Punching Behavior of Compact Slabs

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Summary

Most design codes do not differentiate between the punching shear strength of flat slabs and footings. However, a former research program at the Institute of Structural Concrete approved the assumption that the punching behavior of reinforced concrete footings is significantly influenced by the shear slenderness. To investigate the punching behavior of compact slabs more closely, 13 tests on footings have been performed and another 9 tests will be conducted in the coming months. In this paper, the first results of the experimental investigations are presented. In the present tests and tests from literature, the footings often did not reach the calculated punching shear capacity according to the different code provisions. Broms derived a mechanical model for the punching behavior of flat slabs. Later, he extended the model in particular for footings. The present tests as well as tests from literature are compared to the calculated punching shear resistances according to the model of Broms, the ACI 318-05 Building Code and Eurocode 2.

Keywords: compact slab; concrete; footing; punching; shear; soil-structure-interaction

1. Introduction

The determination of the punching shear resistance is an essential problem in the design of footings. Although punching of reinforced concrete slabs have been investigated extensively in literature, there is only limited data available for punching of footings. As a consequence, the code provisions are mainly based on punching tests on slender slabs, even though footings have much smaller values of the shear span to depth ratio. Based on tests, the aim of the present investigations is to study the structural behavior of compact slabs with and without shear reinforcement. In this paper, the test results are briefly discussed and different international design provisions for footings are reviewed.

2. Experimental Investigations

Presently, 13 footings have been tested in punching shear. The dimensions were chosen according to a scale factor of 1/2 to 1/3 of an ordinary footing. Nine footings were tested realistically supported on sand (**Error! Reference source not found.**, left). Since a former research program showed that the influence of the soil pressure distribution is minor at the ultimate limit state, four specimens were loaded with uniform surface loads (**Error! Reference source not found.**, right). In the near future, one more footing supported on sand will be tested and another eight specimens will be loaded with uniform surface loads. The main test variables were the shear slenderness, the sand consistency, the influence of shear reinforcement and the concrete compressive strength.

3. Analytical Investigations

To evaluate the performance of the Building Code ACI 318-05, the Eurocode 2 and a mechanical model developed by Broms, the failure loads of the present tests are compared to the calculated punching shear resistances according to the different provisions. First, only the specimens without shear reinforcement are considered. ACI 318-05 conservatively predicts the punching loads. Euro-

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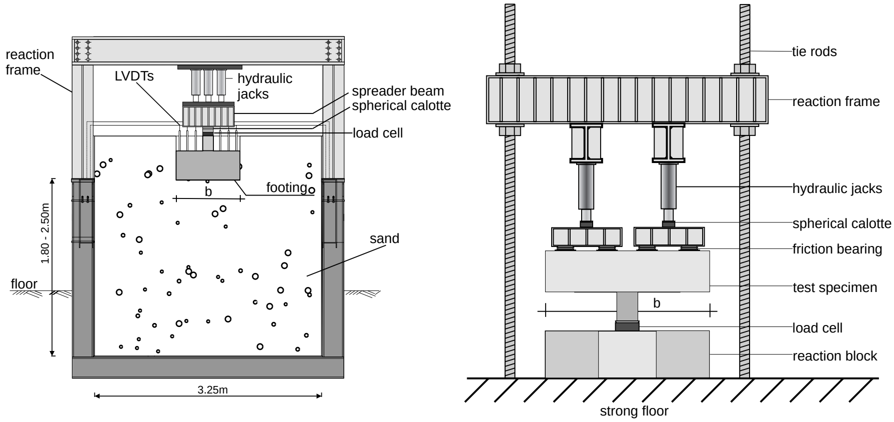

Fig. 1: Test set-up for the tests on footings supported on sand (left) and for the test specimens charged with uniform surface loads (right)

code 2 defines the maximum punching shear capacity similar to the web crushing limit for beams with shear reinforcement. Footings typically have small ratios of column perimeter and effective depth. Therefore, the maximum punching shear resistance according to Eurocode 2 often controls the design of footings. In this case, Eurocode 2 leads in most cases to a safe design, but cannot satisfactorily reflect the influence of the main parameters on the punching shear resistance, leading to a high scatter. If the v_{max} limitation is neglected, the scatter will be reduced but then the European code will overestimate the punching shear capacity of the footings. The model according to Broms shows a higher scatter than ACI 318-05 because the model cannot appropriately predict the punching shear resistance of the more compact footing DF6. In addition, one test specimen with a higher concrete grade indicates that the model slightly overestimates the influence of the concrete strength.

The specimens with shear reinforcement failed when the maximum punching shear capacity was achieved. ACI 318-05 defines the maximum punching shear capacity as 1.5 times the punching shear capacity of a similar slab without shear reinforcement. Due to the improved anchorage behavior by welded anchor plates and the large slab thickness, this assumption leads to conservative predictions. Eurocode 2 and the model according to Broms define the maximum punching shear resistance independent of the shear reinforcement. Thus according to Eurocode 2 and Broms' model the punching shear capacity of compact footings cannot be improved by shear reinforcement. This is a conservative assumption and cannot be confirmed by the present tests.

4. Summary and conclusions

Based on the present tests on footings the following conclusions can be drawn:

- The observed angle of the failure cone is steeper than for more slender slabs.
- ACI 318-05 predicts more conservative punching loads than Eurocode 2.
- Eurocode 2 and the model according to Broms define a maximum punching shear capacity which is also valid for slabs without shear reinforcement. For compact slabs without shear reinforcement, the maximum punching shear capacity controls the design. Thus, the arrangement of shear reinforcement does not increase the calculated punching shear resistance. This assumption was not confirmed by the present tests because the arrangement of shear reinforcement in the specimen DF3 and DF9 significantly increased the punching shear strength.

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