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Strengthening of Footing by Using Flexural and Shear Reinforcements

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Abstract: *Punching shear failure is one of the most common problems in shallow foundations (pad footings).Therefore, this investigation is conducted to study the effect of increasing of the flexural reinforcement ratios as (0.0036, 0.0047, and 0.0057) and using funnel-shaped punching shear preventers (FSPSP)on the punching shear failure of self-compacting concrete(SCC) pad footing. Four footing specimens were supported on a bed of steel(car)springs and loaded by vertical forcetill failure. The results show that the first crack load, the ultimate load, the ductility and the punching shear strength were improved by using the FSPSP. The results showed that the first crack load and ultimate load increased with increasing of the flexural reinforcement ratio while the ductility and the deflection are decreased. In contract, the using of the FSPSP showed an improve of the first crack load, the ultimate load, the ductility and the punching shear strength.*

Keywords*: punching shear; footings; reinforced concrete SCC; funnel-shaped punching shear preventers.*

I. Introduction

Shallow foundations transmit structural loads to the near-surface soil. Column footings (pad footings) are the main types of shallow foundations and structural members which support columns. Control of punching of the columns through those footings is a mandatory part of the design of reinforced concrete footings exposed to notable concentrated forces through the columns. In general, punching shear failure is brittle failure which happened without visible signs before the occurrence of the failure. Therefore, Extensive studies[1-8] have been conducted for punching shear failure of the pad footing in the past decades to enhance the punching shear strength of the footing-column connection.

Talbot in 1913[1] conducted the initial experimental investigations with regard to the pad footings at Illinois University. Such tests have been conducted on 197 column footings models placed over a bed of springs to simulate the interaction between the footing and the soil. Investigations in Illinois about pad footing continued by Richart in (1948) [2]. Richart tested 156 footings of various shapes and construction details by placing them on a bed of automotive coil springs, Cole [3] studied the basic mechanism of failure in shear of RC footings through the use of high strength gypsum plaster models were constructed and loaded to failure on a foundation of sand in the box.

Hallgren et al. (1998)[4] Studied the effect of the concrete strength, the ratio of flexural reinforcement, the type of anchorage of the reinforcement, usage and the type of shear reinforcement, method of applying loading and shapes of the slabs on punching shear strength of 14 column footings that were loaded by uniform line loads and with uniform surface loads. Hegger et al.[5] also examined punching shear failure regarding five RC footings with different thickness and reinforcement ratios supported on sand in the box. furthermore, Hegger et al.[6] investigated the punching shear behavior of footings supported on the sand and on a column stub and a uniform surface load was applied over the footings with taking different parameters such as shear span to depth ratio (a/d), concrete compressive strength and punching shear reinforcement which is consists of vertical stirrups with different diameters. Lee et al. [7] studied a new method to improve the strength and ductility of the footing by inserting steel funnel-shaped to act as Punching Shear Preventers (PSP) into the footing. Shill et al.[8] studied the punching shear behavior of pad footings by using brick aggregate as a coarse aggregate and the footings model was supported on soil and tested under field conditions.

This study focused on punching shear behavior of the footing-column connection. A total number of four specimens were constructed and tested in order to investigate the effect of Percentage of steel reinforcement (ρ) and using the funnel-shaped punching shear preventers(FSPSP) as a shear reinforcement.

II. Experimental Part

Six square reinforced concrete footing models were constructed and tested till the failure. All specimens had square shape with side length of 1000mm and thickness equal to 120mm as shown in the Figure(1). The axial load was applied through the solid square steel column of dimensions of 150*150 mm over the center of the footing. All the footings were cast at the same time and had the same compressive strength equal to 21.2 MPa. The type of concrete that used in this study is self-compacting concrete (SCC) of mix contains (cement 290 kg/m3, water 160 liters/m3, sand 814 kg/m3, gravel 910 kg/m3, limestone 190 kg/m3 and superplasticizer 1%). specimens S1, S2 and S3 are specified to study the effect of the increase of flexural reinforcement ratio as of (36,47, and 57)% respectively as shown in the figure (1). Fourfunnel-shaped punching shear preventers (FSPSP) are used in this investigation as a shear reinforcements. The FSPSP are made of galvanized metal and are had a smooth surface inclined by 45° as well as had four holes (diameter of the holes was 10 mm) which enhancement the attachment between the FSPSP and the concrete as shown in the Figure (2) and all the FSPSP installed around the column at zone of compressive strength as shown in the Figure(3). The size of the FSPSP as namely (the top diameter “d_t” * the bottom diameter “d_b” * height “h”) as (120*40*40) mm and thickness of 1mm. Table (1) shows the detail of the footing specimens . It is worth pointing out here that the specimens are supported on a bed of springs and loaded concentrically which is applied by using a universal testing machine of the type (EPP300MFL system) with a capacity of 3000kN as shown in the Figure (4), applying the load in steps 5kN. During the experiments, the strains in the reinforcement bars and vertical displacements at the quarter of the span of footings were measured every load step. Strain gauge which is used in the test is installed at the bottom of the flexural reinforcement bar as shown in Figure (5).

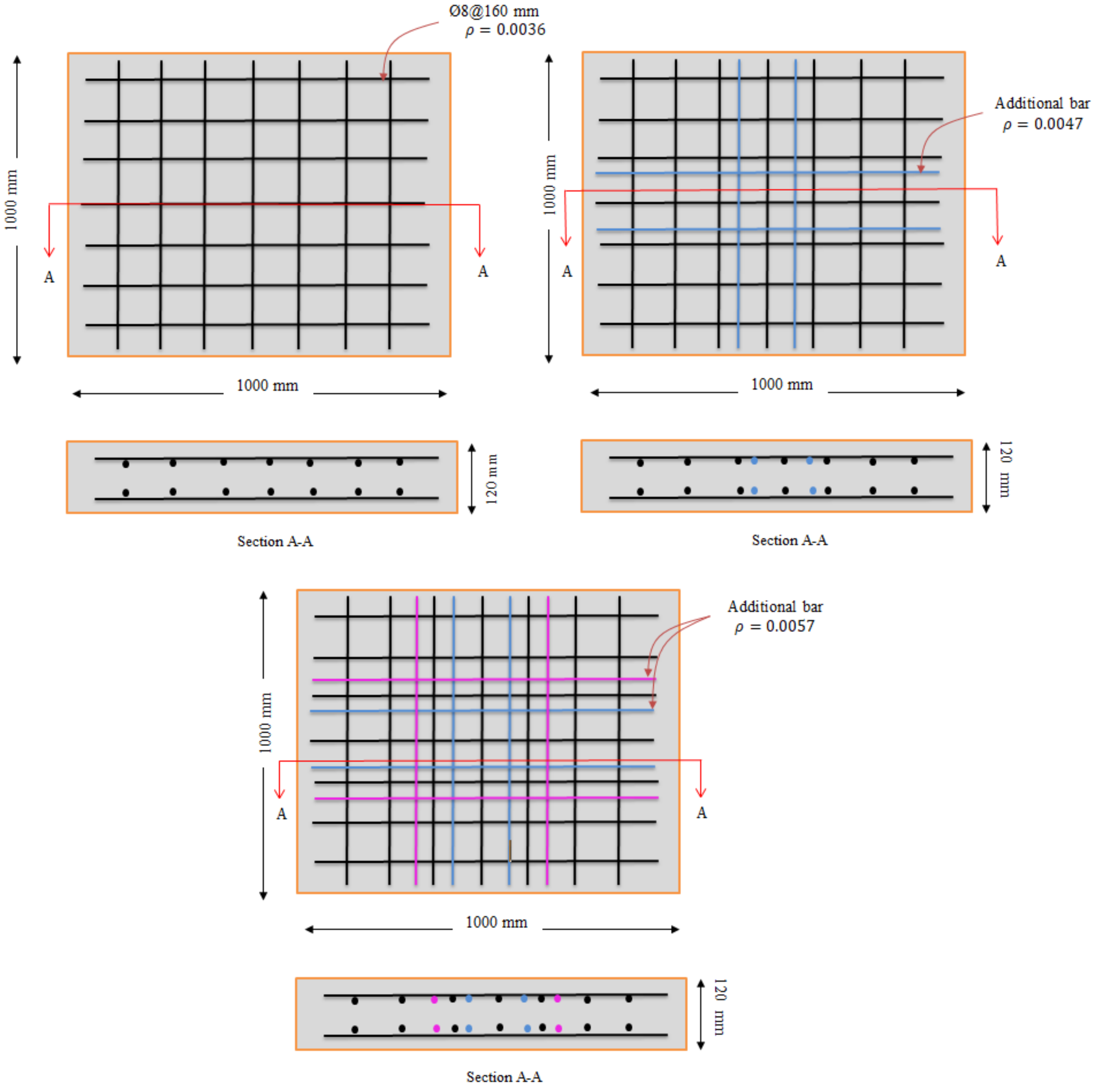
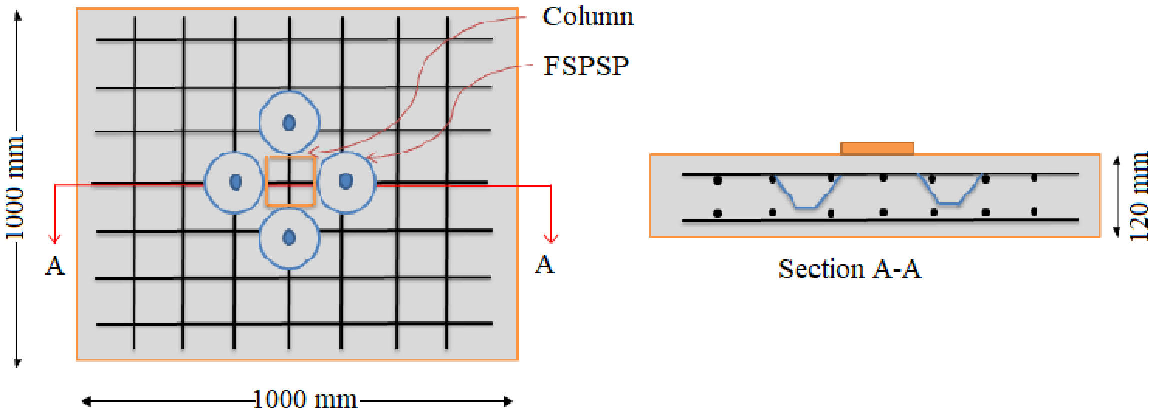


Figure (1) Dimensions and reinforcement layouts of the test specimens.

Figure (2) Funnel –Shape Punching Shear Preventers (FSPSP).

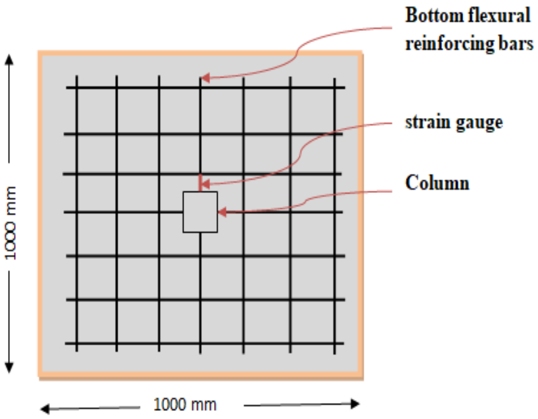


Figure(3) Location of the FSPSP.

Table(1) Details of specimens and test results.

Specimens	ρ	FSPSP number	First crack load P_{cr} (kN)	Ultimate load P_u (kN)	Difference of P_u %	Deflection at ultimate load Δu (mm)	Ductility (Δu/Δcr)
S_1	0.0036	-	63	98	-	1.51	2.96
S_2	0.0047	-	72	110	+12.24	1.20	2.88
S_3	0.0057	-	80	120	+22.44	1.10	2.50
S_4	0.0036	4	73.5	163	66.32	1.83	10.28

Figure (4) Test setup.



Figure(5) Location of strain gauge.

III. Discussion of Experimental Results

1. Footing Punching Shear

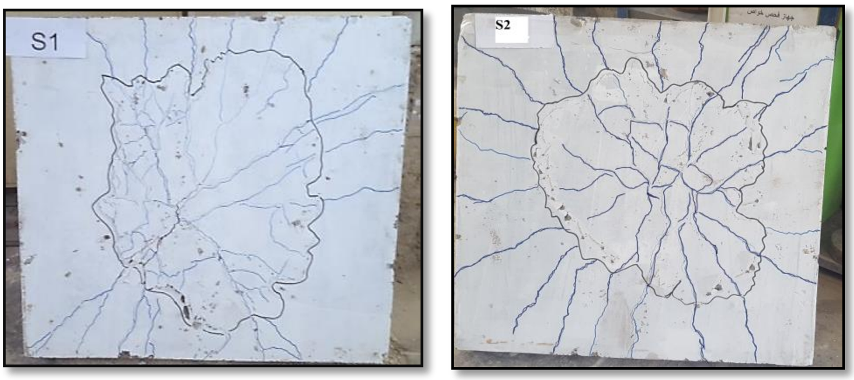
First group (the effect offlexural reinforcement ratio): To study the effect offlexural reinforcement ratio, group one is employed which consists of three specimens (S_1, S_2, and S_3) with different flexural reinforcement ratios of (36,47, and 57)% respectively.

The test results are illustrated in Table (1). During the testing procedure where the load was applied incrementally, springs became closed under the load of (50±1 kN) with no sign of failure was observed for all specimens. Later the first cracks were recorded at load level equal to 64.2,65.4, and 66.6% of the ultimate load of S_1, S_2, and S_3 respectively. The propagation of cracks was traced and marked without stopping the loading process till the final crack pattern was mapped in tension face as shown in figure (6).

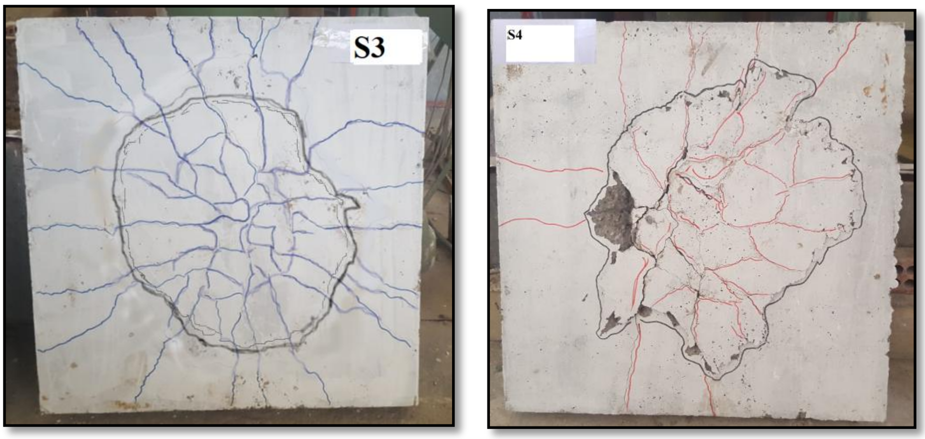
The results showed that the first crack load and ultimate load increase by increasing the flexural steel reinforcement ratio of the footing specimens as shown in table (1). From table(1)it can be found that the increase flexural reinforcement ratios about (30.5 and 58.3) % for specimens (S_2, and S_3) over that of reference specimen S_1, the ultimate load is increased (12.24 and 22.44)% respectively relative to the reference. Therefore, it can be concluded that the effect of the flexure reinforcement ratio can be considered as an important parameter.

Figure (7) shows the relationship between the load and the deflection at the quarter of the span of footings specimens is such that, initially almost linear elastic behavior at a low loading stage was observed. The load gradually increased up to failure, where after cracking the load and deflection curve is significantly changed. It can also be noted from figure (7) the gradient of the curves increases with the increasing of the flexural reinforcement ratio. As can be observed from the load-deflection curve, at a certain load, the deflection decreased by about 43.19 and 52.16 % for S_4 and S_5 respectivelyrelative to the reference concrete specimens S_1. Also, it can be seen that despite the increase in punching shear strength by increasing the flexural reinforcement ratio, but the ductility and the deflection at the ultimate load is reduced and this indicates that the model becomes more brittleness, this behavior is agreement with[9-10].

Second group (effect of the FSPSP):To investigate the influence of the size of FSPSP on the punching shear behavior, two specimens are available (S_1, and S_4). All specimens had the same (dimensions, reinforcing bar layout and concrete type). The cracks have begun to appear after the springs closing as the previous cases. The first cracks were recorded at load level equal to 64.2 and 45.1 % of the ultimate load in S_1, and S_4 respectively. The crack patterns of the specimens are shown in figure (6). It can be seen that the using of the FSPSP showed an increase of the first crack load and ultimate load by about (, and 66.32%) relative to the reference specimen without FSPSP S_1 as shown in the table(3). From figure (8) it can be noted that the gradient of the load-deflection curves increase with the addition of FSPSP. The deflection at an equivalent load increased by about,78.47 for S_2 respectively relative to the reference concrete specimens S_1. Also it can be observed that the toughness and ductility considerably increased in footingswith FSPSP compared to that results of the specimen without FSPSP, this results are a good agreement with [7].



(a) (b)



(c) (d)

Figure (6)Crack Patterns of the Footings; (a) S_1, (b) S_2, (c) S_3, (d) S_4.

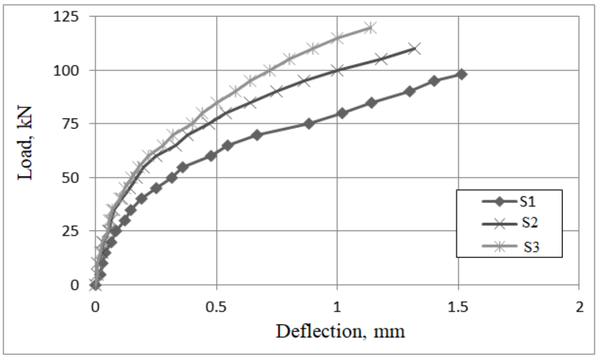
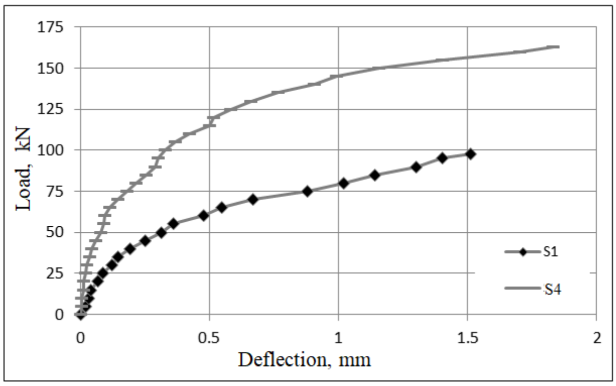


Figure (7) Load-Deflection relationship of the footings with different Flexural Steel Reinforcement Ratios.



Figure(8) Load-Deflection relationship of the footings with the FSPSP.

2. Failure Characteristics

The punching failure is divided into two different types. The first one is shear failure that occurs suddenly with a small deflection. This type of failure is frequently observed in the footing or slab with a large flexural reinforcement ratio. The second type of failure mode is the flexural failure. This failure takes place when the flexural reinforcement ratio is small, and the footing or slab is failed by the yielding of the reinforcing bar [7, 11, 12]. Therefore, to classify the failure mode of the specimens, the ultimate strain in the flexural reinforcing bar has been evaluated from strain gauges that were installed at the bottom flexural reinforcing bars as shown in the table (2).From table (2) it can be noted that the ultimate strains of flexural reinforcing bar of S_1, S_2, and S_3 decrease as the flexural reinforced ratios increase and did not reach the yield strain, so all specimens are failed by punching shear. After adding FSPSP to specimens (S_4), it can be noted that the strain of the flexural reinforcing bars of S_4 could exceed the yield strain and prevent the brittle punching shear failure by redistributing the applied load to the flexural reinforcing bars. Whereas, the ultimate strain of the flexural reinforcing bars of the remaining specimens did not achieve the yield strain so they are failed by punching shear failure.

The punching failure mode was typically in the shape of truncated pyramid making an angle (θ) with the bottom face of the footing. The failure angels and area of the punching failure zones are measured by AutoCAD software and their values are illustrated in Table (2) and figure (9). The test results show that increasing of flexural reinforcement ratios lead to decrease of the size of the failure zone and increase of the angle of failure. Also, the using of the FSPSP showed an decrease of the size of the failure zone and considerably increase of the angle of failure.

Table (2) Failure characteristics of footings.

Specimens	Ultimate Strain in Reinforcing Bar $\times 10^{-6}$	Yield Strain (ε_y) $\times 10^{-6}$	Mode of Failure	Measured Failure area (mm^2)	The angle of Failure (θ°)
S_1	350.1	577	Shear	363840	42°
S_2	340.2		Shear	316800	52°
S_3	330.2		shear	268400	58°
S_4	930.0		flexure	335040	74°

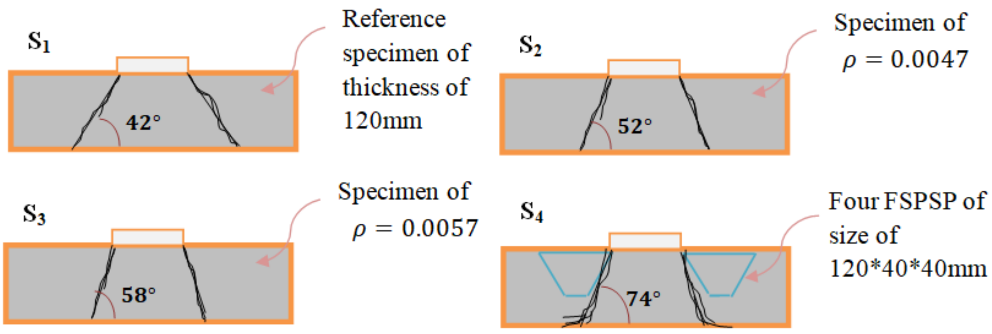


Figure (9) Angle of failure of the specimens

Comparative Notes between Experimental Results and ACI Design Code

According to ACI318-14[13], The resistance punching shear force which developed in the concrete slab or footing that subjected to a square column can be determined as

$$V_c = 0.33\sqrt{f_c'}\lambda b_0 d \qquad (1)$$

Where d is the effective depth of the slab or the footing, $b_0$is the control perimeter and it is located at 0.5d from the loaded area, λ is the modification factor to take into account the effect of lightweight concrete. For the normal weight concrete, λ is equal to 1.

The corresponding punching shear force is calculated and presented in the table (3). As shown in the table (3) ACI-318 formulas generally give shear strength higher than the experimental method.

Table (3) Comparison with ACI design code.

Specimens	$f_c{}'$ (MPa)	Ultimate load (Pu) (kN)	Effective depth (mm)	b_0 (mm)	V_c (kN)	Pu/V_c
S_1	21.2	98	96	984	143.53	0.68
S_2	21.2	110	96	984	143.53	0.76
S_3	21.2	120	96	984	143.53	0.84
S_4	21.2	163	96	984	143.53	1.13

Conclusion

The conclusions from this investigation can be summarized as the following clauses:

1- Increasing the flexure reinforcement ratio by 30.5 and 58.3 % lead to increase of first crack load and ultimate load by (14.28, 26.98%), (12.24, 22.44%) respectively relative to the reference specimen, slightly increase of the angle of failure and decreasing of ductility and the deflection at equivalent load. Furthermore, increasing of the flexural reinforcement ratio lead to make the footing more brittleness and failed by shear.

2- The footings that contain FSPSP showed an increase of the ultimate load, first crack load, ductility, deflection at the ultimate load and angle of failure. The results also showed that the using of the FSPSP. lead to increasing of the ultimate load as 66.32% relative to reference specimen without FSPSP as well as lead to an increase of the ductility and angle of failure, also it lead to decrease all the deformations at all stages of loading.

3- From the study of the previous parameters, it can be found that the best result obtained by using FSPSP, which led to the highest rate of increase in ultimate load, ductility, and angle of failure, in addition to reducing deformation at all stages of loading. Further, the cost of FSPSP was less than the other parameters.

References

[1.] A. N. Talbot, “Reinforced Concrete Wall Footings and Column Footings”, Engineering Experiment Station, University of Illinois, Urbana, Bulletin No. 67, Mar. 1913, 114p.

[2.] F.E. Richart, “Reinforced Concrete Wall and Column Footings”, American Concrete Institute, Vol. 20, No.2, (1948) pp.97-127.

[3.] F.V. Cole, “A Study of Shear Failures in Footing”, M.Sc. Thesis, University of Missouri,Rolla,US (1966).

[4.] M. Hallgren, S. Kinnunen and B. Nylander, “Punching Shear Tests on Column Footings”, Nordic Concrete Research, Vol. 21, No.3, (1998) pp.1-22.

[5.] J. Hegger, A. G. Sherif, and M. Ricker, “Experimental Investigations on Punching Behavior of Reinforced Concrete Footings”, ACI Structural Journal, Vol. 103, No. 4, (2006)pp. 604–613.

[6.] J. Hegger, M. Ricker, and A. G. Sherif, “Punching Strength of reinforced Concrete Footings”, ACI Structural Journal, Vol. 106, No. 5, (2009)pp. 706–716.

[7.] S.S. Lee, J. Moon, K. S. Park, and K. W. Bae, “Strength of Footing with Punching Shear Preventers”, Scientific World Journal, Vol. 2014, (2014)pp1- 15.

[8.] S. K. Shill, M. M. Hoque, M. Shaifullah, “Punching Shear Behavior of RC Column Footing on Stabilized Ground”, International Journal of Engineering Technology, Management and Applied Sciences, Vol. 3, September (2015)pp.264-253.

[9.] H. F. Hassan, “ Punching Shear Behavior of Normal and Modified Reactive Powder Concretes Slabs”, Ph.D. Thesis, University of Mustansiriyah, Baghdad (2012).

[10.] P. Menetrey, “Synthesis of Punching Failure in Reinforced Concrete”, Cement and Concrete Composites, Vo1.24, No.6, December (2002) pp.497-507.

[11.] H. Marzouk and A. Hussein, “Experimental Investigation on the Behavior of High-Strength Concrete Slabs”, ACI Structural Journal, Vol. 88, No. 6, November (1992)pp. 701–713.

[12.] S. Guandalini, O. L. Burdet, and A. Muttoni, “Punching Tests of Slabs with Low Reinforcement Ratios”, ACI Structural Journal, Vol. 106, No. 1, December (2009)pp. 87–95.

[13.] ACI Code 318M-14, “Building Code Requirements for Structural Concrete and Commentary”, American Concrete Institute, Farmington Hills, Michigan, USA(2015).