failing in a similar manner that the tested specimens with strengthening, where the mode of failure for the tested specimen S_{1b} was flexural punching failure, but it was flexural for the tested specimens S_{1c} , S_{3a} and S_{3b}.

Fig (7) :The crack patterns and mode of failures (S_{3a} , S_{3b})

3.3.2 Cracking load and ultimate load with corresponding deflection

The effect of strengthening with two rows of Basalt studs in tested slabs (S_{3a} , S_{3b}) comparing to tested slabs without strengthening (S_{1b} , S_{1c}) on the values of cracking loads, ultimate loads and corresponding maximum deflections was summarized in Table (2).

It is clear from Table (2) , when applying the concentric vertical load on the tested specimens, that the ultimate load increased from 190.5 kN to 204.5 kN in specimen S_{1b} and from 190.2 kN to 220.5 kN in specimen S_{1c} , and the maximum deflection corresponding to the ultimate load increased from 14.1 mm to 17.05 mm in specimen S_{1b} and decreased from 16.784 mm to 15.783 mm) in specimen S_{1c} .

3.3.3 Load-deflection curve

Figure (8) show the effect of strengthening with two rows of Basalt studs on the behavior of tested specimens. The stiffness of the tested specimens without strengthening (S_{1b} , S_{1c}) was lower than the specimens with strengthening (S_{3a} , S_{3b}). The area under this load-deflection curve which express the energy absorption capacity increased with percentage 29 % and 9 % for tested specimens S_{1b} and S_{1c} respectively, it is shown clearly in Table (2).

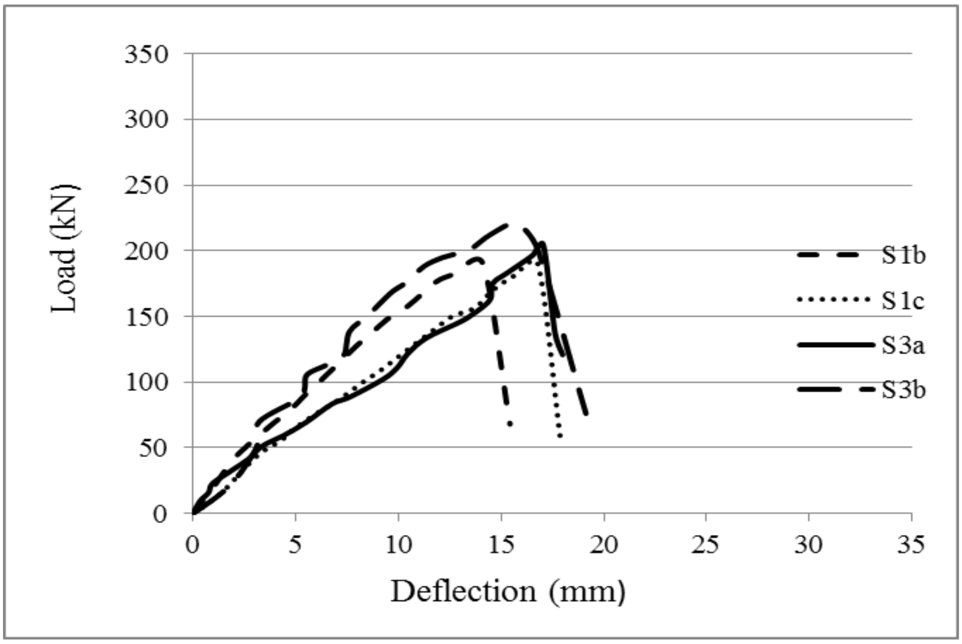

Fig (8) The effect of strengthening with two rows of Basalt on the load-deflection curves.

3.4. Effect of the strengthening with three rows of Basalt studs in the case of opening in different positions

This section illustrates the effect of strengthening with three rows of Basalt studs around column and longitudinal Basalt rebars around opening in tested specimens with different positions, the results were analyzed and a comparison among the tested specimens S_{1b} , S_{1c} , S_{4a} and S_{4b} was done.

3.4.1 Cracks pattern and mode of failure

The cracks patterns and modes of failures for the tested specimens taking the effect of strengthening are analyzed and comparing between them as follows. The effect of strengthening with three rows of Basalt on the cracks pattern and mode of failure was shown in Figure (9) **.** The tested specimens without strengthening failing in a similar manner that the tested specimens with strengthening, where the mode of failure for the tested specimen S_{1b} and S_{4b} was flexural punching failure, but it was flexural for the tested specimens S_{1c} and S_{4a}

Fig (9) the crack patterns and mode of failures (S_{4a} , S_{4b})

3.4.2 Cracking load and ultimate load with corresponding deflection

The effect of strengthening with three rows of Basalt studs in tested slabs (S_{4a} , S_{4b}) comparing to tested slabs without strengthening (S_{1b} , S_{1c}) on the values of cracking loads, ultimate loads and corresponding maximum deflections was summarized in Table (2). The ultimate load increased from 190.5 kN to 197.5 kN in specimen S_{1b} and from 190.2 kN to 193 kN in specimen S_{1c} , and the maximum deflection corresponding to the ultimate load increased from 14.1 mm to 19.12 mm in specimen S_{1b} and decreased from 16.784 mm to 14.75 mm) in specimen S_{1c} .

3.4.3 Load-deflection curve

Figure (10) show the effect of strengthening with three rows of Basalt studs on the behavior of tested specimens. The stiffness of the tested specimens without strengthening (S_{1b} , S_{1c}) was lower than the specimens with strengthening (S_{4a} , S_{4b}) . It is noted that strengthening using longitudinal Basalt bars has no effect on the stiffness of tested specimens. The area under this load-deflection curve which express the energy absorption capacity increased with percentage 40 % and decreased with percentage 10 % for tested specimens S_{1b} and S_{1c} respectively, it is shown clearly in Table (2).

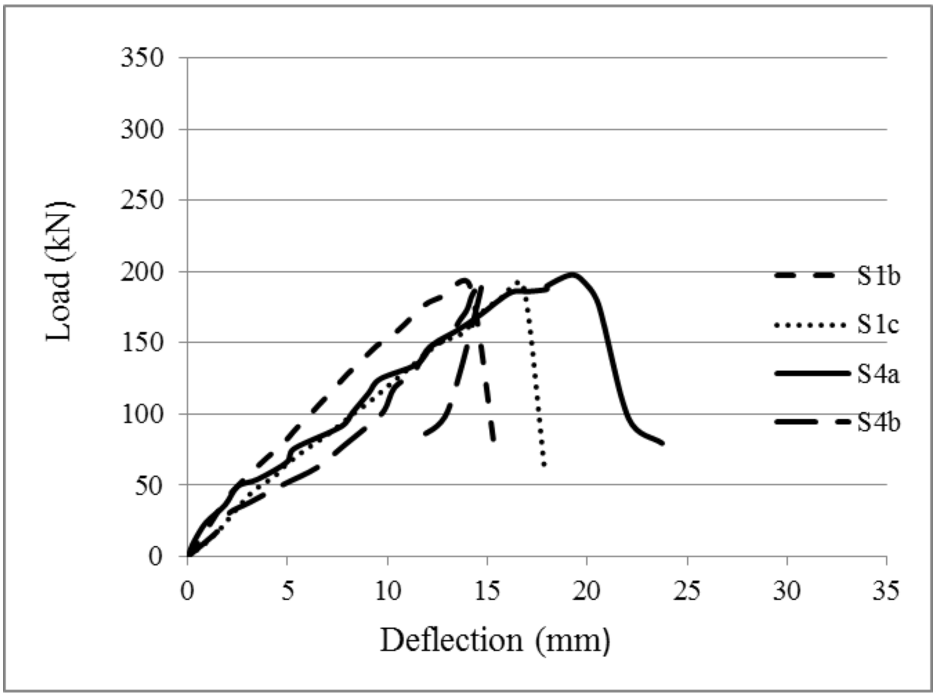

Fig (10) The effect of strengthening with three rows of Basalt on the load-deflection curves.

4.Conclusions

From the experimental study conducted in the present investigation, the following conclusions may be drawn:

1. The existence of the opening in the slab decreases the ultimate load capacity with ratio reach up to 30% .
2. The opening decreases cracking load and ductility, it decreases the energy absorption capacity with ratio reach up to 73 %.
3. The opening increases steel strain and concrete strain with ratio reach up to 90 %.
4. The opening increases number of cracks and convert the mode of failure from punching to flexural because of the cutting of main steel.
5. The position of the opening at the side of the column causes more cracks, less failure load and more deflection than the opening at the corner of the column, this happened because of decreasing the shear perimeter . Thus the position of opening at the side of the column is the worst position , it is recommended to avoid this position as possible.
6. The strengthening using one row of basalt studs around both column and opening enable the slab to regain almost 20% of its ultimate load capacity.

5. References

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