Deformation of Foundation Structure and their Experimental Testing

SMIRAKOVA MARTINA, MATECKOVA PAVLINA, BUCHTA VOJTECH
Department of Building Structures, Faculty of Civil Engineering
VŠB-Technical University of Ostrava
17.listopadu 2172/15, 708 00 Ostrava-Poruba
CZECH REPUBLIC
martina.smirakova@vsb.cz http://www.fast.vsb.cz

Abstract: - This paper deals with experimental tests of concrete foundation slabs which are loaded by concentrated load. Tests are carried out at the steel test frame structure which is placed open air at the Faculty of Civil Engineering in Ostrava. Tested slabs are usually by dimension 2 x 2m and have different thickness between 100 and 200mm. 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 paper addresses especially with punching shear analysis and maximum punching resistance of tested slab. If the slab was failed by punching shear, it was monitored and measured dimension and shape of punching failure and results compared between themselves. Attention will be also given to contact surface which is changed during experimental test. Last but not last results from the experiment and results according to design methods used in EC2 are compared in this paper.

Key-Words: - foundation structure, reinforced concrete, subsoil, slab deformation.

1 Introduction

Foundation structures, their testing and modelling is a wide area to research. A lot of different concrete elements are tested and also modeled in the world [1, 2, 3, 4 and 5]. Analysis of interaction between the foundation structures and the subsoil has been developed for many years. For the determination of stress in foundation structure is needed to determine the influence of the stiffness respectively pliability of subsoil to structural internal forces, and vice versa, how the stiffness of the foundation structure affects the resulting subsidence.

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

2 Experimental tests

In this part basic principle of experimental testing will be described.

2.1 Test equipment

Aforementioned tests are performed on the steel-frame test equipment (Fig.1) which is placed outside the premises of Faculty of Civil Engineering in Ostrava (Czech Republic) [6, 7, 8, 9 and 10]. The basic principle on this equipment is clear from the Fig.1.

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 thickness of 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 steel frame is original subsoil which consists from clayey soil.

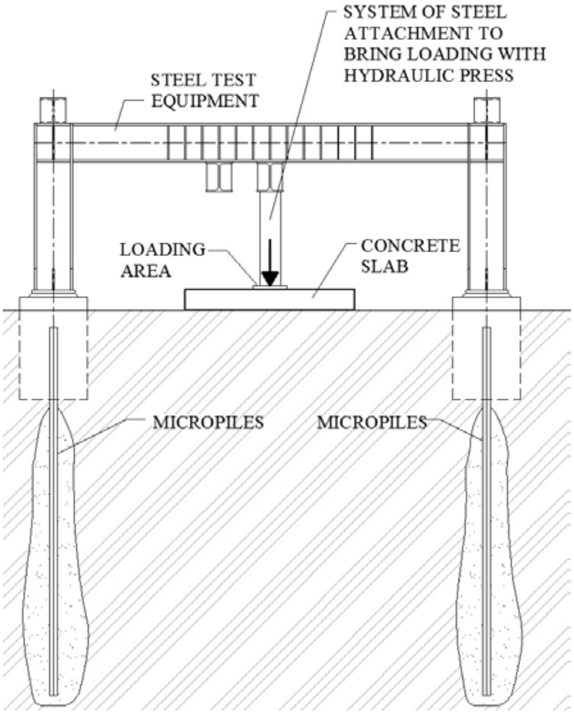

Fig. 1 Basic schema of test equipment

2.2 Basic principle and course of test

This paper deals with the slab by dimension 150 x 2000 x 2000 mm from the concrete C35/45 reinforced by hand knotted mesh 8/100/100 (Fig. 2).

Fig. 2 Reinforcement of the slab

Average value of characteristic compressive strength was 47.6 MPa which means that it is rather concrete class C45/55. It is probably caused by long time between concreting and testing (about four months). Loaded area has been chosen 400 x 400 mm large. 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 was introduced load and 30 minutes keep calm because creep. Because of the subsoil longer time period would be better but 30minutes is compromise with regard to the feasibility of test in one day. On the Fig. 3 is shown concrete slab at the test.

Fig. 3 Concrete slab at the test

However calculated value of bearing capacity was much lower it was decided during the testing to test this slab to destruction but maximal to 750 kN at first. But slab was not corrupted at first set of loading. Then were decided about second test and in this test should be reached 1000 kN what is also maximal bearing capacity of steel test equipment.

3 Results

3.1 Deformations of the concrete slab.

Vertical deformation of slab are monitored using 16 sensors which are placed on upper surface of the slab see photo on Fig.3 (or also on the Fig.6). In the graph on the Fig.4 are shown deformations at the first set of test of this slab. It is clear from this figure that great part of deformation was returnable already after 15minutes. It means that majority of the test was performed in elastic area.

On this base was carried out second test on the same slab with the same loading steps and with the same parameters as in first set of measurement. In this test was the slab corrupted by punching shear at the force 945 kN. Results deformation from this test are shown on the Fig. 5. Results from the test are used to other analysis as numerical modeling of interaction between foundations and subsoil [11, 12, 13] or comparison with other computing method [14, 15].

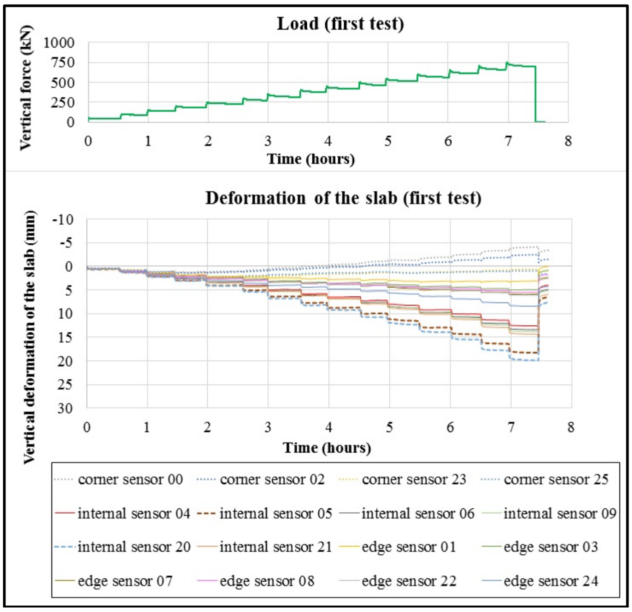

Fig. 4 Deformation after first test

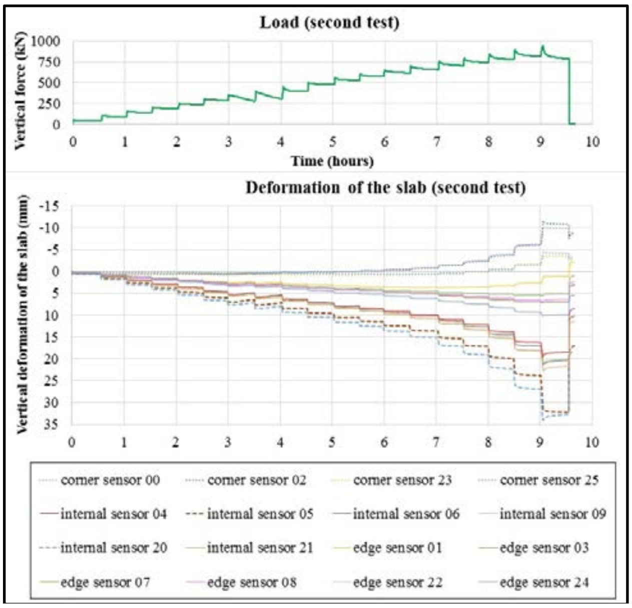

Fig. 5 Deformation after second test

For further calculations dimension of contact surface can be interesting because it influences stress distribution and also bearing capacity of the whole slab. It is assumed that foundation slab acts in its whole surface in theory but it is not always true. At the test it was shown that slab corners are up-lifted. From measured deformations are derived approximately dimension of contact surface using data from cuts which are shown on the Fig. 6.

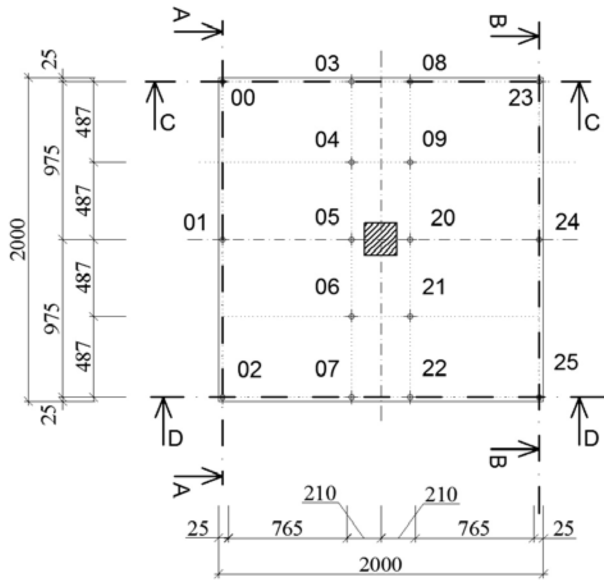

Fig. 6 Scheme of cuts (the same for both of test)

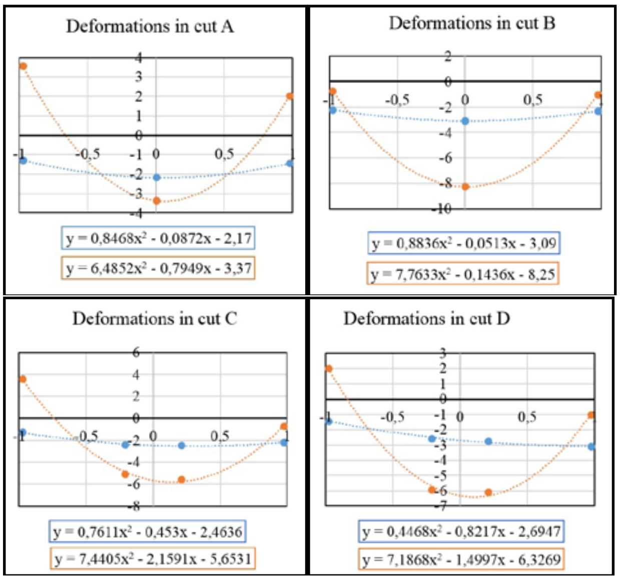

Fig. 7 Deformation in cuts on the edge of slab (after first test)

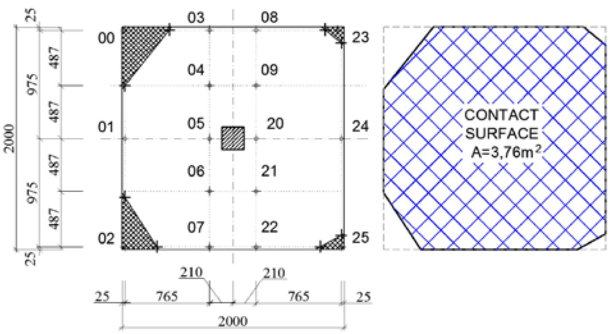

Fig. 8 Contact surface after first test

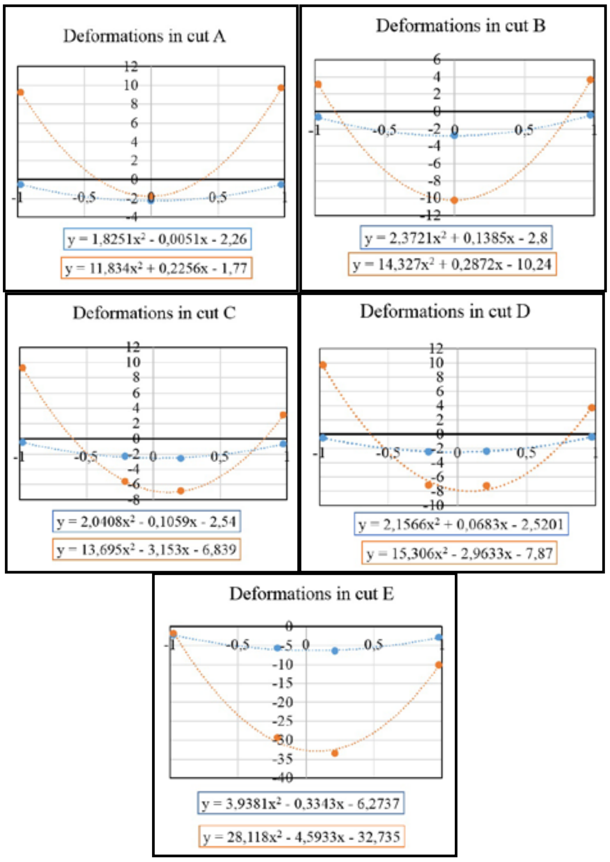

Fig. 9 Deformation in cuts on the edge of slab (after second test)

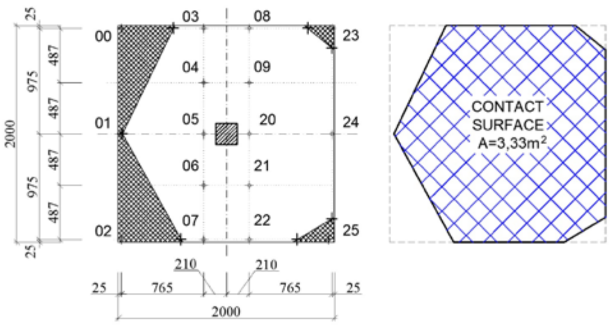

Fig. 10 Contact surface after second test

If there were assumed that deformation of slab is approximately polynomial curve on second order than contact surface may be calculated at least indicative. On Fig. 7 are shown graphs of deformations from cuts on edge of slab for first test and on graph on Fig.9 are shown deformation from second test. In graph are shown two steps – step where it occurs to maximal uniform distribution of load and also uniform deformation of the whole slab respectively last step before corners began to up-lift and last step, when was the slab corrupted. From polynomic equations is possible to calculate approximately points where occurs to lifting-up of slab corners or edges respectively where slab is separated from subsoil. These points are then plotted on slab´s plan and from this is calculated contact surface (Fig.8 and Fig.10).

It is clear from these pictures that the contact surface was at first set greater than at the second test what was also assumed. At the first test were up-lifted only small parts of corners but at second test was up-lifted greater part of corners and one edge was also up-lifted in their whole length.

On the Fig.8 and Fig.10 is also possible to seen that corners lifting is not symmetric. It is caused by unhomogenous subsoil and with different properties of subsoil in slab surface. Another cause is inaccuracy in concreting and placement of hydraulic press.

3.2 Punching shear failure

Because several slabs including described slab were failed by punching shear attention is focused on punching shear analysis and punching shear failure monitoring which is wide area to research [16, 17,18 and 19]. Bearing capacity is compared with calculating according to Eurocode 2 [20].

Slabs were not reinforced with shear reinforcing so bearing capacity were calculated according to equation for element without shear reinforcement which is valid in the interval:

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

where f_{ck} is in MPa
d is the distance from the periphery of the column to the control perimeter considered

Fig. 11 Cracks on the bottom surface of the slab

The maximal shear stress for described slab according (1) is 0.999 MPa and from this value maximal possible applied force were calculated that causes slab damage is 393 kN (with characteristic values) and 190 kN (according to EC including all safety coefficient). It was achieved value 945 kN at the second test. On the Fig. 11 are shown cracks on the bottom surface of the slab and on Fig.12 and Fig.13 are shown cuts on this slab.

Fig. 12 Lateral cuts of slab

Fig. 13 Diagonal cuts of slab

4 Conclusion

The experimental test on the concrete foundation slab was introduced in this paper. The calculated value for the punching shear resistance was 393 kN. This 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 was the real resistance more than two times higher than calculated value.

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