Swimmer Bars as Shear Reinforcement in Reinforced Concrete Flat Slabs

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Abstract— Punching shear failure takes the form of a truncated pyramid or truncated cone. A counteract steel cage truncated pyramid using swimmer bars will generate four inclined planes intercepting at perpendicular angles approximately the four inclined planes of the failure The swimmer bars themselves are a new type of shear reinforcement; these are short inclined bars welded to the steel rectangles forming the base and the top of the truncated steel cage pyramid. The number of steel cages needed depends on the thickness of the concrete plate, the grade of the concrete, and the size of the punching shear force. The results obtained from testing proved the effectiveness of this new system. The slope of swimmer bars may be used an extra parameter to force more than one steel cage truncated pyramid to resist punching shear force. The number of truncated pyramid-crack interceptor may be increased for heavy punching shear forces. The main advantage of this new system will enable the designers to use slabs with uniform economical thickness.

Index Terms— Punching shear, swimmer bars, truncated pyramid, truncated cones.

I. INTRODUCTION

Slabs may be divided into two general categories: beamless slabs and slabs supported on beams located at sides of panels. Beamless slabs are described by the generic terms flat plates and flat slabs. The flat plate is an extremely simple structure in construction, consisting of a slab of uniform thickness supported directly on columns. The flat plate is a direct development from the earlier flat slab structure which is characterized by the presence of capitals at the top of the columns and usually also by drop panels or thickened areas of the slab surrounding each column [1].

Reinforced concrete flat slabs are extensively used in buildings and parking garages. Their design is governed by deflection at the serviceability limit state and punching shear at the ultimate limit state. When no punching shear reinforcement is provided, failure develops in a brittle manner. Punching shear failure occurs with almost no warning signs, because deflections are small and cracks at the top side of the slab is usually not visible [2].

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. Earlier research covered slabs without punching shear reinforcement, followed by investigations on flat slabs with punching shear reinforcement. The first shear reinforcement used was bent-up bars. Later on, new systems have been developed such stirrup systems and shear studs. In which punching shear capacity of plates under static load affected by concrete strength, column dimension, slab thickness, flexural reinforcing ratio and pattern, shear reinforcement. An overview of the developments regarding punching of flat slabs with shear reinforcement is summarized as follows: Flat plates undergo two kinds of shear failure mechanism which may be critical in the design of flat slabs, flat plates, and raft footings; the first one is the diagonal tension failure; applicable particularly to long narrow slab or footing, in which slab consider as wide beam by which potential diagonal crack extends in a plane across the entire width of the slab; the second one is the punching shear failure: in this failure, potential diagonal cracks following the surface of a truncated cone or pyramid around the column capital, in which failure surface extends from the bottom of the slab at the support, diagonally upward to the top surface. The angle of inclination depends upon the nature and amount of reinforcement in the slab; it may range between 20 and 45°. The critical shear section in ACI Code is taken at d/2 from periphery of the support. The simultaneous presence of vertical and horizontal compression increases the shear strength of concrete. The control perimeter is defined in Clause 11.11.1.2, which would suggest that the perimeter is, alike other codes, circular at the corners, however, Clause 11.11.1.3 allows using straight sides at the corner in the case of square or rectangular columns. Since, in practice, it seems more reasonable to use the largest control perimeter allowed, the critical perimeter is used with straight lines for the comparison of the tests with the ACI 318-11 Code [3].Asha, Al-Nasra, and Najmi investigated the use of swimmer bars in reinforced concrete beams [4]. The experimental test results showed substantial improvement in the shear performance of the reinforced concrete beams in comparison with the traditional stirrup system. The impact of using swimmer bars left a remarkable enhancement on the deflection of the beams. It was also noted that the width of the cracks in the beams that had swimmer bars were smaller by far than the beams reinforced with the traditional stirrup system.

Al-Nasra, Duweib, and Najmi studied the effective use of space swimmer bars in reinforced concrete flat slabs as punching shear reinforcement [5] and [6]. The test results showed that the space form of swimmer bars increased the punching shear strength of the tested slabs. The use of swimmer bars as part of the pyramid steel cage could give the designer the option of reducing the slab thickness and

consequently reducing the cost. The deflection was also reduced and the tested slabs showed an increase in their flexural rigidity.

II. TESTED SLABS

Five slab specimens were tested for this study; all the specimens have the same dimensions (3m x2m and 0.25 m thickness) as shown in Fig. 1. The five specimens have been cast in the same day using the same concrete mix, and all of them have the same flexural reinforcement (top steel mesh of diameter 10 mm at 100 mm spacing, while the bottom steel mesh of diameter 14 mm at 100 mm spacing in the short direction and diameter 25 mm at 100 mm spacing in the long direction as shown in Fig. 2, and Fig. 3, were vibrated and cured under the same conditions. The first specimen (RFS) has no swimmer bars, and was used as a reference (control) specimen (sample). The other four specimens with swimmer bars had the same steel flexural reinforcement. A stub column 0.25 m x 0.25 m reinforced with 4 ϕ 12mm was constructed at the middle of the slab to resemble a normal punching load. Table (I) summarizes the main properties of the five specimens. For example, specimen 2 (FSW8), indicates that 8 swimmer bars of diameter 8 mm were used. Fig. 1 shows that the bottom base dimensions of the closest steel pyramid are just outside the stub of the column and have the dimensions of 0.25 x 0.25 m. This base is formed by four bars situated above the lowest grid of flexural reinforcement and fixed to it by welding. The 8 swimmer bars were inclined to the horizontal plane by 45° and each is welded at its ends to both the bottom and the top bases of the pyramid. The top base of the pyramid is just underneath the upper grid of the top mesh of the flexural reinforcement. The top base is welded to both the flexural bars and the swimmer bars. Four of the swimmers bars are welded to the corners of the pyramid bases, and four are welded to the middle of theses bases. By welding the eight swimmer bars, four relatively rigid planes are formed, Fig.4 shows a three dimensional modeling of swimmer bars and transverse bars cage used in test. This rigidity may be increased by using larger diameter bars, as implemented in the other three samples FSW10, FSW12 and FSW14, or by increasing the number of swimmer bars per pyramid. The number of swimmer bars must be a multiple of four to maintain the symmetry of the four rigid inclined planes of the pyramid.
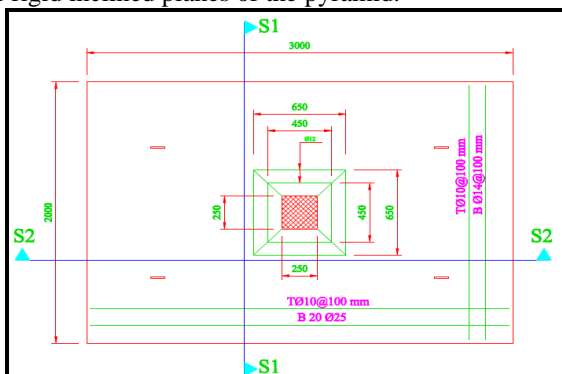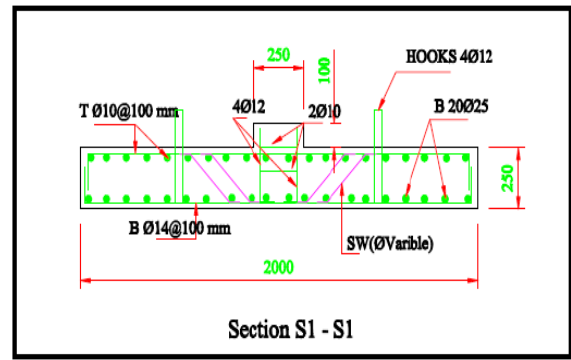

Figure 1: Flat slab reinforcement
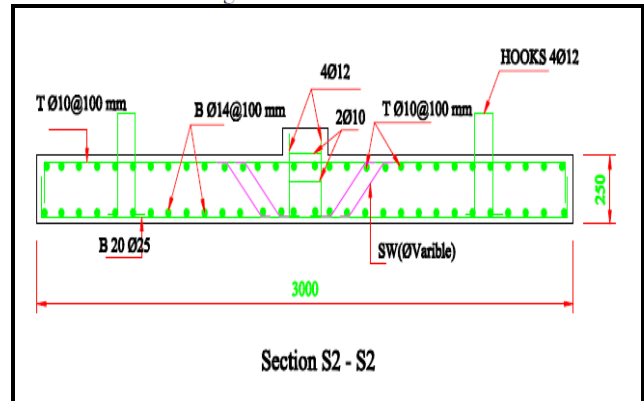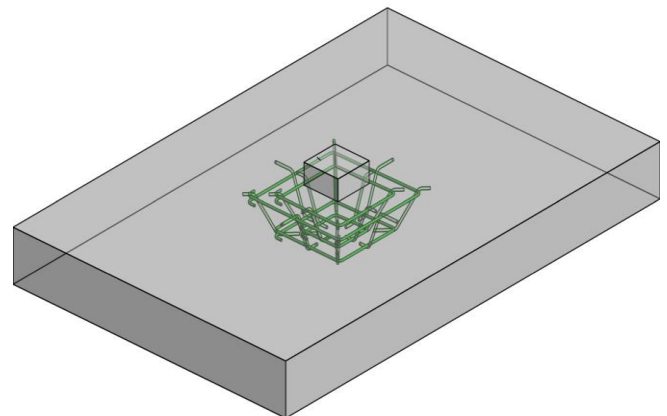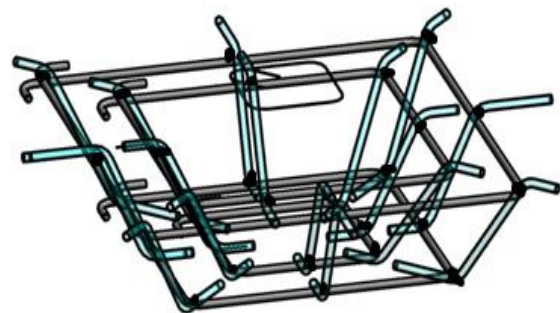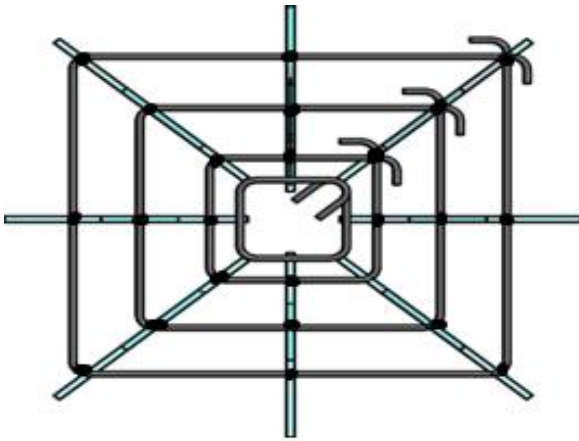

Figure 2: Section S1-S1

Figure 3: Section S1-S1

4. (a) Tested specimen

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4. (b) Pyramid and plan view for cage

Table I: main parameters of the test specimens

Specimen	Dimension (m)	Total depth (h) (m)	Effective depth (d) (m)	f_c' MPa	f_y MPa	Shear reinforcement Swimmer bars
RFS	3 x 2	0.25	0.2125	20.0	420	-
FSW8	3 x 2	0.25	0.2125	20.0	280	8ø8
FSW10	3 x 2	0.25	0.2125	20.0	420	8ø10
FSW12	3 x 2	0.25	0.2125	20.0	420	8ø12

III. TEST PROCEDURE

All test specimens were painted with white emulsion so that detection of cracks during testing became easier and pencil marking on the side of the cracks made them clearer. Each specimen was mounted on two steel beams, made of two channels back to back to serve as simple support for the two edges of the concrete plate specimen. A solid round steel bar was installed between the concrete plate and the steel beams to ensure that the plate can be dealt with as simply supported member. The test was carried out with the specimen placed horizontally in a simple loading arrangement. All the plates were designed to ensure that the specimens will fail in shear and not in flexure. The load was applied through the column stub that is located at the middle of the concrete plate delivered by a hydraulic jack. The load was transferred to the specimen by two steel plates of 30 mm thick located underneath the jack's head. Flat plate dimensions are 3.0 m x 2.0 m with 250 mm thickness. There is a stub column that is 250 mm by 250 mm located at the middle of concrete plate as shown in Figs. 5 and 6.
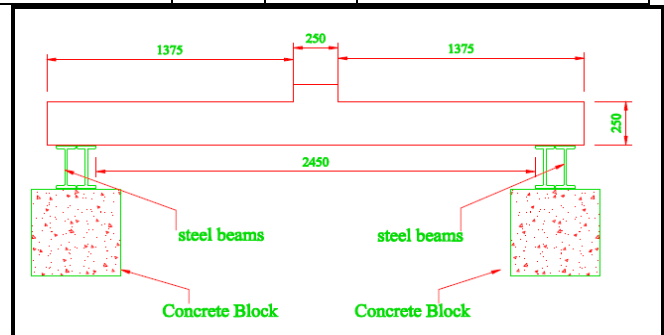

Figure 5: Specimen setup

Figure 6: Test setup

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The punching shear tests of all specimens were carried out by using a 730-kN test frame (TONI-MFL). The frame was connected to data acquisition system displaying a record of the load during test. Strain and deflection measurements of the specimen were recorded after each load increment, until failure by punching shear. Two linear variable displacement transducers (LVDT), were used to measure the deflection at 300 mm from face of column in both direction parallel and perpendicular to the support, as shown in Fig.7. These transducers have 0.01 mm accuracy. Strain gauge transducers were installed on the side face and the top surface of specimen to measure the concrete strain with an accuracy of 0.002 mm.
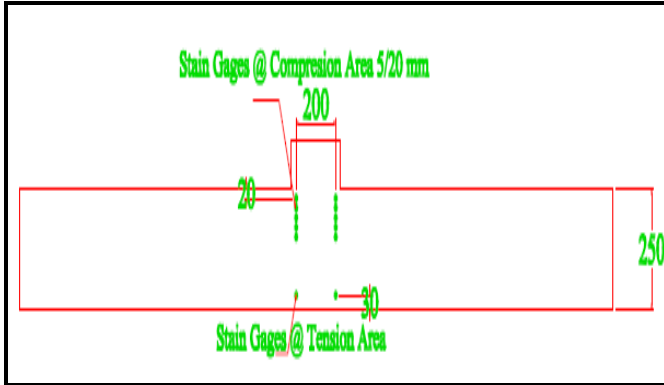

Figure 7: LVDT distribution of side face of specimen

for FSW10, and at 682 KN load for FSW12. Figure 8 shows the mode of failure for the sample FSW12, which was

IV. TEST RESULTS

The reference specimen RFS, that has no swimmer bars and the one which was used as control sample was tested first. For RFS, loading started at 50 kN, when loading reached 300 kN hair cracks appeared at the side perpendicular to the supports. Additional increase of the applied load gradually, beyond 300 kN, cracks began to appear and increased in width at the side and bottom face of specimen. Finally punching shear failure occurred at the load of 584 kN which was a brittle mode of failure. For the second specimen FSW8, loading started at 50 kN and hair cracks appeared at 400 kN, cracks appeared and increased in width at the side and bottom face of specimen. Finally, punching shear failure occurred at the load of 640 kN. As the load increased, more cracks appeared with the gradual increase of the load; the cracks located at the sides of plate and at its bottom, grew in size and became significant at the bottom face of the specimen. Finally, punching shear failure occurred at the load of 640 kN

similar to the mode of failure of sample RFS, but failure depart in to ductile mode of failure.

Figure 8: Failure of specimen FSW12

The last sample FSW14 plate with maximum swimmer bars diameter used in the test was loaded in the same way for shear reinforcement, it had no failure mode under maximum jack load with lowest deflection reading compared with previous three tested specimen, and exhibit similar performance in terms of cracks and deformation at 400 kN jack load in which concrete flat plate behavior was enhanced. Table II, and Fig. 9 show the punching shear strength of the five samples.

Table II: percentage of ultimate load for all specimens

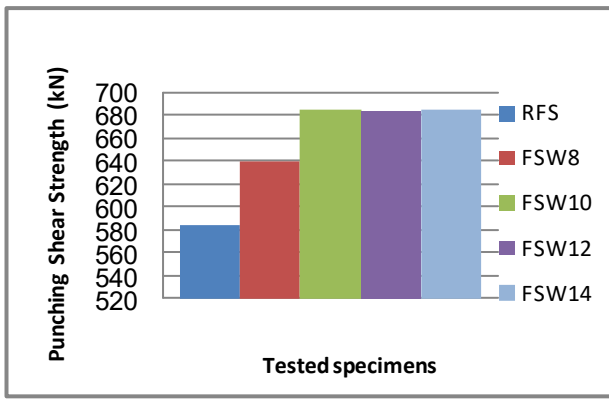| Plate label	Experimental ultimate load (kN)	Type of failure	Type of Swimmer bars	The percentages of ultimate load compared with control specimen RFS (%)
RFS	584	Punching shear	-	-
FSW8	640	Punching shear	∅8	9.6
FSW10	685	Punching shear	∅10	17.3
FSW12	682	Punching shear	∅12	16.8
FSW14	685.5	No failure	∅14	17.4

Figure 9: Punching shear strength for tested specimens

V. DEFLECTION

The deflection was measured at each increment of load. The load deflection was plotted for the tested samples as shown in Fig. 10. The results show an increase in slab rigidity due to the use of the swimmer bars, and how the increasing of swimmer bar size affects the rigidity of slabs.
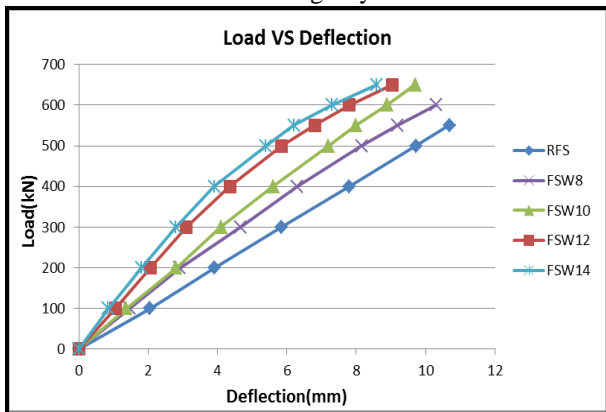

Figure 10: Load deflection curves for the tested slab samples

VI. CONCLUSION

The main conclusions can be summarized as follows:

1) Test results show that this form of swimmer bars increased the punching shear strength of the tested slabs and improved the deformation capacity of concrete flat plate.

2) Generally the punching shear strength values specified in different codes vary with concrete compressive strength f'c and are usually expressed in terms of fc^n results showed that the low quality of the concrete did not affect the performance of the steel cage truncated pyramid.

3) Results showed that the use of swimmer bars enhances the plate punching capacity up to 17% compared with the reference specimen by departs the mode of failure from brittle into ductile one.

4) The use of swimmer bars as part of the pyramid steel cage proved that this form of punching shear reinforcement can give the designer the ability to reduce the slab thickness and consequently reducing the cost of construction. Also the added punching shear strength by using this type of reinforcement can give the designer options to avoid using drop panels.

5) This type of punching shear reinforcement showed a substantial increase in the slab rigidity by reducing the deflection. The increase in deformation capacity is desired so that the load can be distributed to other supports preventing a total collapse of the structure in the case of the occurrence of a local failure.

6) Shear reinforcement transfers most of the forces across the shear cracks and delays further widening of the shear cracks thus increasing the punching shear capacity. The improvement in performance of the slab is influenced by bar size of shear reinforcement size parameter. Specimen with swimmer bars fail at a load higher than reference plate.

REFERENCES

[1] Robert Park and William L. Gamble, (2000), ″Reinforced Concrete Slabs″, Second Edition, John Wiley & Sons, Inc., ISBN: 978-0-471-34850-4.
[2] Wight, James K. and Macgregor, James G. Mac, (2005), ″Reinforced Concrete Mechanics and Design″ 4th Edition, Pearson Prentice Hall, New Jersey, USA, ISBN-13:978-0132176521.
[3] ACI, Building Code Requirements for Structural Concrete (ACI 318M-11) - Metric Building Code Requirements for Structural Concrete and Commentary, an AC Standard and Commentary, 2011.http://www.concrete.org/pubs/newpubs/318M11.htm .
[4] Asha, N. , Al-Nasra, M. , Najmi, A. , "Optimizing the Use of Swimmer Bars as Shear Reinforcement in the Reinforced Concrete Beams", International Journal of Civil and Structural Engineering, Vol. 3, No. 2, November 2012, Pages 313-320, ISSN 0976-4399, DOI: 10.6088/ijcser.201203013030.
[5] AL-Nasra, M., Najmi, A., Duweib, I., "Effective Use of Space Swimmer Bars in Reinforced Concrete Flat Slabs", International Journal of Civil and Structural Engineering, Feb., 2013, ISSN: 2277-9655.
[6] AL-Nasra, M., Duweib, I., Najmi, A., "The Use of Pyramid Swimmer Bars as Punching Shear Reinforcement in Reinforced Concrete Flat Slabs", Journal of Civil Engineering Research 2013, 3(2): 75-80, DOI: 10.5923/j.jce.201303.

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