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The use of Swimmer Bars as Shear Reinforcement in Reinforced Concrete Structures

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Abstract: The use of swimmer bars in reinforced concrete structures represents new concept of shear reinforcement. The design of flat plates focuses on the punching shear strength of the flat plates while the design of reinforced concrete beams focuses on the flexural strength and the shear strength. The thickness of the flat plates is mainly controlled by the punching shear forces. The drop panels as well as the column capitals are used extensively in the design of flat plates to resist some of the applied punching shear force. Swimmer bars concept is new concept used mainly to take care of the excessive punching shear in flat plates and excess shear force in beams. The swimmer bars are inclined bars welded at both of their ends forming a rigid steel cage that has the capability of intercepting the punching shear in a plane. These swimmers bars form a shape similar to truncated pyramid in plates and shear plane interceptor in beams. These types are proven to be very effective in taking care of the applied shear forces. At the same time, the swimmer bars configuration, made of swimmer bars and longitudinal bars is proven to be economical. The generated shapes represents shear plane interceptors. Each plane acts as a crack plane that has the capability of resisting plane applied shear. The main advantage of this new concept is eliminating the need for the use of drop panels or any extra measure dictated by excessive applied shear forces. In this study, two different groups of flat plates are experimentally tested. Each group is of different concrete compressive strength. Each group is composed of at least three flat plates. Each flat plate is built with different swimmer bar diameter. The effect of the swimmer total steel area on the punching shear strength of flat plates is presented. The effect of different values of concrete compressive strength on the punching shear strength of flat plates is also discussed. Two different groups of beams were also tested. The first group uses the traditional shear reinforcement while the second group uses the swimmer bars as shear reinforcement. The deflection and deformation are monitored during the experimental test. The mode of failure is one of the main objectives of this study, especially, in slabs built with the new perimeter swimmer bars punching shear reinforcement system.

Key words: Swimmer bars, slabs, punching shear, flat plates, slab deflection, stirrups

INTRODUCTION

Concrete beams and flat plates are essential structural elements. Modeling the reinforced concrete flat plates could be an elaborate effort, especially when the elastic-plastic behavior of these plates are the focus of the research. The supports as well as the boundary conditions add to the complexity of the mathematical model.

Concrete shear strength is a function of the concrete compressive strength. The increase in the compressive strength increases the shear strength of concrete. The focus of many researchers was to increase the concrete strength by improving the mix design (Al-Nasra, 2013a, b). One of the main cause of concrete deterioration is the penetration of the water into the concrete (Al-Nasra *et al*., 2015; Ramadan and Al-Nasra, 2017). Many studies focused on improving the concrete strength by the means of internal curing using polymer concrete (Al-Nasra and Daoud, 2013; Al-Nasra, 2017a-c)

Reinforced concrete slabs are usually supported by columns directly or by beams then columns. The beamless slabs are called flat plates. The main concern in the design of flat plates is the punching shear. The American Concrete Institute (ACI) requires investigating the shear at a distance equal to half of the slab depth (ACI. (American Concrete Institute), 1999). To increase the flat plates punching shear strength, one can increase the depth, especially, around the critical section by adding drop panels. The drop panel solution is not economical at the same time it increases the weight of the slab. Other solution is to increase the dimension of the column especially at the top. This increase in the column dimensions increases the punching shear length which in turn has the potential to decrease the slab thickness. This solution is also not an economical solution. Providing punching shear reinforcement by using swimmer bars is not only an economical solution but also it saves space and reduces the slab weight.

There are two types of shear failure that should be considered in the design of flat plates; wide beam shear one way shear and the punching shear two way shear. The drastic punching shear mode of failure demonstrated by field observation urged the code officials to have a second look at the design criteria of flat plates for shear. Many demanded making the drop panels as a requirement for all flat plates.

Experimental studies of circular slab specimens showed that the critical mode of failure is due to the punching shear (Mu and Meyer, 2003). The specimens were supported by a ring and loaded at the center. The focus of this experimental study was to study the shape of the punching shear failure code. Other slabs were tested to study the punching shear strength (El-Salakawy *et al*., 2003). Shear bolts were used to improve the performance of the reinforced slabs in shear. Al-Nasra and Wang (1994) studied the shear performance of slabs. They developed theoretical model to conduct parametric study. Other researchers focused on providing special shear reinforcing system (Asha *et al*., 2012). Swimmer bars were used as new shear reinforcing system (Al-Nasra, 2013a, b). Al-Nasra (2015) investigated the use of swimmer bars shear reinforcing system in reinforced concrete beams. Al-Nasra and Asha (2013) used several types of swimmer bars to improve the shear performance of the reinforced concrete beams. U-links were used as an alternative to the welding. Other studies focused on the economical aspect of the use of the swimmer bars as shear reinforcing system (Al-Nasra and Asha, 2013; Al-Nasra *et al*., 2013).

Other experimental studies focused on the punching shear reinforcement using large samples (Hegger *et al*., 2006; Al-Nasra *et al*. 2013a-c). Some of these samples were tested by supporting the slabs on column stub and subjecting the slabs to uniform load. They concluded that the punching shear strength decreases with the increase in span to depth ratio. Other tests were conducted on thick reinforced concrete slabs (Risk *et al*., 2011; Al-Nasra *et al*., 2013a-c). The tests focused also on the punching shear strength of slabs loaded concentrically (Al-Nasra, 2017a-c). One of the major conclusions of these tests is that the increase in the slab thickness increases the punching shear strength and also increases the slab ductility.

Researchers studied the possibility of changing the shape of the reinforced concrete beams and slab in order to reduce the internal stresses leading to substantial reduction in steel reinforcement (Al-Nasra and Daoud, 2016; Al-Nasra, 2017a-c). Changing the shape of flat plat from two dimensional element to three dimensional element not only reduces the flexural stresses but also helps in improving the shear performance of the flat slabs (Al-Nasra, 2017a-c).

Flat plates are subjected to large punching shear force generating cracks in the vicinity of the columns. These cracks propagate at an angle ranges between 20-50° across the thickness of the flat plate forming a truncated pyramid. This phenomena is known as the pyramid shear failure surface. The increase in the area of that shear surface increases the punching shear strength. The thickness as well as the width and length increase the area of that surface. The width and length can be increased by increasing the column dimensions. Other factors can be considered to increase the punching shear strength such as the concrete compressive strength and the steel shear reinforcement. In this study, new punching shear reinforcing system is used to study its effect on increasing the punching shear strength of flat plates. This system uses swimmer bars as a major punching shear reinforcing system.

Six samples are tested in this study. The first three are made of concrete that has compressive strength of 40.7 MPa. The other three samples are made of concrete that has compressive strength of 34.7 MPa. The flat plate dimensions are kept the same for all of the samples. The dimensions of the tested flat plates are 2, 2 m by 0.17 m. The steel yield strength is also kept constant of 420 MPa for all samples. The effective depth is taken to be 0.14 m.

Shear reinforcement of reinforced concrete members has been great challenge, especially for reinforced concrete beams. The structural design codes usually emphasize on safety as a first priority that should be taken into consideration when designing steel and concrete structures. The sudden failure mode requires higher factor of safety. The design engineer has to make sure that the mode of failure is acceptable and gives enough warning before failure. The shear failure is not one of the desirable modes of failures and should be avoided. Reinforced concrete beams are one of the common structural elements that carry transversal loads mainly by flexure and shear. The common design approach is to design the beam for flexure then design the beam for shear. The available design codes emphasizes on the ductile flexural failure by reducing the amount of steel reinforcement in the tension area in order to make sure that the longitudinal tension bars yield first. While the design for shear focuses on providing enough shear resistance exceeding the applied shear force by a margin of safety factor. The shear resistance comes from two different sources; the concrete and the shear reinforcing bars. The concrete shear strength depends on the cross section of the beam and the concrete compressive strength. Large applied shear force requires shear reinforcing bars of large diameter placed at closer spacing.

Beams are subjected to large shear force exhibit diagonal cracks initiated near supports. These diagonal cracks have the tendency to widen and propagate moving toward the center of the beam. These cracks are proven to propagate at a faster rate compared with the bending flexural cracks. Steel stirrups which are shear reinforcing bars are placed perpendicular to the longitudinal flexural bars and used to reduce the shear cracks. Swimmer bars system is considered an alternative to the stirrups placed in the concrete beams to resist the applied shear.

MATERIALS AND METHODS

Shear strength: There are several alternatives to increase the punching shear strength of flat plates including, closed stirrups, bent-up bars, shear studs and shear heads. In this study, new punching shear reinforcing system is used. This system uses swimmer bars formed in a shape similar to the truncated pyramid shape in order to maximize the resisting shear strength. This swimmer bar punching shear reinforcing system is used around the columns where the applied punching shear is critical. The critical punching shear section defined by the ACI code is at a distance of half the effective depth measured from the face of the column. The design for shear in general is controlled by the following equation (ACI. (American Concrete Institute), 1999):

$$V_u \leq \phi V_n \quad (1)$$

Where:

V_u = Factored applied shear force
V_n = Nominal shear strength
ϕ = Eduction safety factor for shear = 0.75

The nominal shear strength is generated from two different sources. The concrete (V_c) and the reinforcing steel (V_s) as shown in the following equation:

$$V_n = V_c + V_s \quad (2)$$

V_c, and V_s can be calculated using the following ACI equations:

$$V_s = \frac{A_v f_y (\sin\alpha + \cos\alpha) d}{s} \quad (3)$$

Where:

S = The Spacing between shear reinforcement in mm
A_υ = Area of steel reinforcement
α = The angle between the inclined bars and the longitudinal bars
d = The effective depth
f_y = The yield strength of the steel reinforcement
V_c = Limited by the ACI code as shown in the following equations

$$V_c = \min.\left\{ \begin{matrix} 0.33\lambda\sqrt{f_c^{'}} b_o d \\ 0.17\lambda\sqrt{f_c^{'}}\left(1+\frac{2}{\beta_c}\right) b_o d \\ 0.083\lambda\sqrt{f_c^{'}}\left(2+\frac{a_s d}{b_o}\right) b_o d \end{matrix} \right\} kN \quad (4)$$

Where:

β_c = The ratio of the cross-sectional length to the cross sectional width of the column
b_o = The total perimeter length of the critical section
f_c' = The concrete compressive strength λ = 1.0 for normal weight concrete and
α_s = 40, 30, 20 for interior, edge and corner column, respectively

Swimmer bars: The swimmer bar is an inclined bar where both ends are bent to a horizontal position. This bar is then welded at both of its bent parts. Eight swimmer bars are used here to form truncated pyramid. The eight swimmer bar system is uniquely arranged to form rigid steel cage for the purpose of intercepting the punching shear forces in planes along the sides of the truncated pyramid. Figure 1 shows a single swimmer bar. The inclined bar is welded at the bent sections as shown in Fig. 2 and 3 shows the eight swimmer bar arrangement used in flat plates. Four of these swimmer bars are at the corners and the other four are located at the edges.

Figure 4 shows the steel cage with the swimmer bar system. The slabs are made of 2×2×0.17 m. They are reinforced with 10Φ10 mm bars in the direction parallel to the direction of the support and 10Φ12 mm bars in the direction perpendicular to the direction of the support. This steel reinforcement is used for both; the top steel mesh and the bottom steel mesh.

Test procedure: The slabs were painted with white paint to monitor the cracks during the test. Strain gauges were also mounted on the one of the edges of the slab and

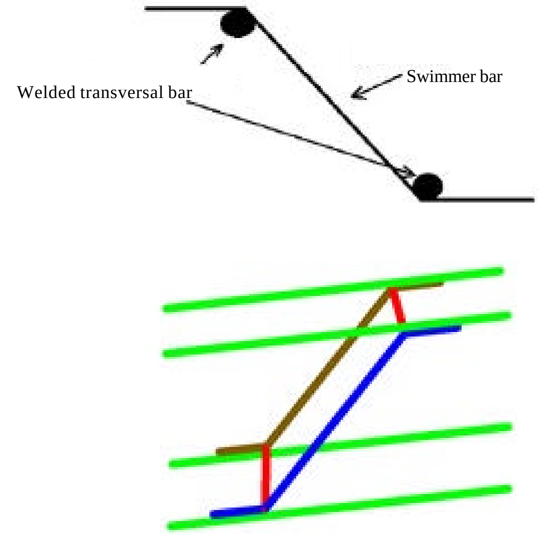

Fig. 1: Single swimmer bar

Fig. 2: Typical welded swimmer bars used in beams

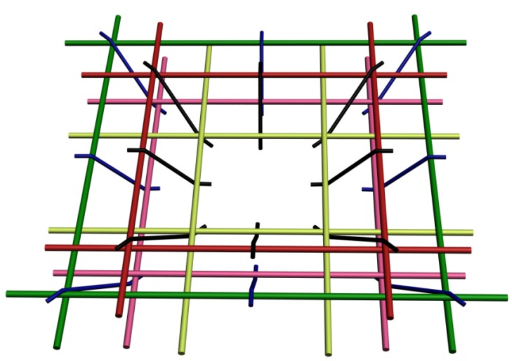

Fig. 3: Eight swimmer bar arrangement

across the top. Dial gauges are used to measure the deflection of the slab during the test. Figure 5 shows the experimental set-up. The load is applied gradually at the top of the column as shown in Fig. 6. The clear span of the tested slabs is 1.8 m. Figure 7 shows the test set up for reinforced concrete beams.

Fig. 4: Steel reinforcement mesh with perimeter swimmer bars

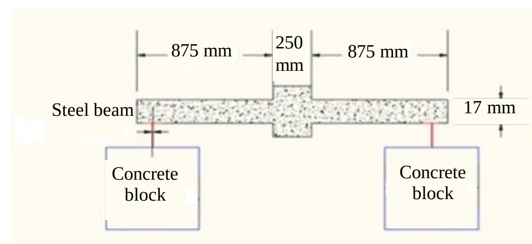

Fig. 5: Experimental set-up of slabs showing the dimensions

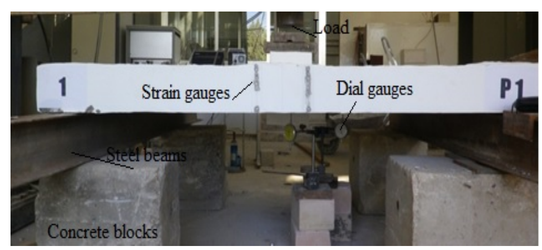

Fig. 6: Slab ready to be tested

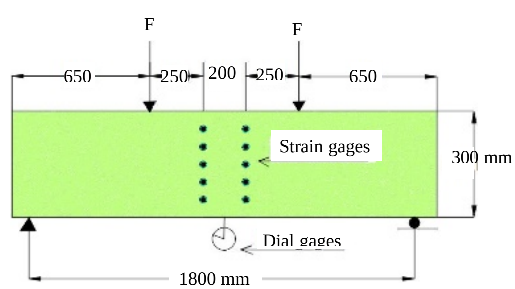

Fig. 7: Typical test set up of reinforced concrete beams

Flat slab test results: Table 1 shows the summary of the results of the tested slabs. The table shows two groups of flat plates tested. The first group is of 40.7 MPa concrete compressive strength and the second group is of 34.7 MPa concrete compressive strength. The first crack was observed for the first groups at the load of 100 kN while the first crack was observed for the

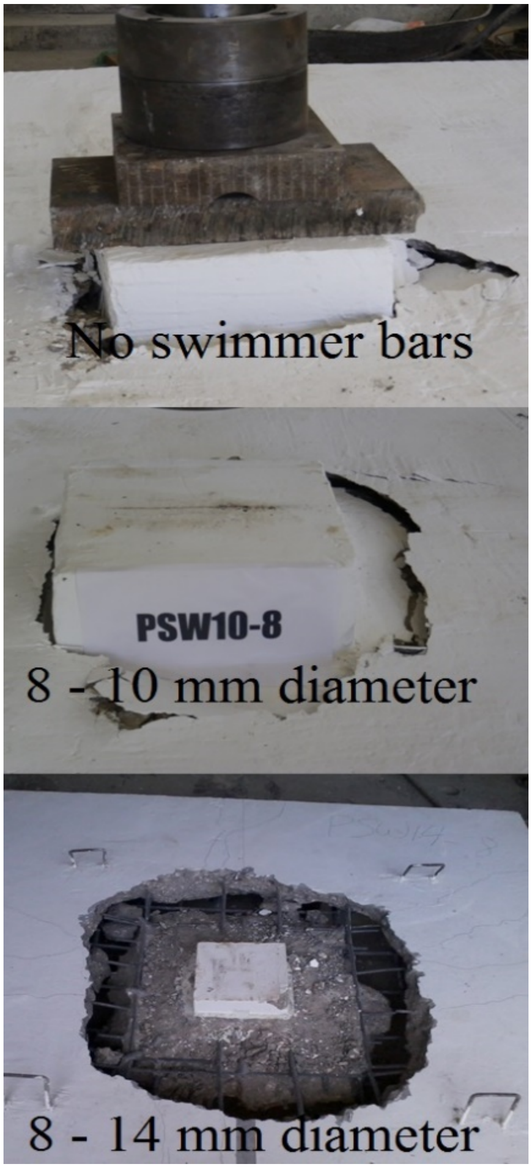

Fig. 8: Failure mode comparison in slabs

Table 1: Summary of results representing the six tested slabs

Codes	Con.comp. strength, f_c' (MPa)	Ultimate load P_u (kN)	Note
P0-1	40.7	506	No swimmer bars
P8×8	40.7	523	8 D-8 S. bars
P8×10	40.7	535	8 D-10 S. bars
P0-2	34.7	407	No swimmer bars
P8×12	34.7	534	8 D-12 S. bars
P8×14	34.7	660	8 D-14 S. bars

second group at 150 kN. Figure 8 shows the mode of failure of the three slabs; No. swimmer bars, 8 Φ 10 mm swimmer bars and 8 Φ 14 m swimmer bars. These three slabs are put together for comparison. The shear failure surface migrate away from the column face as the total area of the swimmer bar reinforcement increases. The punching shear strength increases with the increase in the total steel area of swimmer bar reinforcement used in the slab. This increase in the punching shear strength alters the mode of failure of the slab as shown in the figure.

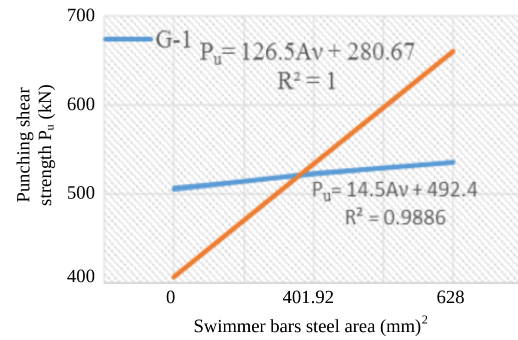

Fig. 9: Punching shear strength

Figure 9 shows the punching shear strength of the tested slabs. The first curve represents the results of the first group, G-1 with the concrete compressive strength of 40.7 MPa. The second curve represents the second group, G-2 with the concrete compressive strength of 34.7 MPa.

Equation 5 shows the relationship between the punching strength and the total steel area of the swimmer bars used for the first group (f_c' = 40.7 MPa). This relationship is derived from the curve fitting statistics. The sum of squares of the residuals is calculated to be 0.988 which is a measure of the deviation from the true experimental values. Equation 6 shows the relationship between the punching shear strength and the total area of steel of the swimmer bars used for the second group (f_c' = 34.7 MPa). The sum of squares of the residuals of this group is calculated to be 1.0, meaning that the experimental results matches the derived relationships with no significant deviation:

$$P_u = 14.5A_\upsilon + 492 \quad (5)$$

$$P_u = 126.5A_\upsilon + 280 \quad (6)$$

Where:

P_u = The punching shear strength
A_υ = The total swimmer bars steel area

Figure 10 shows the central deflection applied load relationship for the first group with the concrete compressive strength of 40.7 MPa. This figure shows experimental results as recoded during the test. Figure 11 shows the central deflection applied load relationship for

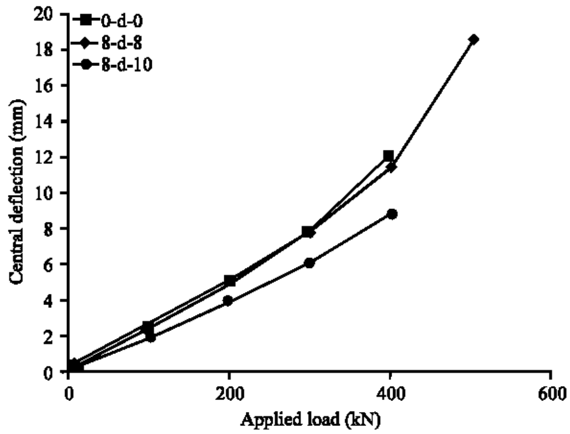

Fig. 10: Central defection applied load relationship for group 1 slabs (fc'= 40.7 MPa)

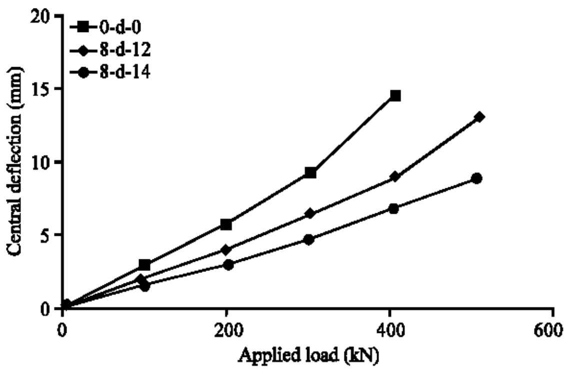

Fig. 11: Central defection-applied load relationship for group 2 slabs (fc' = 34.7 MPa)

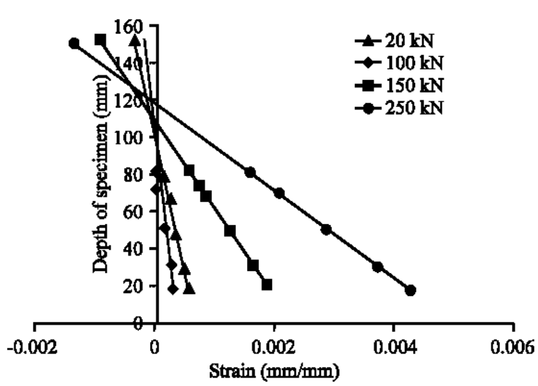

Fig. 12: Typical strain measurement of the tested slabs

the second group with the concrete compressive strength of 34.7 MPa. These figures show that the added swimmer bars enhance the slab rigidity and reduce the central deflection. Figure 12 shows typical strain measurement of one of the tested slab. In this particular one, the figure shows the slab with no swimmer bars of the first group. Other slabs exhibited almost similar behavior.

Fig. 13: Typical shear failure

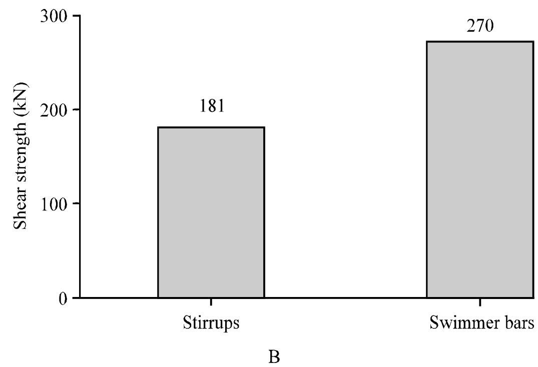

Fig. 14: Shear strength of beams of similar shear reinforcement by weight

RESULTS AND DISCUSSION

Reinforced concrete beams test results: The beams prepared for the test were painted, labeled and marked. Special attention is given to the propagation of the concrete cracks during the test. The applied load is increased gradually at a paste just enough to take readings and observe the progress of the concrete cracks. The cracks became visible initially at a load of 60 kN. The initial crack starts at the support with smaller angle. Soon after, other cracks become visible and start moving toward the center of the beam at larger angles. The flexural crack starts at approximately 90° near the mid-span. Figure 13 shows the typical shear failure of a beam reinforced with space swimmer bars. The initial and major shear cracks start at angle of approximately 30° measured with respect to the horizontal line. The following shear cracks start at higher angle. Soon after the major shear crack becomes visible bending cracks start to appear at the mid-span of the beam. The width of the shear cracks is visibly larger than the width of the flexural cracks. The shear cracks propagate at a faster rate than the flexural cracks (Al-Nasra and Daoud, 2006; Al-Nasra *et al.*, 1926).

Figure 14 shows the shear strength of beam reinforced with swimmer bars. The welded swimmer bars exhibit an increase in shear strength, especially, at high range of bar

Fig. 15: Load deflection relation of the two types of beams before failure

spacing. In order to make this study meaningful, the weight of the steel cage used in the beams of stirrups is very close to the weight of the steel cage used in the beams of swimmer bars. Figure 15 shows the beam deflection of the two different types of beams at failure. This shows that the rigidity of the beams reinforced with swimmer bars for shear is higher than the rigidity of the beams reinforced with the standard stirrups.

CONCLUSION

The swimmer bars system in this study, improved the punching shear performance of the tested slabs and the shear strength in beams. The new arrangement of eight swimmer bar system forming truncated pyramid punching shear reinforcing system in slabs is proven to be effective in increasing the punching shear strength by providing plane shear interception. This added strength has the potential to give the design engineer the needed tools to avoid using drop panels or column capitals. This option saves material and labor compared with the drop panel option or column capital option. The swimmer bar punching shear reinforcing system improved the slab rigidity and reduced the slab central deflection. There is a direct correlation between the diameter of the swimmer bars used and the punching shear strength. Also, the swimmer bars system used in beams is proven to be effective and economical in reinforced concrete beams. The swimmer bars system used in slabs and beams in this study added rigidity to the structural elements.

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