The 2019 World Congress on
Advances in Structural Engineering and Mechanics (ASEM19)
Jeju Island, Korea, September 17 - 21, 2019

Punching Shear Test of Footings Considering Size Effect and Frictional Force

*Ju-Ok Noh[1] and Hong-Gun Park[2]

[1], [2] Department of Architecture & Architectural Engineering, Seoul National University, Seoul, 08826, Rep. of Korea
[1] nojuok@snu.ac.kr

ABSTRACT

Currently, all domestic and international structural standards, including KBC (Korea Building Code), KCI (Korea Structural Concrete Design Code), and ACI, provide the same equation for predicting the punching shear strength for slabs and footings. Most of these equations are tuned to the slab and tend to underestimate the shear strength of the footing. Therefore, the present study aims to improve the method of calculating the punching shear strength of the footing in consideration of the size effect and the friction between the concrete of the footing and the lower ground. As one of the methods, this study carried out punching shear tests on four footing specimens. The test parameters were shear span to depth ratio (a/d) and surface condition (presence of friction between concrete and soil). As a results, the punching shear strength was decreased in proportion to the shear span ratio of the footing, and the strength was increased by the influence of the soil.

1. INTRODUCTION

In all design standards, the punching shear strength of slab and footing is specified using the same equation. In the case of slabs, however, they have elongated shapes with large ratios of shear span to slab thickness (l/d). Therefore, it is controlled by flexure and the compression zone mainly resist forces. On the other hand, in the case of the thick footing, the range of flexural damage is partial and strut action is added to compression zone. In addition, interaction with the underlying ground creates additional resistance to friction. Therefore, in this study, the difference was observed by experiments considering the effect of shear span ratio (a/d) of the footing and the lower ground.

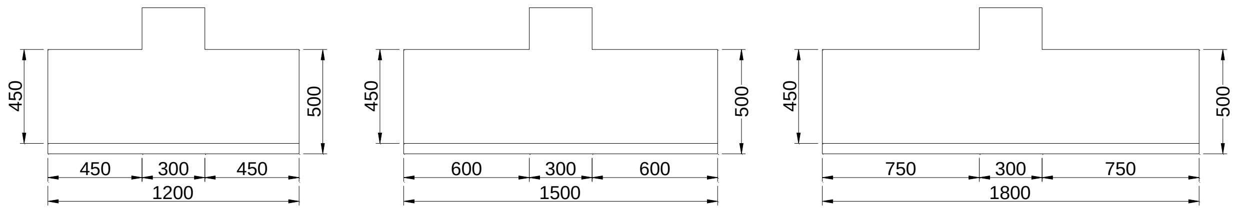
---

[1] Student
[2] Professor

2. TEST PLAN

2.1 Test Parameter

Punching shear tests were performed on four footing specimens. The thickness of the footing was 500 mm, and the shear span ratio was varied by changing the size of the footing. For the largest specimen, the effect of the bottom soil was considered by using sand under the test specimen.



a/d=1.0 specimen 1.0 | a/d=1.33 specimen 1.33 | a/d=1.67 specimen 1.67

Fig. 1 Test specimens

Except for the experimental variables, the conditions were the same in all the specimens. The flexural rebar ratio of 0.64% was applied using the SD500-D19. The column size was 300x300 mm, and the SD600-D25 was used as the column reinforcement to withstand the large loads applied to the footings.

2.2 Test Set-up

Figure 2 shows test setup of specimens. Two experimental settings were used as shown. The first is the general method of supporting only the edge of the test specimen, and the other is to put the soil under the specimen to consider the effect of the underlying soil. As the soil, sand was used and compacted into three layers using a compactor to make the compactness of the soil uniform. The test was carried out at a speed of 0.5 mm/min using an actuator of a capacity of 5000 kN. To measure the displacement of the specimen and the deflection of footing, LVDTs were installed. In addition, a total of 21 to 25 strain gages were attached to each specimen to identify the strain of the flexural reinforcing bar in the critical section.

2.3 Material Test

A nominal strength of 24 MPa concrete was used for specimen, and the concrete mixture is shown in Table 1. The compressive strength test of concrete cylinder was done on the day of the column test. The results of concrete strength were 24 MPa for all specimens.

Fig. 2 Test setup

Nominal strength (MPa)	W/C (%)	Unit weight (kg/m³)			
		W	C	S	G
24	48.0	165	344	860	968

W: water, C: cement, S: fine aggregate, G: coarse aggregate
Table 1: Mixture proportions of concrete

SD500-D19 was used for flexural reinforcing bars. SD400-D10 and SD600-D25 were used for column. The tensile strength test of reinforcing bar specimens was done before footing test. The test results are shown in Table 2.

Type	f_y (MPa)	f_u (MPa)	E_s (GPa)
SD400-D10	566	700	211
SD500-D19	601	674	203
SD600-D25	638	753	195

Table 2: Result of tensile strength test (reinforcing bars)

3. TEST RESULTS

3.1 Axial Load-Strain Relationship

Figure 3 shows axial load and strain relationship of test specimens. The load is the value applied to the actuator, and the displacement is the average of the two values measured by LVDTs which was installed on either side of the column.

Punching shear strength of a specimen 1.0, 1.33, and 1.67 showed 3309 kN at 12.1 mm, 2612 kN at 9.71 mm, and 2018 kN at 6.5 mm respectively, followed by rapidly reducing strength and a brittle failure.

For specimen set on the sand, punching shear strength was 3464 kN at 27.5mm. In this case, after the punching shear strength was applied, the load continued to increase, and the load decreased again at 3820 kN. It is considered that the punching shear failure occurred at the first load reduction due to the fracture behavior of the specimen.

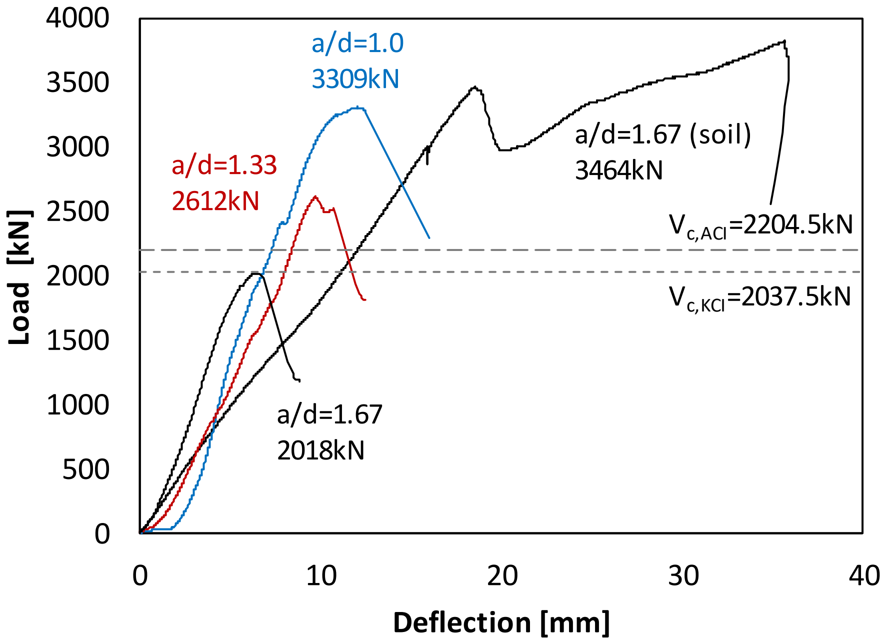
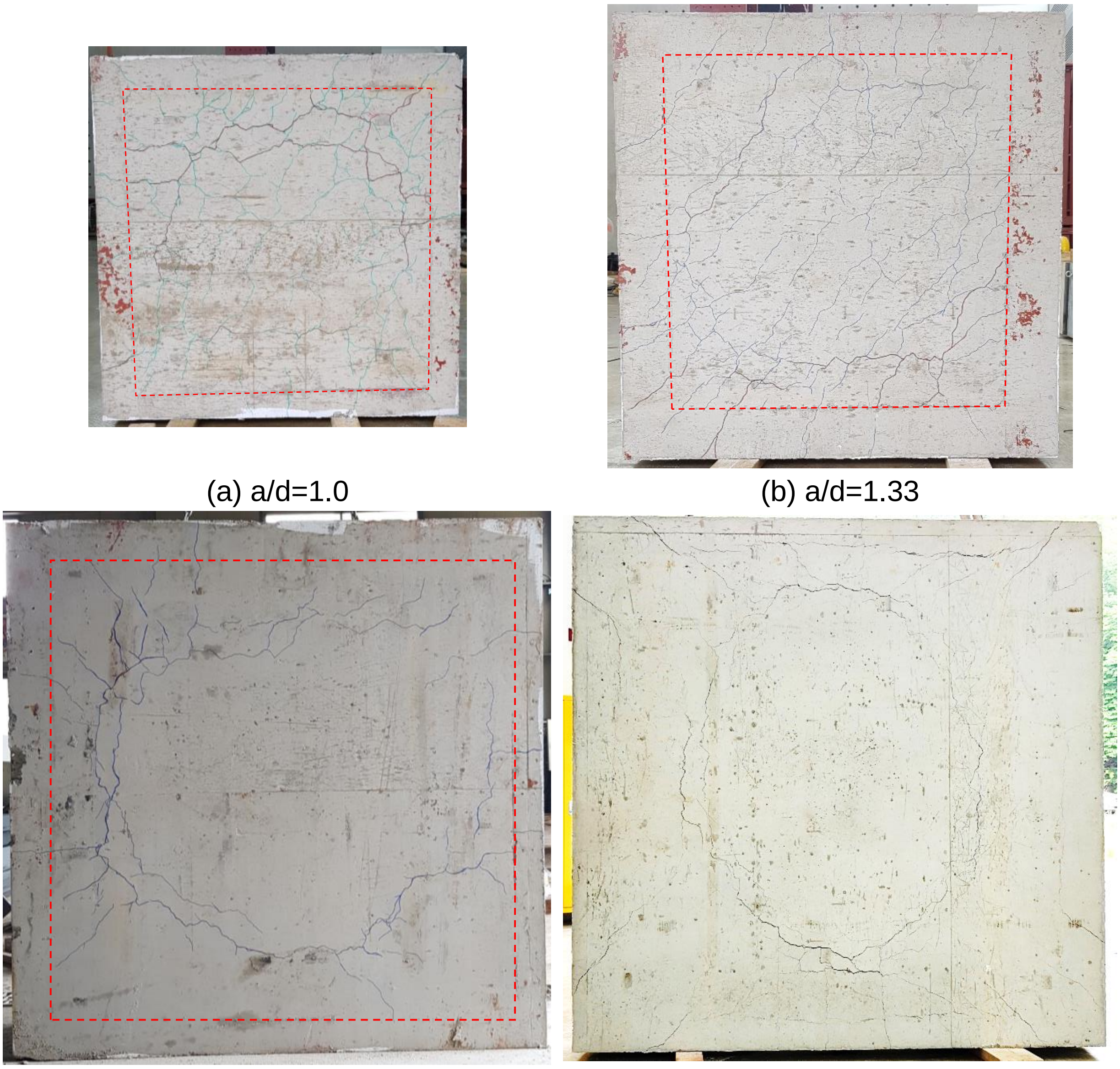


Fig. 3 Load-displacement relationship

3.2 Failure Behavior

Figure 4 shows the crack patterns on the bottom surface of test specimens after the test. All the specimens can be seen that the punching shear failure occurred.



(a) a/d=1.0 (b) a/d=1.33

(c) a/d=1.67 (d) a/d=1.67 (on soil)

Fig. 4 Crack patterns of test specimens after the test
(Bottom surface, the side in tension)

4. CONCLUSION

Although the shear span ratio is not a variable in the current standard, the punching shear strength increased as the shear span ratio decreased. The correlation between shear span ratio and shear strength is analyzed to improve the shear strength equation.

It was confirmed that the punching shear strength of the footing was increased by the ground under the footing. In a certain range of the lower part of the column, the load is transferred directly to the ground. So the extent to which the equally distributed ground forces below the footing are negligible should be set. In the current standard, it is 0.5d for slab and 0.75d for footing. Based on the existing experimental results and analytical studies, we will determine whether this value is appropriate and suggest a suitable value.

In order to understand the effect of friction between the footing and the ground on the punching shear strength, the strength model is developed through the modeling using the material test. Finally, a method to predict the shear strength of the footing more accurately will be proposed.

ACKNOWLEDGEMENT

This work is supported by the Korea Agency for Infrastructure Technology Advancement(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 0668-20190005).

REFERENCES

Frank E. R. (1948), “Reinforced Concrete Wall and Column Footings”, Journal of the American Concrete Institute, **20**(2), 97-127, 20(3), 237-260.

Hegger, J., Sherif, A. G., and Ricker, M. (2006), “Experimental Investigations on Punching Behavior of Reinforced Concrete Footings”, ACI Structural Journal, **103**(4), 604-613.

Hegger, J., Ricker, M., and Sherif, A. G. (2009), “Punching Strength of Reinforced Concrete Footings”, ACI Structural Journal, **106**(5), 706-716.