Effect of using column capital on the punching shear strength of flat slab-edge column connection under eccentric loading

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Abstract. The influence of column capital on punching resistance at the edge column is virtually not fully studied. This is a significant omission, as column capital under eccentric loading can arise in flat slab buildings under lateral loading from wind and earthquakes. This paper deals with the effect of using reinforced concrete column capital on the punching shear strength of the flat slab-edge column connection under eccentric loading. The study involves testing experimentally six reinforced concrete flat slab-edge column models with dimensions (1000×1600×100 mm) with two different dimensions of column capital (300×400 mm, and 500×800 mm) in addition to reference model without columns capital (column dimension 200×200mm). Two specimens as a control without column capital where the first specimen under axial load according to column section but another under eccentric loading with eccentricity (e=half width of column). The effect of size of the column capital and were studied experimentally. We observed an increase in punching resistance by (17.02% and 27.66%) respectively over that of the reference specimen under axial load, and about (18.18% and 25%) respectively over that of the reference specimen under eccentric loading.

Keywords: Flat Slab; Punching Shear; Column Capital; Eccentric Loading

1. Introduction
Flat slab is commonly used nowadays, especially in tall buildings and large loads, it's consist from reinforce concrete slab without interior beams where the loads transfer from slab to column directly. There are many advantages for use the flat slab like economical in formwork this leads a speedy completion because there are no internal beams. In addition to the architectural aesthetic. However; there is a major problem faced by this type (Flat Slab) is a shear stresses around the column known as punching shear. This type of failure accrues around the column when the slab exposed the high loads Guan and Loo[1]. And it's one of the dangerous stresses that cause sudden collapse of the structure. Just as it happened in the Sampoong store in South Korea, as shown in the figure (1) , it consist of five floors, at June 1995 as it collapsed suddenly leaving behind a large number of people Xuesong Zhang[2].

Punching shear failure happens as cracks in the slab area at an angle between (26 to 45) degrees Khandokar[3]. There are several methods and techniques for increasing punching shear resistance, one of these methods is to increase the thickness of column head or what is known as "Column Capital". Several researchers have studied the effect of changing slab thickness on punching shear strength. Lips, Ruiz and Muttoni[4] performed a laboratory tests of samples with dimensions of (3000×3000) mm, and with reinforcement ratio about (1.5)% in three models with diameter bars (20,20and 26,26) mm, respectively, with slab thickness (250,300,400) mm respectively, all the specimens content of reinforcement with diameter bars (10) mm in compression side with (100) mm spacing. From these
studies noticed the results are a significant increase in punching shear strength of the models with thickness (320,400) mm, respectively and by an increase (67 and 156) % respectively, compared with original model.

Ammash, Kadhim and Ellk [5] analyzed samples of reinforced concrete slabs to study the behavior of punching shear resistance by changing the thickness for flat slab, where dealt with the effect of three rate of tension reinforcement (0.01, 0.02, 0.03) with the change of the thickness of concrete slab from (75 to 300) mm. they observed an increase in the shear resistance of (700) % for first model as the ratios of the tension reinforcement changed from (1 and 2) % and (660) % for other model when the ratio of tension reinforcement equal (3) % and change the thickness of slab from (75 to 300) mm. Said and Chasib [6] showed the effect of change the slab thickness in model of slab column with interior column with dimensions (1150 ×1150) mm, for slab with different thickness (80 ,100 ,120 ,150) mm, respectively for four specimens under axial load and (150 ×150) mm, column dimensions, showed effect change thickness by (55) % for slab, that lead to change in punching shear strength approximately (70) % compared with original slab. Aziz and L.H [7] studied the effect of the shape of flat slab (triangular and trapezoidal) self-compacting on the punching shear strength and flexural strength.

Kadhim and Ammash [8] analyzed four models of slab with interior column connection with dimension (1600×1600×100) mm, under axial loading and (200×200) mm dimension of column, and strengthen by column capital with different size (400×400, 600×600, 800×800) mm, respectively for three models in addition to the reference model without strengthen, results were obtained by changing the punching shear resistance by a percentage (57.03, 67.97, 109.37) respectively compared with the source model.

![Figure 1. Sampoong Building Collapse](image)

2. Test Program

In this study made six models of normal reinforced concrete (1:2:4) with compression strength of (25) MPa, with dimensions of (1000×1600) mm flat slab, and a thickness of (100) mm, connected to square edge column with a height of (500) mm, and a section dimension of (200×200) mm, the slab was reinforced with one layer of steel bar (Ø10) mm, with a spacing (200)mm center to center, with (75) mm the effective depth. And a diameter of (Ø10) mm, also with eight bars to reinforce the edge column according to the specification of the ACI318-19[9], the yield strength and ultimate strength for steel bars that used in this study was (672,745)MPa, respectively determined by experimental test. Where the study was divided into two groups, see table (1), the first group (G1), includes three models of the slab-column connection under the influence of an axial load, and it has been strengthened by using the reinforced column capital casted together with flat slab, of different sizes for the purpose of studying the behavior of changing the column capital on the punching shear resistance, (300×400) mm and (500×800) mm respectively, plus the reference form for comparison purpose, see figure (2).

As for the second group (G2), where three models were also included, under the eccentric load with a distance (100) mm, (equal to half the length of the column side) Sayed[10]. Two models were
strengthened using the column capital, and with the same dimensions of the first group in addition to the reference model, see figure (3). This study focused on comparison between the maximum performances of the reinforcement systems by the capital of the reinforced concrete column of different sizes. As shown in figure (4).

**Figure 2.** Geometry of Flat Slab in First Group (G1) Under Axial Load

**Figure 3.** Geometry of Flat Slab in Second Group (G2) Under Eccentric Load
### Table 1. Specimens Description

| Slabs       | Specimen Symbol | Specimen Name                        | Effective Depth (mm) | $f_c'$(MPa) | Column Capital Size (mm) | Height of Column Capital (mm) |
|-------------|-----------------|--------------------------------------|----------------------|-------------|--------------------------|-------------------------------|
| G1 Axial Load | (A) RS          | Reference Specimen                   | 75                   | 25          | ---                      | ---                           |
|             | (B) SWCC100     | Specimen with Column Capital 100     | 75                   | 25          | 300×400                  | 100                           |
|             | (C) SWCC300     | Specimen with Column Capital 300     | 75                   | 25          | 500×800                  | 300                           |
| G2 Ecc. Load | (A) RS          | Reference Specimen                   | 75                   | 25          | ---                      | ---                           |
|             | (B) SWCC100     | Specimen with Column Capital 100     | 75                   | 25          | 300×400                  | 100                           |
|             | (C) SWCC300     | Specimen with Column Capital 300     | 75                   | 25          | 500×800                  | 300                           |

**Figure 4.** Reinforcement Details for specimens in each group

3. **Test Procedure**
   
   This process of laboratory experiment for the models was carried out under the influence of static loads and an increase of each (10) KN until the failure occurred. The deflection was observed at each stage of the loading and the values were recorded by means of accurate electronic devices under the column. The model was fixed from the bottom and on three sides by simple supported, leaving one side under the column free to match the real model in reality. Where the support was made in the form of a simply support and with span length of (1500) mm, as shown in figure (5).
Figure 5. Installation of the Specimen

4. Results

4.1 Failure Mode

where examined the specimens under the load device with a capacity of (2000) KN, in the laboratories of the College of Engineering, Al-Qadisiyah University. Passes the axial forces of the first group (G1), and the eccentric force from the column axis of the second group (G2), until failure occurs, noted the failure of all specimens by punching shear and the appearance of cracks on the surface of the concrete inclination angle of 45 degrees from the external edges of the column, see Figures (6 and 7), the effect of the column capital was observed on the shear change forces site failure occurrence while retaining the same mechanism of failure.

Figure 6. Deflection Mode for First Group (G1)
4.2 Load And Deflection

The results in table 2 from the experimental test for all slabs, cracking load ($P_{cr.}$), is the load when first crack appeared, and ultimate load ($P_{u.}$), is the ultimate load the slab reaches when failure, and ultimate deflection ($\Delta u.$) is the maximum deflection that were recorder during the experimental tests.

The results in each group (G1 and G2) of (SWCC100 and SWCC300), are compared with (RS) the reference specimen in the same group. However, when add the column capital that lead to increase the punching shear strengthening in different values according the column capital size. The punching shear capacity of the slabs tested showed the slabs in first group (G1) that strengthening with column capital (SWCC100 and SWCC300) there are increasing in the ($P_{u.}$), the ultimate load for each specimen compared with the reference specimen (RS) by about (17.02% and 27.66%) respectively, and about (18.18% and 25%) for the specimens in second group (G2). This refers the column capital lead to a larger area of strengthening the punching shear stresses in the critical zone; generally, the specimens that strengthen with column capital showed developing in the punching shear strength and reduced the deflection with increase the size of column capital.

Figure 7. Deflection Mode for Second Group (G2)
In figures below shows the relationships between the punching load and the deflection using the electronic devices (Dial Gauge) located under the center of the column. All the slabs tested showed same load–deflection relationships responses up to happened the sudden failure of punching shear. All curves for the load deflection for slabs tested in (G1 and G2) with column capital (SWCC100 and SWCC300) were stiffer and stronger than the reference slabs (RS) without strengthening.

Table 2. The Ultimate Load and Deflection for the Tested Slabs

| Slabs  | Specimen Symbol | First Crack (Pcr.) (KN) | Ultimate Load (Pu.) (KN) | Ultimate Deflection (Δu.) (mm) | Pu. Cap. /Pu. Ref. |
|--------|----------------|------------------------|--------------------------|--------------------------------|------------------|
| G1 Axial Load | RS | 39 | 47 | 26.08 | 1.00 |
|  | SWCC100 | 44 | 55 | 24.62 | 0.94 |
|  | SWCC300 | 48 | 60 | 9.12 | 0.35 |
| G2 Ecc. Load | RS | 27 | 44 | 16.00 | 1.00 |
|  | SWCC100 | 33 | 52 | 16.32 | 1.02 |
|  | SWCC300 | 36 | 55 | 6.95 | 0.44 |

Figure 8. Load–Deflection curve for all specimens in first group (G1)
5. Conclusion

After the experimental testing for six specimens of flat slab column connection, there are many conclusions and recommendations are drawn and observed for the strengthened of flat slab by using the column capital, this study presents and show an effective and practical strengthening technique, used for enhancement the punching shear resistance in the flat slabs. These conclusions we can summarize it as follows:

1- In slabs with edge columns in the first group (G1) exposed to axial loads, an increase in the resistance of punching shear was observed by about (17.02% and 27.66%), for two specimens respectively. And increasing about (18.18% and 25%), for specimens in second group (G2), exposed to eccentric load, respectively, all results compared with reference specimen (RS) in each group.

2- The failure zone for the flat slab with rectangular column capital increased significantly according to increasing in the size for column capital. This means, the changing in size of column capital represent the main zone to specify failure zone surrounding the column capital called (failure perimeter).

3- In general, the behavior observed from the load-deflection curves, the mode of failure for the slab rectangular column capital is stiffer and stronger than the slab column without strengthening.

4- Finally, the increase in the average column capital size for flat reinforced concrete slabs is analogous to an increase in the rate of punching shear resistance, as a result of the increase in the area of contact of the column with the slab.
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