Chapter 30

Experimental Testing of Punching Shear Resistance of Concrete Foundations

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/66807

Abstract

Foundation structures, their testing, and modeling are a wide area to research. A lot of different concrete elements are tested and modeled in the world. Analysis of interaction between the foundation structures and the subsoil has been developed for many years. For the determination of stress in foundation structure, it is needed to determine the influence of the stiffness, respectively, the pliability of subsoil to structural internal forces, and vice versa, how the stiffness of the foundation structure affects the resulting subsidence. This chapter deals with experimental tests of concrete foundation slabs. Tests are carried out at the steel test frame structure by dimension 2 × 2.5 × 5 m, which is placed open air at the Faculty of Civil Engineering in Ostrava. Tested slabs are by dimension 2 × 2 m and have different thickness between 100 and 200 mm. A lot of physical quantities are tested in those experiments and experiments are then multidisciplinary because geotechnical, acoustic, strain gauges, and deformation measurements are conducted. This chapter addresses especially with punching shear analysis and maximum punching resistance. A number of experimental tests of concrete foundation slabs were carried out. Slabs classically reinforced, prestressed, or FRC were tested, but slabs were not reinforced with shear reinforcement. During the experiment, the interaction between the concrete foundation and the subsoil was monitored. Most of the slabs were disrupted by punching shear. If the slab was disrupted by punching shear, dimension and shape of the punching failure were monitored and measured, and results were compared between them. Last but not the least, results from the experiment and results according to design methods used in EC2 are compared in this chapter. The maximum shear design force according to EC2 was lower than the one from the experiment.

Keywords: punching shear analysis, punching, shear resistance, soil–foundation interaction

1. Introduction

A series of experimental test are carried out at the Faculty of Civil Engineering through various project. Most of them concentrate on interaction between subsoil and foundation structures because it is very interesting and an important field of research in civil engineering. Foundation structure is the most important part of whole structure and their quality has an important effect on quality of buildings. Properly designed and carried out foundations can be used for a very long time. These foundations can influence durability of the building. On the contrary, wrongly designed and carried out foundation can cause a lot of problems. For the right design of foundation structure it is necessary to know the behavior of the concrete foundation on the subsoil. For this reason experimental test of foundation slab are performed. Slabs with dimension 2 × 2 m and with thickness 0.1–0.2 m are tested with concentrated load. Load is introduced through distributing plates with dimension 0.2 × 0.2 m or 0.4 × 0.4 m. Slabs are reinforced with classic reinforced bars, with prestressed bars, as FRC concrete or its combination. This chapter is focused on classically reinforced slabs.

2. Experimental tests

2.1. Steel test equipment

Aforementioned tests are performed on the steel frame test equipment (**Figures 1** and **2**) which is placed outside the premises of the Faculty of Civil Engineering in Ostrava (Czech Republic) (Cajka, 2014; Cajka et al., 2016a,b; Mynarcik et al., 2016; Buchta et al., 2016). The basic principle on this equipment is clear from **Figures 1** and **2**.

Steel frame is built on concrete strips which are anchored in the soil using micropiles to ensure the bearing capacity and to prevent the lifting of steel frame. Foundation slab is concreted under steel frame approximately in the center between foundation strips to prevent influencing of test results by eccentric placement of slab between foundation strips. Tested foundation slabs are loaded with vertical force which is introduced using system of steel attachment which can be changed according to the thickness of the tested slab. These steel attachments are placed on hydraulic press which makes vertical force on the foundation. Maximal force which can be developed is 1000 kN. Under the steel frame is the original subsoil which consists from clayey soil.

2.2. Basic principle and course of test

This chapter deals with slab of dimension 150 × 2000 × 2000 mm from the concrete C35/45 reinforced by hand-knotted mesh 8/100/100 (**Figure 3**). Average value of characteristic compressive strength was 47.6 MPa, which means that it is rather a concrete class C45/55. It is probably caused by the long time between concreting and testing (about 4 months). Loaded area of 400 × 400 mm large was chosen. The soil is going to creep during the loading of foundations so the load is introduced in steps. Steps 50 kN after 30 minutes were chosen in this test. In each step load was introduced and 30 minutes to keep calm because of creep. Because of the subsoil's behavior a longer period would be better but 30 minutes is a compromise with regard to the

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feasibility of the test which has to be executed in one day. **Figure 3** shows the concrete slab used in the test.

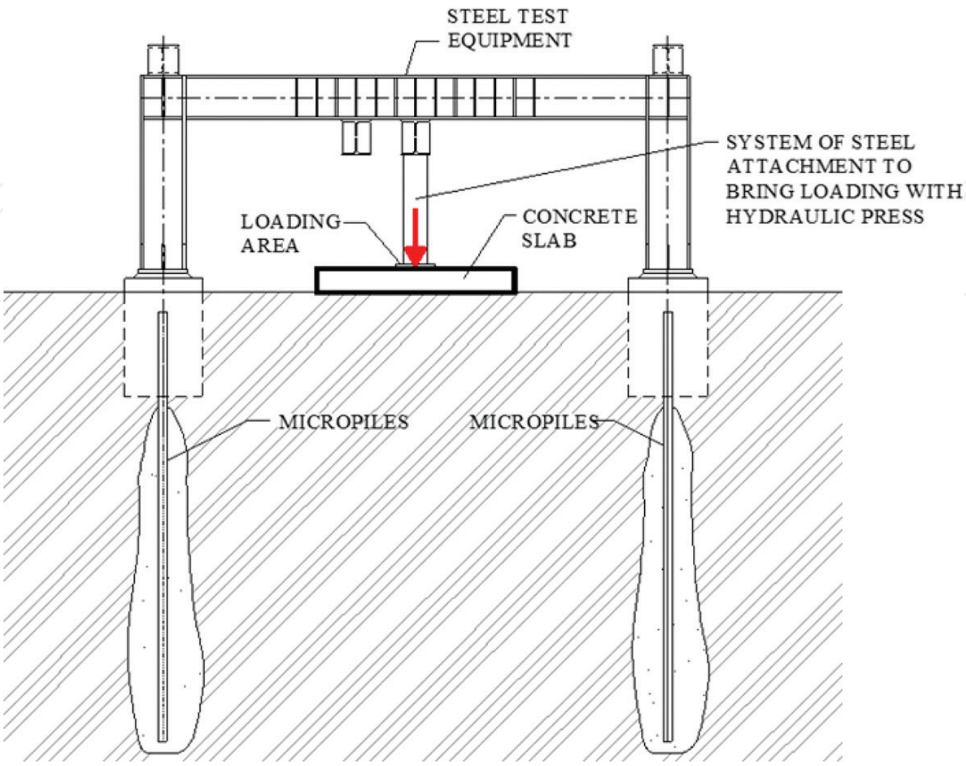

Figure 1. Scheme of steel test equipment.

Figure 2. Photo of steel test equipment.

However, the calculated value of bearing capacity was much lower than it was decided during the testing to test this slab, maximum 750 kN at first. But the slab was not corrupted at the first set of loading. Then it was decided to conduct a second test and in this test 1000 kN was to be applied, which is also the maximal bearing capacity of a steel testing equipment.

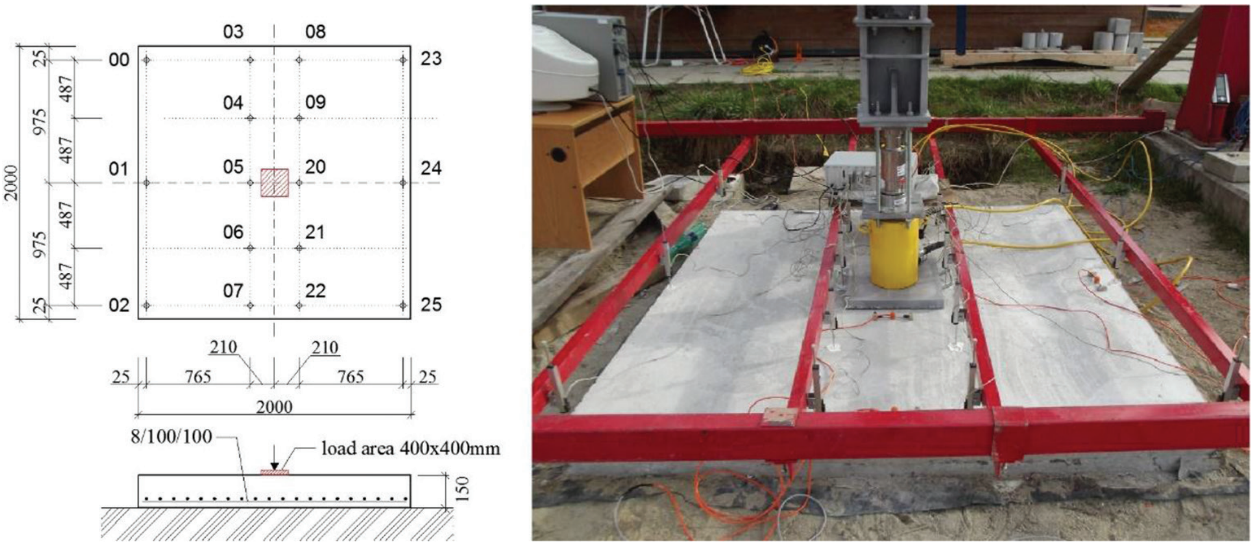

Figure 3. Scheme of tested slab.

3. Results

3.1. Deformation of concrete foundation

Deformations of the concrete slab are monitored using 16 sensors, see **Figure 3**. In the graph of **Figure 4** are shown deformations at the first set of test of this slab. It is clear from this figure that a great part of the deformation was returnable. It means that the majority of the test was performed in elastic area.

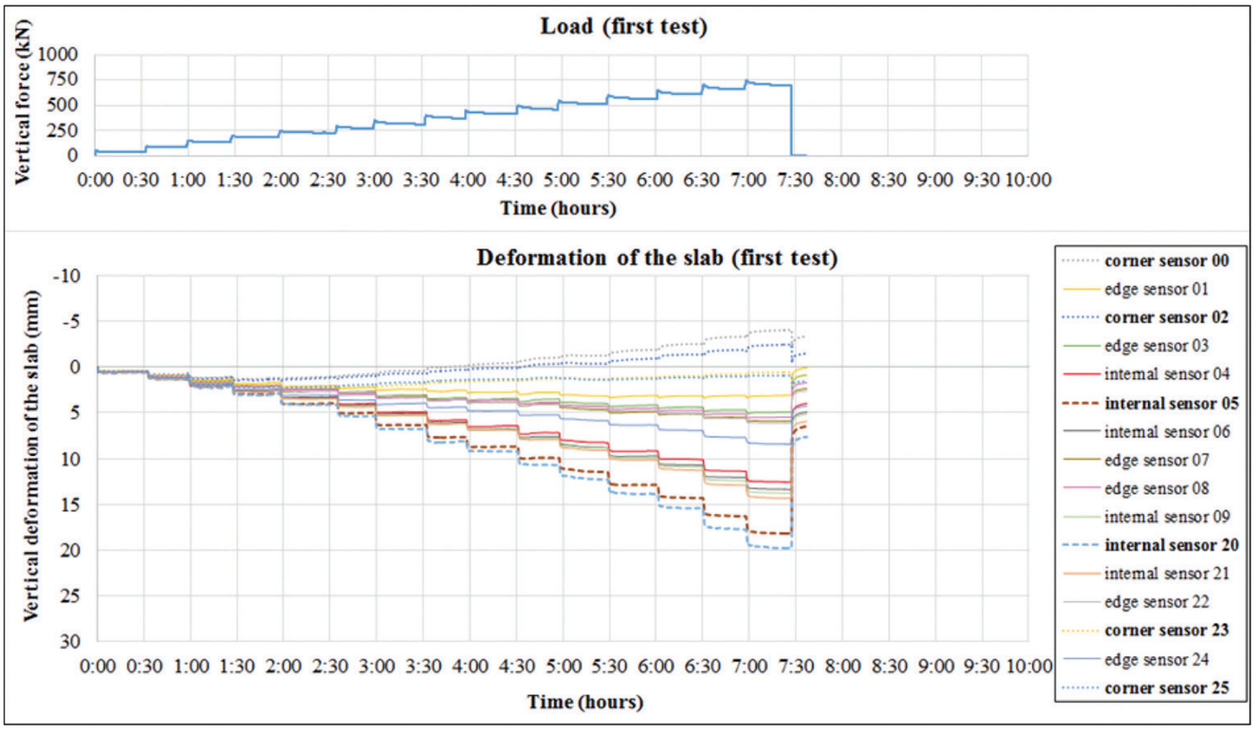

Figure 4. Deformation of the foundation slab (first set of measurement).

On this base a second test on the same slab was carried. In this test the slab was corrupted by punching shear at a force of 945 kN. Results from this test are shown in **Figure 5**.

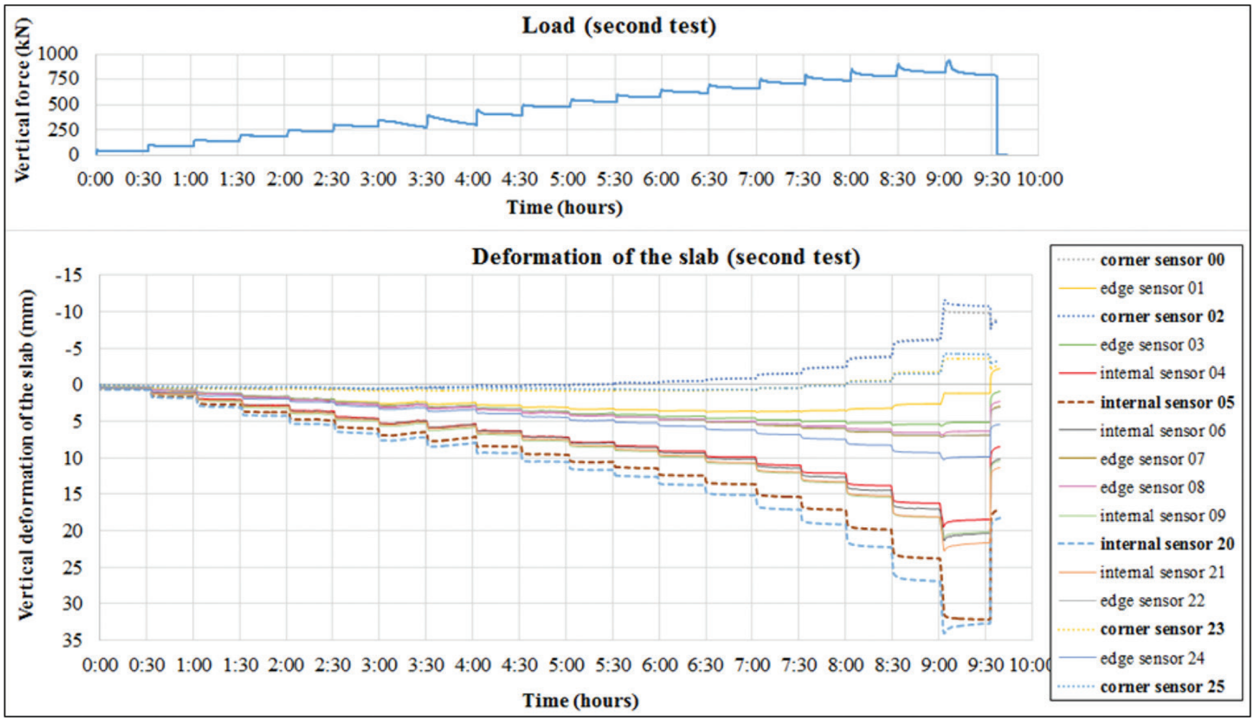

Figure 5. Deformation of the foundation slab (second set of measurement).

Results from the test are used for the analysis of other numerical modeling (Cajka et al., 2016a,b) or comparison with other computing methods (Labudkova and Cajka, 2015).

3.2. Punching shear failure

Because several slabs were failed by punching, shear attention is focused on punching shear analysis and punching shear failure monitoring which is a wide area to research (Hegger et al., 2007, Siburg and Hegger, 2014; Siburg et al., 2014). Punching capacity is compared through calculation according to Eurocode 2.

Slabs were not reinforced with shear reinforcing so bearing capacity were calculated according to the equation for element without shear reinforcement which is valid in the interval $\langle a; 2d \rangle$:

$$v_{Rd} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_1 f_{ck})^{\frac{1}{3}} \cdot 2d/a \geq v_{\min} 2d/a \quad (1)$$

where f_{ck} is in MPa, and a is the distance from the periphery of the column to the control perimeter considered.

The maximal shear stress for the described slab according Eq. (1) is 0.999 MPa and from this value maximal possible applied force were calculated that causes the slab damage is 393 kN (with characteristic values) and 190 kN (according to EC including all safety coefficient). The achieved value was 945 kN at the second test. In **Figure 6** are shown cracks on the bottom surface of the slab and **Figures 7** and **8** show cuts on this slab.

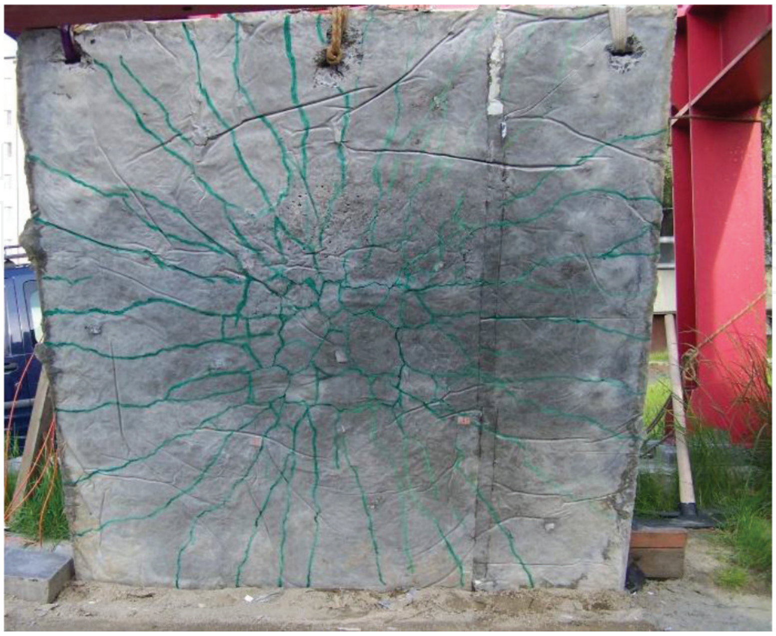

Figure 6. Cracks on the bottom surface of the slab.

Figure 7. Lateral cuts of slab.

Figure 8. Diagonal cuts of slab.

4. Conclusion

The experimental test on the concrete foundation slab was introduced in this chapter. The calculated value for the punching shear resistance was 392.6 kN (characteristic value). This

http://dx.doi.org/10.5772/66807

slab was corrupted by force 945 kN. The real value of shear resistance is, as expected, larger as according to Eurocodes. That means that Eurocodes are of course on the safe side. In this case, the real resistance was more than two times higher than the calculated value.

Acknowledgements

This outcome has been achieved with the financial support of the project GACR No. 16-08937S "State of stress and strain of fiber reinforced composites in interaction with the soil environment." In this undertaking, theoretical results gained by conceptual development of research, development, and innovations for 2016 at the VŠB-Technical University of Ostrava (granted by the Ministry of Education, Youths and Sports of the Czech Republic) were partially exploited.

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References

R. Cajka. Comparison of the calculated and experimentally measured values of settlement and stress state of concrete slab on subsoil. Applied Mechanics and Materials. 501–504, 867–876, 2014. DOI: 10.4028/www.scientific.net/AMM.501-504.867.

R. Cajka, P. Mynarcik, J. Labudkova.. Experimetal measurement of soil-prestressed foundation interaction. International Journal of GEOMATE. 10, 2101–2108, 2016a.

R. Cajka, J. Labudkova, P. Mynarcik. Numerical solution of soil-foundation interaction and comparison of results with experimetal measurements. International Journal of GEOMATE. 11, 2116–2122, 2016b.

P. Mynarcik, J. Labudkova, J. Koktan. Experimental and numerical analysis of interaction between subsoil and post-ensioned slab-on-ground. Jurnal Teknologi. 78, 23–27, 2016. DOI: 10.11113/jt.v78.8530.

V. Buchta, M. Janulikova, R. Fojtik. Experimental tests of reinforced concrete foundation slab. Procedia Engineering. 114, 530–537, 2016. DOI: 10.1016/j.proeng.2015.08.102.

R. Cajka, J. Labudkova. Numerical modeling of the subsoil-structure interaction. Key Engineering Materials. 691, 333–343, 2016. DOI: 10.4028/www.scientific.net/KEM.691.333.

J. Labudkova, R. Cajka. Comparison of the results from analysis of nonlinear homogeneous and nonlinear inhomogeneous half-space. Procedia Engineering. 114, 522–529, 2015. DOI: 10.1016/j.proeng.2015.08.101.

C. Siburg, J. Hegger. Experimental investigations on the punching behaviour of reinforced concrete footings with structural dimensions. Structural Concrete. 15, 331–339, 2014. DOI: 10.1002/suco.201300083.

J. Hegger, M. Ricker, B. Ulke, M. Ziegler. Investigations on the punching behaviour of reinforced concrete footings. Engineering Structures. 29, 2233–2241, 2007. DOI:10.1016/j.engstruct.2006.11.012.

J. Hegger, G. A. Sherif, M. Ricker. Experimental investigations on punching behavior of reinforced concrete footings. ACI Structural Journal. 103, 604–613, 2006.

C. Siburg, M. Ricker, J. Hegger. Punching shear design of footings: critical review of different code provisions. Structural Concrete. 15, 497–508, 2014. DOI: 10.1002/suco.201300092.