INVESTIGATING ACI 318-08 PUNCHING SHEAR PROVISIONS FOR DESIGN OF ISOLATED FOOTINGS

دراسة إشتراطات الكود الأمريكي ACI 318-08 الخاصة بقص الإختراق لتصميم القواعد المنفصلة

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ملخص البحث

هذه الدراسة مرتبطة بدراسة اشتراطات كود معهد الخرسانة الأمريكي (لجنة رقم ٣١٨ للعام ٢٠٠٨) والخاصة بقص الإختراق مع التركيز على المعادلة رقم ١١-32 من هذا الكود. لتصميم بلاطات الأسقف و القواعد المنفصلة المصنوعة من الخرسانة المسلحة يتم احتساب مقاومة الخرسانة لقص الإختراق على أنها القيمة الدنيا المحسوبة من المعادلات 31-11 و 32-11 و-11 33 من هذا الكود. ومن الخبرة العملية للباحث في تصميم القواعد المنفصلة لوحظ أن المعادلة رقم 32-11 لا تعطي القيمة الدنيا لقص الإختراق عند تصميم القواعد الخرسانية المنفصلة مما يجعلها زائدة ولا جدوى لها. في هذا البحث سيتم بحث هذه المعادلة نظريا وحسابيا لإثبات عدم جدواها عند التصميم العملي للقواعد المنفصلة.

Abstract

This study is concerned with investigating the punching shear provisions of ACI 318-08 with emphasis on Equation (11-32) of this code. For reinforced concrete slabs and footings, shear force resisted by concrete is taken as the smallest value evaluated from ACI Equations (11-31), (11-32) and (11-33). Based on the experience of the author in designing isolated footings, it is noticed that Equation (11-32) has never yielded the smallest shear capacity in isolated footing design, thus making this equation redundant in terms of punching shear design. In this work, Equation (11-32) is to be investigated theoretically and parametrically to prove its redundancy in terms of practical design of isolated footings.

Keywords: Punching shear; Isolated footing; Column dimensions; Column location

1- Introduction

ACI 318-08 [01] code design provisions relate the punching shear strength to the effective depth of the slab d, the perimeter of critical section for shear b_o of a critical section located at distance $d/2$ from the faces of the column, the square root of the compressive strength $\sqrt{f'_c}$, ratio of long to short side of column and column location. Other codes, such as Eurocode 2 [02], include additional parameters such as the flexural reinforcement ratio ρ.

Guandalini et al. [03] showed that the formulation of ACI 318-08 can lead to less conservative estimates of the punching shear strength for thick slabs and for low flexural reinforcement ratios. On the other hand, for slabs with large reinforcement ratios failing in punching, they stated that the predictions given by ACI 318-08 are, in general, conservative. Their tests have also confirmed that, due to the size effect,

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the punching shear strength decreases with increasing thickness. Furthermore, for thick slabs with low reinforcement ratios they concluded that ACI 318-08 is less conservative than their teat results.

Hegger et al. [04] carried out experimental punching tests on reinforced concrete footings supported on soil. The results indicated that the angle of the shear failure plane is steeper than observed in punching tests on flat slabs and the shear slenderness seems to affect the punching shear capacity significantly. Furthermore, the punching loads predicted by different codes tend to be conservative for slender footings. Nevertheless, the authors stated that the codes tend to overestimate the punching resistance for compact footings with small shear slenderness.

Muttoni [05] stated that punching shear provisions present in design codes are generally based on experimental results performed on isolated slab elements representing the part of the slab close to the column. Most tests have been performed on relatively thin slabs, typically 0.1 to 0.2 m thick. The test results are nonetheless commonly extrapolated to design flat slabs with a thickness typically 2 to 3 times larger, and even for foundation mats with thicknesses 10 to 20 times larger.

Experiments carried out by Lovrovich and McClean [06] showed that punching shear strength for loading through rectangular areas with respect ratios greater than 2 is less than that for loading through square areas.

Sălna et al. [07] stated that the main factors influencing the punching shear strength are concrete strength and the size of critical perimeter. Furthermore, they claimed that the punching cone angle depends on concrete strength, the amount of flexural reinforcement, the effective depth of slab and column dimensions.

Ozden et al. [08] showed that the location of the critical perimeter for punching is not dependent on the parameters investigated in the experimental program, i.e., concrete strength, reinforcement ratio, presence of steel fiber reinforcement and eccentricity of loading. They found out that concrete strength has a direct influence on the punching behavior and punching capacity of concrete slabs. Also, they concluded that increasing the plate flexural reinforcement ratio results in an increase in the punching and residual strengths.

Albrecht [09] revealed considerable differences among seven different European and North American codes with respect to the punching shear capacity, the amount and distribution of shear reinforcement and integrity reinforcement in reinforced concrete slabs. He stated that in all codes punching shear capacity calculations are based on a critical perimeter, which is located between $0.5d$ and $2d$ from the face of the column. Except in the North American codes, the punching shear capacity depends on the flexural reinforcement ratio. However, the effect of flexural reinforcement is quite different in each code.

Moehle et al. [10] claims that the ratio of critical punching perimeter to the effective slab depth has an effect on the punching shear strength. For typical small values of this ratio, the most stressed region of the plate-to-column connection is well confined by in-plane stresses. For large ratios, the confinement of the punching zone is likely to be reduced, resulting in a decrease in shear strength.

Based on Section 11.11.2.1 of ACI 318-08 [01] for reinforced concrete slabs and footings, V_c is the smallest value obtained from the following three equations:

$$V_c = 0.17\sqrt{f'_c}\left(1+\frac{2}{\beta}\right)\lambda b_o d \qquad (1)$$

$$V_c = 0.083\sqrt{f'_c}\left(\frac{\alpha_s d}{b_o} + 2\right)\lambda b_o d \quad (2)$$

$$V_c = 0.33\sqrt{f'_c}\,\lambda b_o d \quad (3)$$

Equation (3) was first introduced in ACI 318-1963 [11] where punching shear capacity is dependent on concrete compressive strength, perimeter of critical section for shear and effective depth of concrete section. Later on, Equation (1) appeared for the first time in ACI 318-1977 Code [12] to take into consideration the loaded area aspect ratio which provides a transition between two-way shear $V_c = 0.33\sqrt{f'_c}$ and beam shear as the loaded area becomes more elongated [13]. Finally, test results have indicated a decrease in shear strength as the ratio of the perimeter b_o to the effective depth d increases [14], which lead to the introduction of Equation (2) in ACI 318-1989 [15] to account for a decrease in shear strength affected by the ratio of the critical perimeter b_o to the effective depth d.

Most of the available literature covers two major areas; experimental tests on isolated slabs and footings and comparisons with other codes of practice. In this study, Equations (1), (2) and (3) correspond to ACI Equations (11-31), (11-32) and (11-33), respectively. The current study aims at investigating punching shear provisions for isolated footings according to ACI 318-08 [01]. Emphasis will be stressed on Equation 11-32 to prove its redundancy, when used with other code provisions, especially those associated with bar development requirements.

۲. Determining Effective Depths, for which Equation (2) Controls Punching Shear Design

2-1 Interior Columns

Two cases are considered based on the ratio of long to short side of column β, as shown in Figure (1).

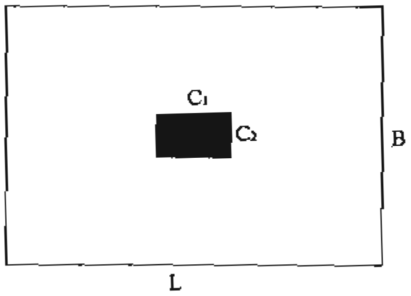

Figure (1): Interior column

2-1-1 Columns being nearly square, in cross section ($\beta \le 2$)

For ratios of long to short sides of column $\beta \le 2$, shear evaluated from Equation (3) is to be set equal to shear evaluated from Equation (2), or

$$\frac{d}{b_o} = \frac{2}{\alpha_s} \quad (4)$$

but,

$b_o = 2C_1 + 2C_2 + 4d$ and $\alpha_s = 40$

Substituting b_o and α_s values in Equation (4), one obtains Equation (5).

$$d = \frac{C_2(\beta + 1)}{8} \quad (5)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-1-2 Columns being rectangular, in cross section ($\beta \ge 2$)

For ratios of long to short sides of column $\beta \ge 2$, shear evaluated from Equation (1) is to be set equal to shear evaluated from Equation (2), or

$$\frac{d}{b_o} = \frac{4}{\beta \alpha_s} \quad (6)$$

Substituting b_o and α_s values in Equation (6), one gets Equation (7) for determination of d

$$d = \frac{C_2(\beta + 1)}{(5\beta - 2)} \quad (7)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-2 Side Columns

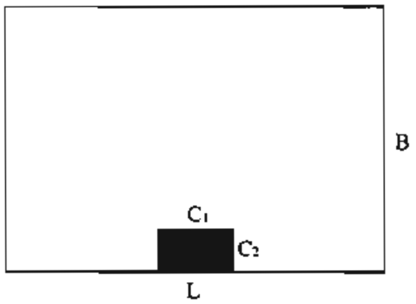

Figure (2-a): First column orientation

Two cases are considered based on the ratio of long to short side of column β , as shown in Figure (2).

2-2-1 C_1 Parallel to L

2-2-1-1 Columns being nearly square, in cross section ($\beta \le 2$)

Substituting $b_o = C_1 + 2C_2 + 2d$ and $\alpha_s = 30$ in Equation (4), one gets Equation (8) for determination of d , or

$$d = \frac{C_2(\beta + 2)}{13} \quad (8)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-2-1-2 Columns being rectangular, in cross section ($\beta \ge 2$)

Substituting $b_o = C_1 + 2C_2 + 2d$ and $\alpha_s = 30$ in Equation (6), one gets Equation (9) for determination of d, or

$$d = \frac{C_2(2\beta + 4)}{(15\beta - 4)} \quad (9)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-2-2 C_1 Parallel to B

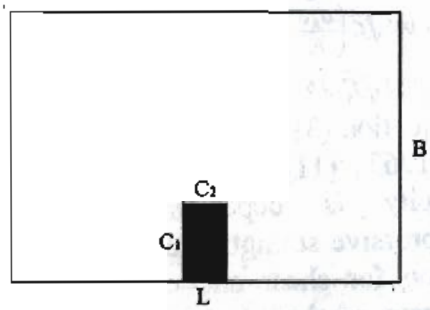

Figure (2-b): Second column orientation

2-2-2-1 Columns being nearly square, in cross section ($\beta \le 2$)

Substituting $b_o = C_2 + 2C_1 + 2d$ and $\alpha_s = 30$ in Equation (4), one gets Equation (10) for determination of d, or

$$d = \frac{C_2(2\beta + 1)}{13} \quad (10)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-2-2-2 Columns being rectangular, in cross section ($\beta \ge 2$)

Substituting $b_o = C_2 + 2C_1 + 2d$ and $\alpha_s = 30$ in Equation (6), one gets Equation (11) for determination of d, or

$$d = \frac{C_2(4\beta + 2)}{(15\beta - 4)} \quad (11)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-3 Corner Columns

Two cases are considered based on the ratio of long to short side of column β , as shown in Figure (3).

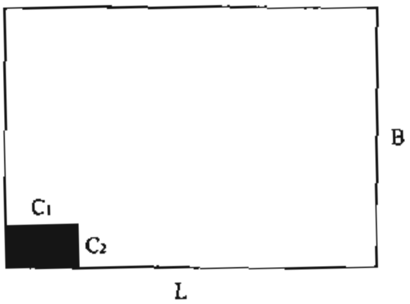

Figure (3): Corner column

2-3-1 Columns being nearly square, in cross section ($\beta \le 2$)

Substituting $b_o = C_1 + C_2 + d$ and $\alpha_s = 20$ in Equation (4), one gets Equation (12) for determination of d,

$$d = \frac{C_2(\beta + 1)}{9} \qquad (12)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

2-3-2 Columns being rectangular, in cross section ($\beta \ge 2$)

Substituting $b_o = C_1 + C_2 + d$ and $\alpha_s = 20$ in Equation (6), one gets Equation (13) for determination of d,

$$d = \frac{C_2(\beta + 1)}{(5\beta - 1)} \qquad (13)$$

For d values smaller than those evaluated from the above-given equation, Equation (2) controls punching shear design.

3- Minimum Effective Depths d to Satisfy Punching Shear Equations

In this section equations are developed to evaluate the minimum effective depths d required for satisfying punching shear equations (1) through (3) for the stated three column locations.

3-1 Interior Columns

The punching shear force is given by Equation (14)

$$V_u = q_u \left[A_f - (C_1 + d)(C_2 + d)\right] \qquad (14)$$

Using Equation (3) and setting $V_u = \Phi V_c$, Equation (15) can be used to determine d

$$\left(q_u + 1.32\,\Phi\sqrt{f_c'}\right)d^2 + 0.66\,\Phi\sqrt{f'_c}(C_1 + C_2)\,d + q_u(C_1 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (15)$$

Similarly, using (1) and setting $V_u = \Phi V_c$, Equation (16) can be used to determine d

$$\left(q_u + 0.66\,\Phi\sqrt{f_c'}\left(1 + \frac{2}{\beta}\right)\right)d^2 + 0.33\,\Phi\sqrt{f'_c}\left(1 + \frac{2}{\beta}\right)(C_1 + C_2)\,d + q_u(C_1 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (16)$$

Similarly, using Equation (2) and setting $V_u = \Phi V_c$, Equation (17) can be used to determine d

$$\left(q_u + 3.96\,\Phi\sqrt{f_c'}\right)d^2 + 0.33\,\Phi\sqrt{f'_c}(C_1 + C_2)\,d + q_u(C_1 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (17)$$

3-2 Side Columns

3-2-1 C_1 Parallel to L

The punching shear force is given by Equation (18)

$$V_u = q_u \left[A_f - (C_1 + d)(C_2 + d/2)\right] \qquad (18)$$

Using Equation (3) and setting $V_u = \Phi V_c$, Equation (19) can be used to determine d

$$\left(q_u/2 + 0.66\,\Phi\sqrt{f_c'}\right)d^2 + 0.33\,\Phi\sqrt{f'_c}(C_1 + 2C_2)\,d + q_u(C_1/2 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (19)$$

Using Equation (1) and setting $V_u = \Phi V_c$, Equation (20) can be used to determine d

$$\left(q_u/2 + 0.66\,\Phi\sqrt{f_c'}\left(1 + \frac{2}{\beta}\right)\right)d^2 + 0.17\,\Phi\sqrt{f'_c}\left(1 + \frac{2}{\beta}\right)(C_1 + 2C_2)\,d + q_u(C_1/2 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (20)$$

Using Equation (2) and setting $V_u = \Phi V_c$, Equation (21) can be used to determine d

$$\left(q_u/2 + 2.89\,\Phi\sqrt{f_c'}\right)d^2 + 0.17\,\Phi\sqrt{f'_c}(C_1 + 2C_2)\,d + q_u(C_1/2 + C_2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (21)$$

3-2-2 C_1 Parallel to B

Using Equation (3) and setting $V_u = \Phi V_c$, Equation (22) can be used to determine d

$$\left(q_u/2 + 0.66\,\Phi\sqrt{f_c'}\right)d^2 + 0.33\,\Phi\sqrt{f'_c}(C_2 + 2C_1)\,d + q_u(C_1 + C_2/2)\,d - q_u(A_f - C_1C_2) = 0 \qquad (22)$$

Using Equation (1) and setting $V_u = \Phi V_c$, Equation (23) can be used to determine d

$$\left(q_u/2+0.33\Phi\sqrt{f_c'}\left(1+\frac{2}{\beta}\right)\right)d^2+0.17\Phi\sqrt{f'_c}\left(1+\frac{2}{\beta}\right)(C_2+2C_1)\,d+$$

$$q_u\,(C_1+C_2/2)\,d-q_u(A_f-C_1C_2)=0 \qquad (23)$$

Using Equation (2) and setting $V_u=\Phi V_c$, Equation (24) can be used to determine d

$$\left(q_u/2+2.89\Phi\sqrt{f_c'}\right)d^2+0.17\Phi\sqrt{f'_c}(C_2+2C_1)\,d+$$

$$q_u\,(C_1+C_2/2)\,d-q_u\,(A_f-C_1\,C_2)=0 \qquad (24)$$

3-3 Corner Columns

Using Equation (3) and setting $V_u=\Phi V_c$, Equation (25) can be used to determine d

$$\left(q_u/4+0.33\Phi\sqrt{f_c'}\right)d^2+0.33\Phi\sqrt{f'_c}(C_1+C_2)\,d+$$

$$q_u\,(C_1/2+C_2/2)\,d-q_u\,(A_f-C_1\,C_2)=0 \qquad (25)$$

Using Equation (1) and setting $V_u=\Phi V_c$, Equation (26) can be used to determine d

$$\left(q_u/4+0..17\Phi\sqrt{f_c'}\left(1+\frac{2}{\beta}\right)\right)d^2+0.17\Phi\sqrt{f'_c}\left(1+\frac{2}{\beta}\right)(C_1+C_2)\,d+$$

$$q_u\,(C_1/2+C_2/2)\,d-q_u(A_f-C_1C_2)=0 \qquad (26)$$

Using Equation (2) and setting $V_u=\Phi V_c$, Equation (27) can be used to determine d

$$\left(q_u/4+1.87\Phi\sqrt{f_c'}\right)d^2+0.17\Phi\sqrt{f'_c}(C_1+C_2)\,d+$$

$$q_u\,(C_1/2+C_2/2)\,d-q_u\,(A_f-C_1\,C_2)=0 \qquad (27)$$

4- Minimum Effective Depth of Footing Based on Bar Development Requirements

Based on ACI 12.3.1 and 12.3.2, the development length of deformed bars in compression is given by Equation (28):

$$l_{dc}=\frac{0.24\,d_b\,f_y}{\lambda\sqrt{f_c}}\geq 0.043\,d_b\,f_y \qquad (28)$$

For a bar diameter of 10 mm, reinforcement yield stress of 420 MPa and concrete compressive strength of 30 MPa, l_{dh} is evaluated as 184 mm.

Based on ACI 12.3.1, the development length of deformed bars in compression is not to be less than 20 cm. For a flexural reinforcement of 10 mm in the footing pad the smallest possible effective depth d equals 21 cm.

5- Parametric Study

A parametric study is carried out for isolated footings with three column locations, long-to-short footing aspect ratios of 1.0 and 2.0 and ratios of long to short sides of column of 1.0, 2.0 and 3.0 are used. Five factored soil pressures q_u are considered; 0.1, 0.2, 0.3, 0.4 and 0.5 MPa. Concrete compressive strength f'_c of 30 MPa is considered for columns and footings while yield steel of steel reinforcement f_y is taken as 420 MPa.

Substituting d = 21 cm, the minimum dimension required to satisfy Equation (28), in Equations (5), (7), (8), (9), (10), (11), (12) and (13), minimum values of shorter column side C_2 for which Equation (11-32) controls punching shear design are evaluated. Column's longer side C_1 is evaluated for each value of β. Column axial factored load capacities are calculated, based on article 10.3.6.1 of ACI 318-08 for each set of C_1 and C_2, assuming a reinforcement ratio of 1 %. Based on column loads P_u and factored soil pressures q_u, footing dimensions L and B are evaluated for each q_u value.

Finally, Equations (15), (16), (17), (19), (20), (21), (22), (23), (24), (25), (26) and (27) are used to evaluate d values required to satisfy punching shear requirements, as per Equations (1) through (3).

6- Results and Discussion

For the three column locations considered in the parametric study, d values d_1, d_2 and d_3 corresponding to Equations (1), (2) and (3), respectively, are presented in Tables (1) through (3). It can be easily seen that Equation (2), which corresponds to Equation (11-32) of ACI 318-08, requires the smallest effective depths d to satisfy punching shear requirements. This means that V_c values evaluated from ACI Equation (11-32) are the highest. Thus this equation doesn't control punching shear design in practical design of isolated footings.

Table (1): Required effective footing depths for interior columns

L/B	β	Column's Dimensions C_1 mm	C_2 mm	P_u kN	d mm	(MPa) q_u 0.10	0.20	0.30	0.40	0.50
1.0	1.00	840	840	10796	d1	NA	NA	NA	NA	NA
					d2	732.8	733.2	714	705.6	696.6
					d3	1021.2	999.6	978.9	960.1	940.7
	2.00	1120	560	9596	d1	945.2	928.9	915.1	887.3	874
					d2	686.6	680	674.7	660.4	654.9
					d3	945.2	928.9	915.1	887.3	874
	3.00	2048	683	21381	d1	1506.7	1470.6	1444.6	1403.9	1545.9
					d2	1003	989.4	981	963.7	1017.7
					d3	NA	NA	NA	NA	NA
2.0	1.00	840	840	10796	d1	NA	NA	NA	NA	NA
					d2	732.4	723.6	715.4	710.7	699.6
					d3	1020.5	1000.3	981.2	968.3	945.3
	2.00	1120	560	9596	d1	948.8	925.3	905.8	899.7	869.6
					d2	686.6	680	674.7	660.4	654.9
					d3	948.8	925.3	905.8	899.7	869.6
	3.00	2048	683	21381	d1	1544.4	1515.8	1479.3	1446	1412.1
					d2	1016.7	1007.9	994.2	981.7	968.3
					d3	NA	NA	NA	NA	NA

Table (2-a): Required effective footing depths for side columns, C1 parallel to L

L/B	β	Column's Dimensions C_1 mm	C_2 mm	P_u kN	d mm	(MPa) q_u 0.10	0.20	0.30	0.40	0.50
1.0	1.00	910	910	12670	d1	NA	NA	NA	NA	NA
					d2	956.7	947.4	931.8	925.3	914.4
					d3	1543	1513	1471.8	1448.8	1417.9
	2.00	1365	683	14254	d1	1659.5	1625.4	1592.5	1569	1531.3
					d2	1016.2	1005.3	994.6	988.4	974.4
					d3	1659.5	1625.4	1592.5	1569	1531.3
	3.00	2583	861	34027	d1	2854.2	2789.4	2724.1	2673.2	2603.8
					d2	1566.3	1549.9	1532.2	1520.4	1499
					d3	NA	NA	NA	NA	NA
					d3	NA	NA	NA	NA	NA
2.0	1.00	910	910	12670	d1	NA	NA	NA	NA	NA
					d2	957.9	966.1	932.7	926.6	922.9
					d3	1545.4	1510.6	1473.5	1451.2	1433.9
	2.00	1365	683	14254	d1	1659.5	1634.4	1601.7	1572.5	1540.7
					d2	1016.2	1010	999.3	990.3	979.3
					d3	1659.5	1634.4	1601.7	1572.5	1540.7
	3.00	2583	861	34027	d1	2855.3	2798.2	2733.3	2678.2	2613.7
					d2	1656.8	1554	1536.5	1522.9	1503.8
					d3	NA	NA	NA	NA	NA

Table (2-b): Required effective footing depths for side columns, C1 parallel to B

L/B	β	Column's Dimensions		P_u kN	d	(MPa) q_u				
		C_1 mm	C_2 mm		mm	0.10	0.20	0.30	0.40	0.50
1.0	1.00	910	910	12670	$d1$	NA	NA	NA	NA	NA
					$d2$	956.7	947.4	931.8	925.3	914.4
					$d3$	1543	1513.4	1471.8	1448.8	1417.9
	2.00	1365	683	14254	$d1$	1232.5	1204.1	1189	1160.8	1138.2
					$d2$	796.4	786.4	783.1	772.5	764.6
					$d3$	1232.5	1204.1	1189	1160.8	1138.2
	3.00	2583	861	34027	$d1$	1831.7	1787.9	1746.7	1692.9	1648.8
					$d2$	1085.8	1073.9	1062.4	1044.1	1029.8
					$d3$	NA	NA	NA	NA	NA
2.0	1.00	910	910	12670	$d1$	NA	NA	NA	NA	NA
					$d2$	957.9	946.1	932.7	926.6	922.9
					$d3$	1545.4	1510.6	1473.5	1451.2	1434
	2.00	1365	683	14254	$d1$	1231.8	1213.6	1178.6	1163.6	1143.3
					$d2$	796	791.4	777.6	774	767.3
					$d3$	1231.8	1213.6	1178.6	1163.6	1143.3
	3.00	2583	861	34027	$d1$	1836.1	1783.6	1742.4	1710.2	1665
					$d2$	1087.9	1071.8	1060.3	1052.7	1038
					$d3$	NA	NA	NA	NA	NA

Table (3): Required effective footing depths for corner columns

L/B	β	Column's Dimensions		P_u kN	d	(MPa) q_u				
		C_1 mm	C_2 mm		mm	0.10	0.20	0.30	0.40	0.50
1.0	1.00	945	945	13663	$d1$	NA	NA	NA	NA	NA
					$d2$	1249.1	1215	1224.1	1213.2	1205.9
					$d3$	2297.8	2260.2	2202.6	2160.3	2126.9
	2.00	1260	630	12145	$d1$	2133	2083.3	2053.6	2015.1	1966.4
					$d2$	1175	1161.2	1155.8	1146.1	1131
					$d3$	2133	2083.3	2053.6	2015.1	1966.4
	3.00	2205	735	24796	$d1$	3322.8	3247.6	3168.3	3104	3022.3
					$d2$	1663.7	1648.6	1630.6	1618	1597
					$d3$	NA	NA	NA	NA	NA
2.0	1.00	945	945	13663	$d1$	NA	NA	NA	NA	NA
					$d2$	1253.5	1237.1	1231.7	1217.6	1201.4
					$d3$	2307.6	2250.6	2219.3	2169.8	2117.2
	2.00	1260	630	12145	$d1$	2128.1	2100.8	2037.9	1997.9	1966.2
					$d2$	1172.8	1169.1	1148.7	1138.1	1131
					$d3$	2128.1	2100.8	2037.9	1997.9	1966.2
	3.00	2205	735	24796	$d1$	3328	3256.3	3178.5	3114.6	3034.9
					$d2$	1665.8	1652.2	1635	1622.5	1602.4
					$d3$	NA	NA	NA	NA	NA

7- Conclusion:

From the developed equations and the parametric study carried out in this research, it is proven that Equation (11-32) of ACI 318-08 does not influence punching shear design of footings, when associated with other code requirements, making this equation useless and redundant in most of practical design situations. On the other hand, when used column dimensions are very much larger than those required by design, only then equation (11-32) may control punching shear design.

8- References:

[01] ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318M-08), American Concrete Institute, Farmington Hills, USA, 2008.

[02] CEN, Eurocode 2- Design of Concrete Structures: Part 1-1 –General

Rules and Rules for Buildings, EN 1992-101, Brussels, Belgium, 225pp, 2004.

[03] Guandalini S., Burdet, O. and Muttoni, A., Punching Tests of Slabs with Low Reinforcement Ratios, ACI Structural Journal, Vol. 126, No. 1, pp. 87-95, 2009.

[04] Hegger, J., Ricker, M., Ulke, Ziegler, M., Investigations on the Punching Behaviour of Reinforced Concrete Footings, Engineering Structures, Vol. 29, No. 9, pp. 2233-2241, 2007.

[05] Muttoni, A., Punching shear strength of reinforced concrete slabs without transverse reinforcement, ACI Structural Journal, Vol. 105, No. 4, pp: 440-450, 2008.

[06] Lovrovich, J. and McLean D., Punching shear behavior of slabs with varying span-depth ratios, ACI Structural Journal, Vol. 87, No. 5, pp: 507-512, 1990.

[07] Sălna, R., Marčiukaitis, G., and Vainiūnas, P., Estimation of factors influencing the punching shear strength of RC floor slabs, Journal of Civil Engineering and Management, Vol. X, Supplement 2, pp: 137-142, 2004.

[08] Ozden, S., Ersoy, U., and Ozturan, T., Punching shear tests of normal- and high-strength concrete flat plates, Canadian Journal of Civil Engineering, Vol. 33, No. 11, pp: 1389-1400, 2006.

[09] Albrecht, U., Design of flat slabs for punching- European and North American practices, Cement and Concrete Composites, Vol. 24, No. 6, pp: 531-538, 2002.

[10] Moehle, J., Kreger, M., and Leon, R., Background to recommendations for design of reinforced concrete slab-column connections, ACI Structural Journal, Vol. 85, No. 6, pp: 663-644, 1988.

[11] ACI Committee 318-1963, Building Code Requirements for Structural Concrete (ACI 318-63), American Concrete Institute, Detroit, USA, 1963.

[12] ACI Committee 318-1977, Building Code Requirements for Structural Concrete (ACI 318-1977), American Concrete Institute, Detroit, USA, 1977.

[13] Notes on ACI 318-1989, Building Code Requirements for Structural Concrete with Design Applications, Portland Cement Association, Skokie, Illinois, USA, 1989.

[14] Vanderbilt, M.D, Shear Strength of Continuous Plates, Journal of The Structural Division, ASCE, V. 89, No.5, pp. 961-973, 1972.

[15] ACI Committee 318-1989, Building Code Requirements for Structural Concrete (ACI 318-1989), American Concrete Institute, Detroit, USA.

Notation:

A_f = base area of footing footings, mm2

B = smaller footing dimension, in plan, mm

b_o = perimeter of critical section for shear in footings, mm

C_1 = larger column dimension, in plan, mm

C_2 = smaller column dimension, in plan, mm

d = distance from extreme compression fiber to centroid of longitudinal reinforcement, mm

d_b = bar diameter, mm

f'_c = specified compressive strength of concrete, MPa

f_y = specified yield strength of reinforcement, MPa

h = overall thickness of member, mm

l_{dc} = development length of deformed bars in compression, mm

L = larger footing dimension, in plan, mm

P_u = factored axial load of column, kN

V_c = nominal shear strength provided by concrete, kN

V_n = nominal shear strength, kN

q_u = factored soil pressure, MPa

Φ = strength reduction factor for shear = 0.75, 0.65 for tied columns

α_s = column location factor; 40 for interior columns, 30 for edge columns and 20 for corner columns

β = ratio of long to short sides of column

λ = modification factor reflecting the reduced mechanical properties of light-weight concrete; equals unity for normal-weight concrete

ρ = reinforcement ratio