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Analytical analysis of Light-weight Concrete slabs under punching Load

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ملخص البحث

لتحسين قوة مقاومة القص للخرسانة خفيفة الوزن تم عمل دراسة نظرية مكونة من ٢٥ عينة من البلاطات الخرسانية المسلحة خفبفة الوزن بمقاومة مميزة ٢٥ ن/مم^2 تحتوي على العديد من المتغيرات. تم اختبار العينات نظربا باستخدام برنامج ANSYS 10.0 للتحليل الغير خطي. نتائج الاختبار تظهر أن الحد الأقصى لتحسن أحمال الأنهيار الناتجة عن خلط الالياف مع الخرسانة هي ٨١ ٪ لنسبة ألياف ٢ ٪ من الحجم الخرساني .

Abstract

Analytical parametric study to investigate the influence of Light-Weight Concert strength, the arrangement, type, yield strength and amount of shear reinforcement steel, tensional and compressive reinforcement steel ratios and the use of steel fiber as shear reinforcement in punching shear behavior of Light-Weight Concrete flat slabs was established. Twenty five flat slab specimens investigated analytically with concrete strength 25 MPa. ANSYS 10.0 software package was used for non-linear analysis. The parameters were tensile steel, compressive steel, shear reinforcement and steel fibers. The maximum enhancement in the punching capacity was 81.0% for steel fiber ratios of 2.0%.

Introduction

The start of the use of flat slabs supported by columns in the beginning of the 20th century led to various researches on the punching strength of flat slabs. One of the most ways to solve the slab-column connection problem is to decrease the weight of the reinforcement concrete slab. The use of foam as a type of admixture for reinforcement concrete tends to develop a new type of concrete called Light Weight Concrete (LWC). However, LWC has disadvantages when compared with normal weight concrete, such as higher creep and shrinkage, greater deflection, and lower splitting tensile strength.

Khaleel et al. (2013) [1] studied the effect of use Fiber Reinforced Polymers (FRP) technique to strengthen the slab–column connection under punching shear. The test results indicated that using steel links, GFRP and CFRP stirrups of the same area increased the initial cracking load by 229%, 35% and 47%, respectively, and the ultimate capacity by 60%%, 60% and 733%, respectively compared with control specimens. The surface failure of tested specimens forms a nearly square shape with tension slab side. Zaher et al. (2015) [2] studied the self-compacting lightweight Concrete (LWC) Slabs punching shear behavior. Polystyrene foam used as a partial aggregate's replacement to reduce the concrete dry unit weight from 23.0 kN/m^3 to 18.5

kN/m^3. Nine medium scale RC slabs were statically examined to failure under concentric axial punching loading. The concrete type, thickness of slab, amount of shear reinforcement and area of loaded plate were the test parameters. The test results indicated that the use of LWC slab when compared to the control slab with nearly similar concrete grade resulted in structural degradations. These degradations of LWC specimens were most pronounced in the post-cracking stage until failure, and included less uniform failure crack patterns, lower post cracking stiffness until failure. Youm et al. (2013) [3] studied the punching shear resisting capacity of lightweight concrete slab. The type of lightweight aggregates was the test parameter and compared with that of normal-weight concrete slab. The results indicated that the surface angle of punching shear failure is significantly affected by the types of lightweight aggregates used.

Caratelli et al. (2016) [4] studied punching shear behavior of lightweight fiber reinforced concrete slabs. Three full-scale slabs, simulating bridge decks, were tested to investigate the effect of lightweight fiber reinforced material on the punching shear resistance. The test results showed that the use of steel fiber reinforced concrete appears a suitable and effective solution for increasing the punching resistance of typical bridge decks. An increase of punching strength of about 48% with respect to an ordinary concrete slab was adopted. A sharp increase of the ultimate displacement and ductility is further measured.

Material aspects of Light Weight Concrete Aggregates (LWCA) have been widely studied by several researchers. Cui et al. [5] proposed the compressive strength, elastic modulus and peak strain of LWCA. Go et al. [6] studied thermal properties of LWCA. Costa et al. [7] studied shrinkage prediction of high-strength LWCA. In addition, Chung et al. [8] evaluated the void distribution and the stiffness of lightweight aggregates using CT imaging. In the case of punching shear behavior of LWCA slab, Cho et al. [9], Marzouk et al. [10], and Pantelides et al. [11] studied the punching shear strength of LWCA slab or deck.

Analytical program

This paper introduces a non-linear finite element analysis; NLFEA, to obtain the analytical results from applying the punching shear strength provisions given in available different design codes. Non-linear analysis conducted using ANSYS 10.0 software package.

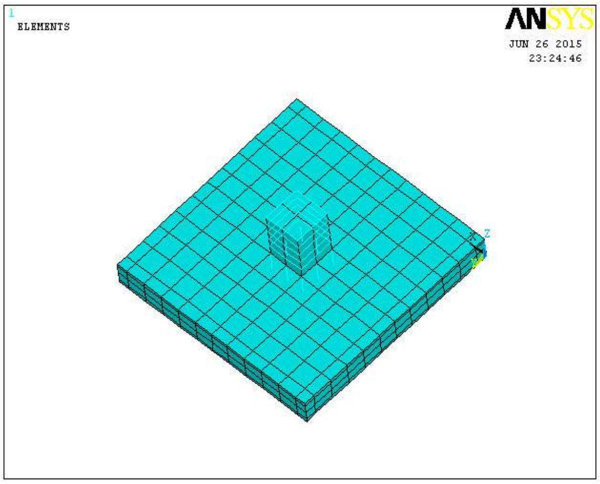
Non-linear finite element analysis

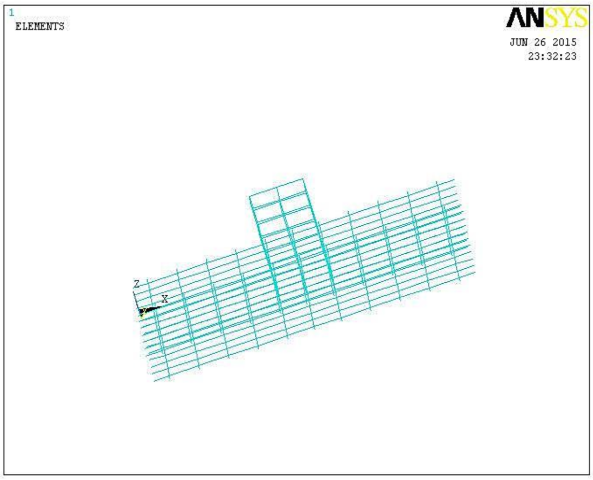
The non-linear finite element analysis in this part was carried out using a computer program “ANSYS 10.0”. The load-deflection properties are considered the most important tool in studying the punching behavior of test light-weight concrete slabs. In the next section a brief discussion for geometric and characteristics for NLFEA modeling for slab specimens will be introduced.

Modeling of tested specimens

Specimen geometry and elements characteristics

The slabs were tested as simply supported along the four sides, shown in figure (1). According to ANSYS technical manual, the 3-D element Solid65 was used to model the concrete element. The Solid65 element is able to present of tension cracks and compression crushing for concrete. The properties of the 3-D Solid65 element are shown in Figure (2). linear and non-linear responses of the concrete were also included. In this study, the reinforcing steel bars were used as a 2-node bar (linear) element (Link8).





a) Concrete element. b) Steel bar element.

Fig. 1 Typical idealization of test slab

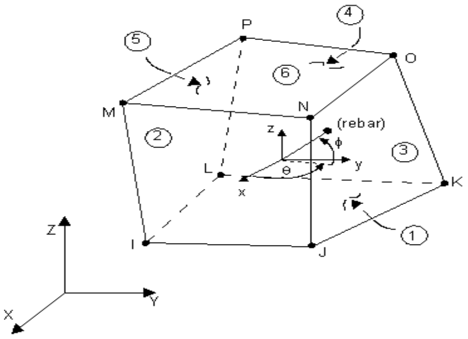


Fig. 2 Geometry of 3-D Solid65 element (concrete element).

Modeling of concrete material

The concrete material model is characterized by its ability to present the failure of brittle materials. Cracking modes and crushing failure modes both were included. Input strength properties f_t, f_c, f_{cb}, f_1 and f_2 are required. The ultimate compressive strength f_c, was taken equal $0.85xf_{cu}$ for all slab specimens, and f_t was taken as recommended by ACI specifications, ($f_t = 0.1\ f_c$). The other parameters were taken with recommended default values ($f_{cb} = 1.2\ f_c$, $f_1 = 1.45\ f_c$, *and* $f_2 = 1.725\ f_c$). Also, the shear transfer coefficient in closed and open crack are required. Shear transfer coefficients were taken as 0.2 for open crack and 0.65 for closed crack. A value of 0.6 for stress relaxation after cracking was taken in the analysis as recommended by technical manual of the software package.

Modeling for steel reinforcement material

The stress-strain curve of steel bars embedded in concrete shown in figure (3).

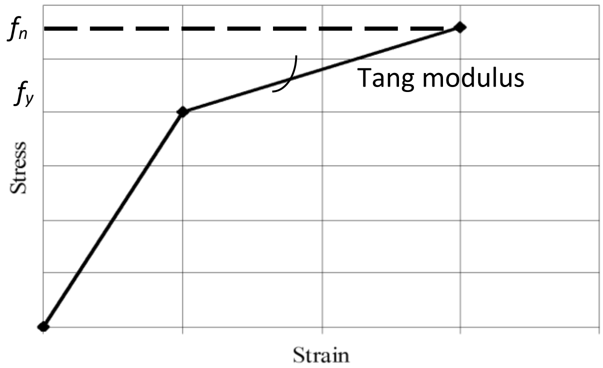


Fig. 3 modeling of reinforcing steel material using bilinear kinematic hardening.

Analytical procedure

The numerical solution scheme designed for non-linear analysis was an increasing rate load procedure. For each load increased, an iterative solution done was a combination of the definite convergence rate of the standard Newton-Raphson method and the low cost of the modified Newton-Raphson method in which the stiffness was recalculated every loading step.

Parametric studies

Ultimate failure loads and load deflection response were recorded for all specimens followed by a comprehensive study to investigate the effect of each parameter on the punching shear response of light-weight concrete slab specimens in terms of ultimate failure loads and load deflection response. Twenty five slab specimens investigated analytically with concrete strength 25 MPa, and divided based on investigation parameters, Table (1) displayed that the slab specimens are identical in concrete dimensions but differentiated according to flexural reinforcement ratio in tension and compression and shear reinforcement (ratio, arrangement, type and yield strength) included.

Parametric study outputs

Table (2) displayed the analytical ultimate failure loads for all slab specimens used in the parametric study. Also, load deflection relationship for all specimens has illustrated to reveal the influence of each parameter on the test slabs.

Table 1 specimen details for analytical study.

Specimen	Bottom RFT	Top RFT	Type of SR	F_y for SR	Area of SR	Arrangement
LWS_{1-1}	0.5%	N/A	N/A	N/A	N/A	N/A
LWS_1	0.75%	N/A	N/A	N/A	N/A	N/A
LWS_{2-2}	0.9%	N/A	N/A	N/A	N/A	N/A
LWS_2	1.1%	N/A	N/A	N/A	N/A	N/A
LWS_{3-3}	1.5%	N/A	N/A	N/A	N/A	N/A
LWS_3	1.9%	N/A	N/A	N/A	N/A	N/A
LWS_4	1.1%	0.44%	N/A	N/A	N/A	N/A
LWS_5	1.1%	0.75%	N/A	N/A	N/A	N/A

LWS_6	1.1%	1.1%	N/A	N/A	N/A	N/A
LWS_{7-1}	1.1%	0.75%	Single leg stirrups	240 MPa	400 mm^2	Perpendicular
LWS_7	1.1%	0.75%	Single leg stirrups	360 MPa	400 mm^2	Perpendicular
LWS_{7-2}	1.1%	0.75%	Single leg stirrups	400 MPa	400 mm^2	Perpendicular
LWS_{8-1}	1.1%	0.75%	Single leg stirrups	240 MPa	600 mm^2	Perpendicular
LWS_8	1.1%	0.75%	Single leg stirrups	360 MPa	600 mm^2	Perpendicular
LWS_{8-2}	1.1%	0.75%	Single leg stirrups	400 MPa	600 mm^2	Perpendicular
LWS_{9-1}	1.1%	0.75%	Single leg stirrups	240 MPa	900 mm^2	Perpendicular
LWS_9	1.1%	0.75%	Single leg stirrups	360 MPa	900 mm^2	Perpendicular
LWS_{9-2}	1.1%	0.75%	Single leg stirrups	400 MPa	900 mm^2	Perpendicular
LWS_{10}	1.1%	0.75%	Single leg stirrups	360 MPa	400 mm^2	Radial
LWS_{11}	1.1%	0.75%	Single leg stirrups	360 MPa	600 mm^2	Radial
LWS_{12}	1.1%	0.75%	Single leg stirrups	360 MPa	900 mm^2	Radial
LWS_{5-1}	1.1%	0.75%	Steel fiber	360 MPa	0.5%	smeared
LWS_{5-2}	1.1%	0.75%	Steel fiber	360 MPa	1.0%	Smeared
LWS_{5-3}	1.1%	0.75%	Steel fiber	360 MPa	1.5%	Smeared
LWS_{5-4}	1.1%	0.75%	Steel fiber	360 MPa	2.0%	smeared

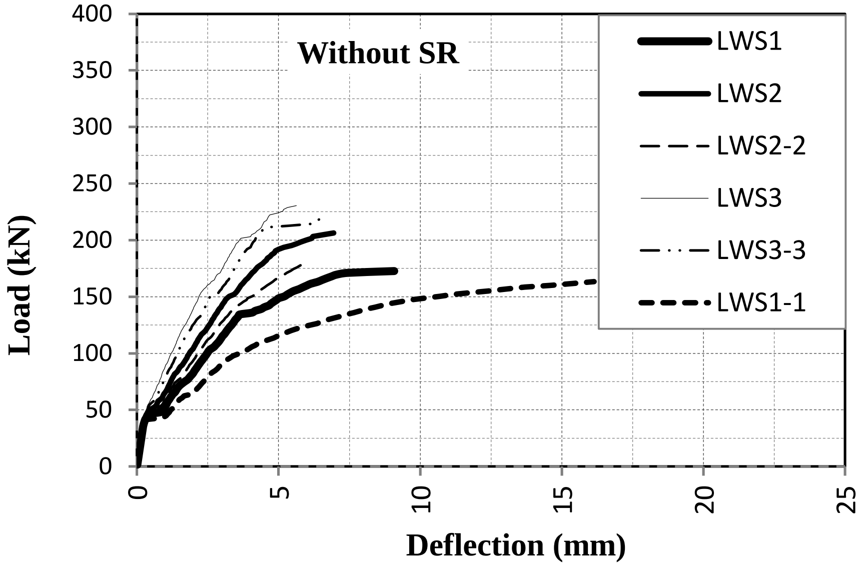
Table 2 analytical failure loads for specimens

Specimen	**Analytical ultimate load (kN)**	**Specimen**	**Analytical ultimate load (kN)**
LWS_{1-1}	163.5	**LWS_{8-1}**	278.5
LWS_1	173	**LWS_8**	278.5
LWS_{2-2}	181	**LWS_{8-2}**	286.5
LWS_2	206.5	**LWS_{9-1}**	288
LWS_{3-3}	221	**LWS_9**	288
LWS_3	230.5	**LWS_{9-2}**	291
LWS_4	210	**LWS_{10}**	281.5
LWS_5	221	**LWS_{11}**	286.5
LWS_6	230.5	**LWS_{12}**	291
LWS_{7-1}	261	**LWS_{5-1}**	281.5
LWS_7	266	**LWS_{5-2}**	333
LWS_{7-2}	273.5	**LWS_{5-3}**	368
		LWS_{5-4}	401.5

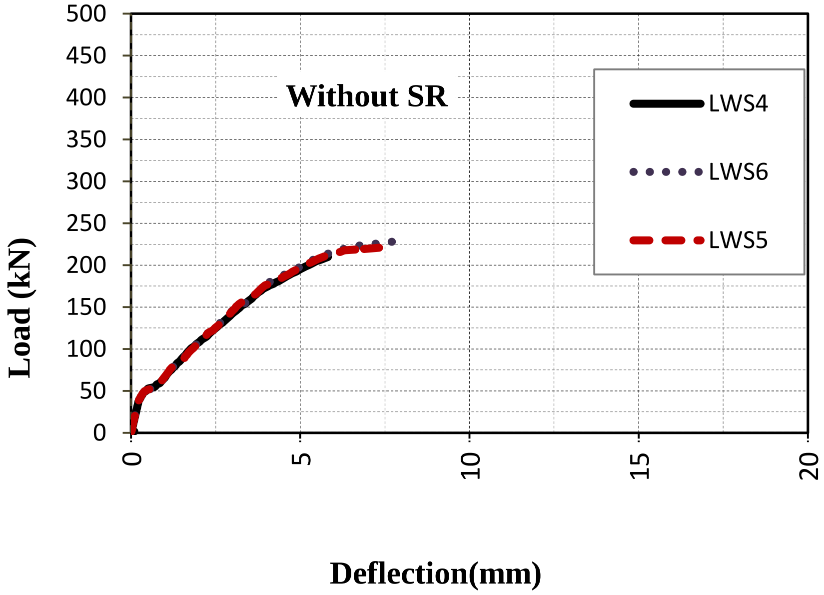
Investigation of parametric study results

Flexural reinforcement effect

From the analytical results the tensile flexure steel ratio had a remarked effect on the punching shear load capacity. As shown in the study, with the wide range tensile steel ratio (from 0.50% to 1.90%) used in the study the maximum achieved enhancement to ultimate failure load was about 42.0%,shown in table (2) and Figure (4-a). Also, the effect of compressive steel was slightly small on the punching share capacity. For the three slab specimens with top reinforcement a 10% enhancement achieved with increasing the compressive steel ratio, shown in table (2) and Figure (4-b).



a) Specimens LWS_1, LWS_{1-1}, LWS_2, LWS_{2-2}, LWS_3, and LWS_{3-3}.

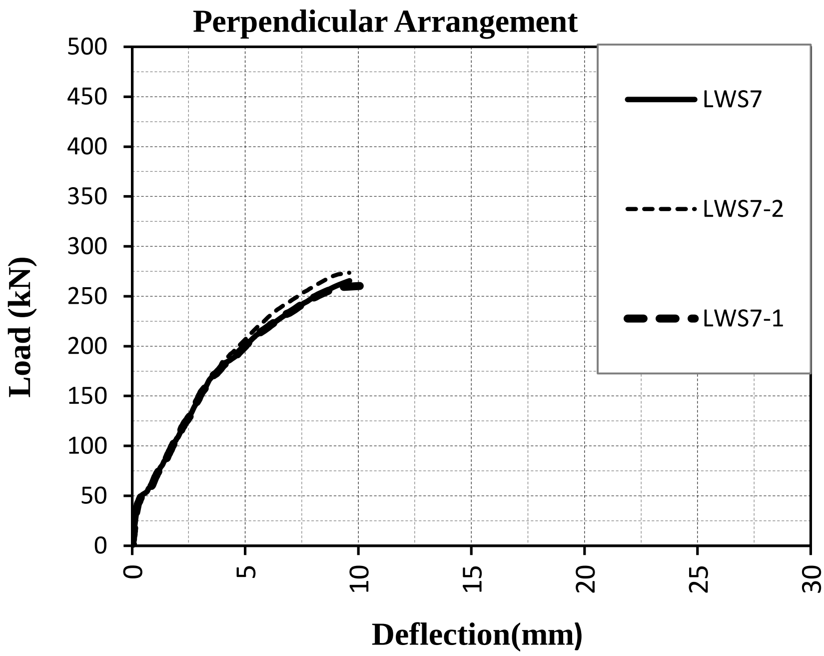


b) Specimens LWS_4, LWS_5,LWS_6,

Fig.4 Analytical Results for flexure steel.

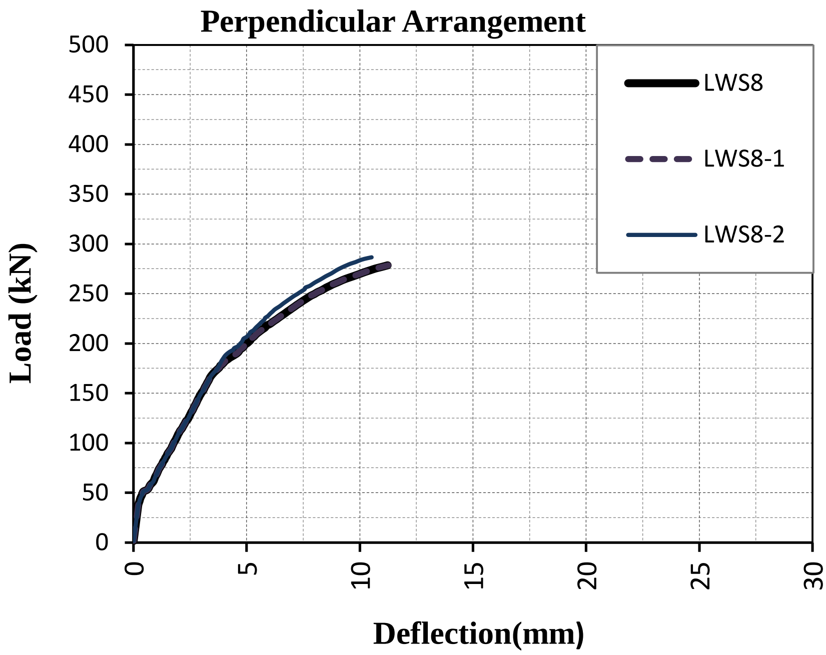
Shear reinforcement contribution

Two type of shear reinforcement arrangement and three values of yield strength for shear reinforcement steel considered a fair judgment can be adopted for twelve slab specimens with single leg stirrups as shear reinforcement. The analytical analysis showed a higher evaluated contribution for shear reinforcement on punching shear capacity. The maximum enhancement achieved in punching load capacity due to perpendicular shear reinforcement arrangement was 30.0% with regardless of yield strength for shear reinforcement steel, shown in table (2) and figure (5-a,b,c). Approximately the same capacity achieved for specimens with radial shear reinforcement arrangement, and the maximum enhancement recorded was 32.0%, shown in table (2) and figure (5-d). It was noted that the yield strength of shear reinforcing steel has a neglected effect on punching shear capacity. That may be explained because all shear reinforcement did not reach the yield strength.

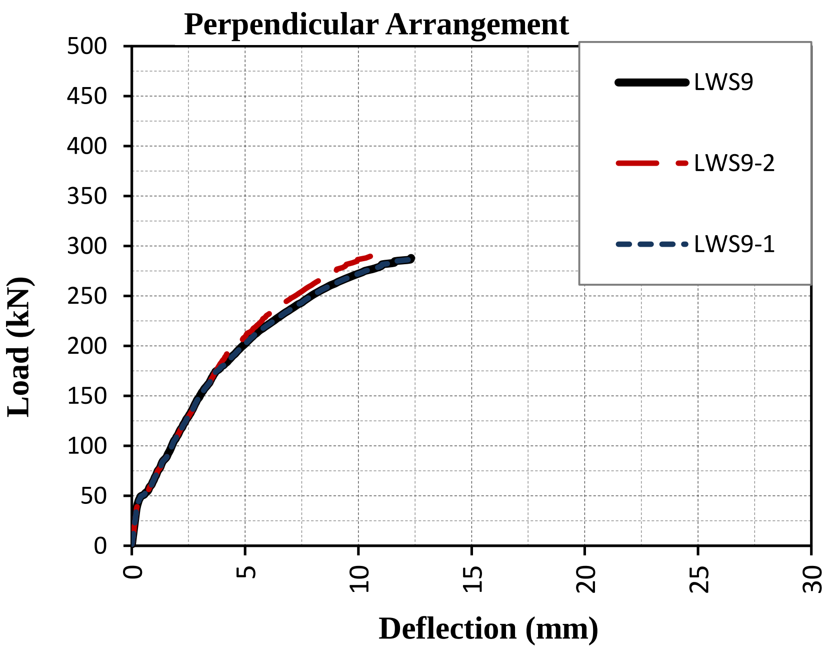


a) Specimens LWS_7, LWS_{7-1}, and LWS_{7-2}

Fig.5 Analytical Results for specimens with single leg stirrups .

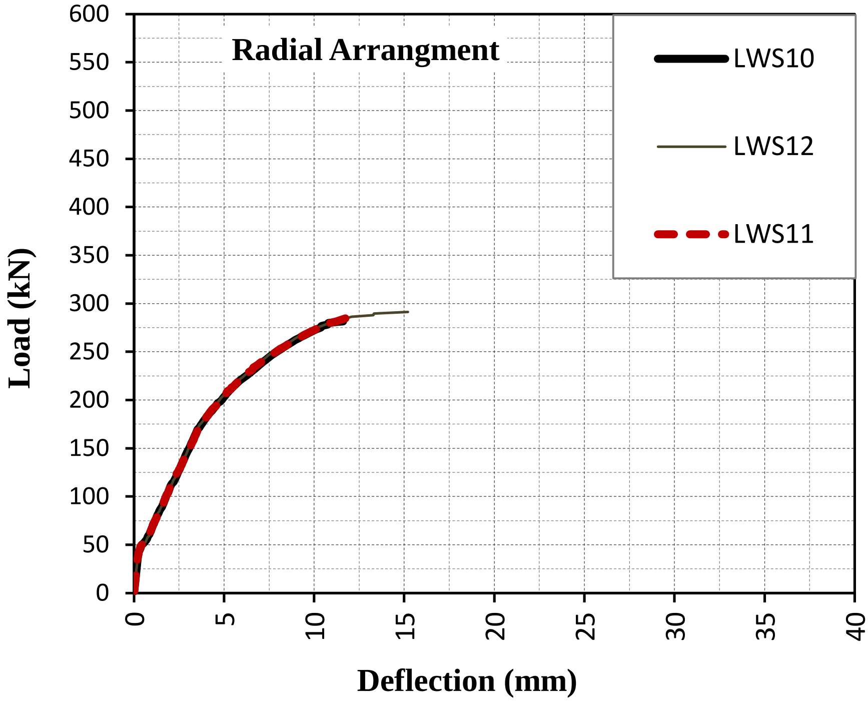


b) Specimens LWS_8, LWS_{8-1}, and LWS_{8-2}.



c) Specimens LWS_9, LWS_{9-1}, and LWS_{9-2}.

Fig.5 Analytical Results for specimens with single leg stirrups (cont.).



d) Specimens LWS_{10}, LWS_{11}, and LWS_{12}.
Fig.5 Analytical Results for specimens with single leg stirrups (cont.).

Steel Fiber contribution

The overall behavior of slab specimens specially the punching shear capacity improved by using steel fiber as shear reinforcement. Four slab specimens investigate the variation of steel fiber ratios were used in the parametric study. A great enhancement in failure punching loads was achieved. The enhancement ratio regarding to the control specimen LWS_5 was 27.0%, 50.0%, 66.0% and 81.0% for steel fiber ratios of 0.50%, 1.0%, 1.50% and 2.0% respectively, shown in Figure (6).

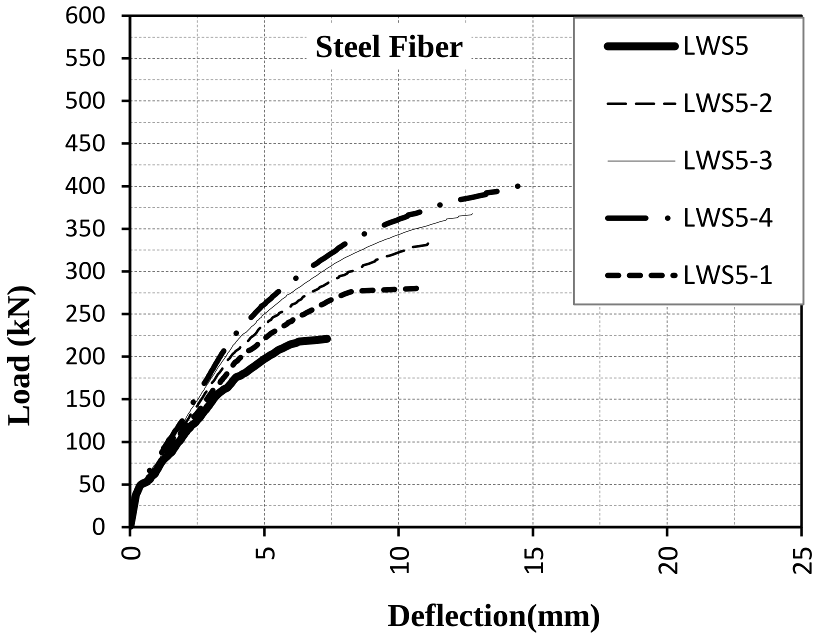


Fig.6 Analytical Results for steel fiber specimens.

Conclusion

Based on the analytical results and discussion presented herein, the following conclusions are drawn:

1. The tensile steel ratio had a noticeable effect on the punching shear capacity. The higher tensile steel ratio the higher failure load capacity, and the maximum enhancement ratio was 42.0% for all specimens with respect to flexure steel ratio.
2. The enhancement results from increasing compressive steel ratio were very small, and the maximum enhancement ratio was 10.0% for all specimens with regard to top reinforcement ratio.
3. The perpendicular shear reinforcement configuration was an effective technique to enhance punching capacity and achieved an enhancement equal 30.0%.
4. The radial shear reinforcement configuration was more effective than the perpendicular shear reinforcement configuration.
5. The yield strength of shear reinforcing steel has a neglected effect on punching shear capacity. That may be explained with the fact that all shear reinforcement did not reach or even approach the yield strength.
6. A great enhancement in failure loads was recoded due to using different ratio of steel fiber, and the maximum enhancement ratio was 81.0% for all specimens with respect to steel fiber ratio.

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