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EXPERIMENTAL AND NUMERICAL ANALYSIS OF INTERACTION BETWEEN SUBSOIL AND POST-ENSIONED SLAB-ON-GROUND

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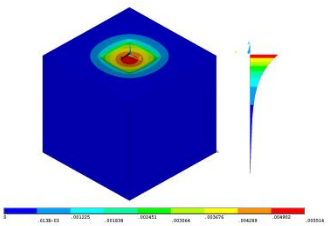
Graphical abstract



Abstract

The paper presents the process of a static load test on post-tensioned concrete industrial floor model in the first part and a numerical model of this task in the second part. The experimental model was designed as a cutout of a post-tensioned concrete industrial floor and the static load test was conceived as a simulation by loading the base plate of a heavy rack. The described static load test was part of a series of experiments focused on the problematics of interaction between concrete structures and subsoil and was realized at the Faculty of Civil Engineering, VŠB –Technical University of Ostrava.

Keywords: Post-tensioned concrete, Industrial concrete floors, Interaction between the foundation slab and the subsoil, Sliding joint, Pre-stressing bar

1.0 INTRODUCTION

The behavior of slab-on-ground constructions – the subsidence of constructions and interaction between a concrete structure and subsoil is one of the main directions of research at the Faculty of Civil Engineering, VŠB – Technical University of Ostrava. Currently, research focuses on the interaction between subsoil and post-tensioned concrete slab-on-ground foundations. In this paper it is more specifically between subsoil and a model of a post-tensioned industrial floor [1, 2, 3].

The experimental model was designed as a cutout of a post-tensioned concrete industrial floor, and the static load test was a simulation by loading the base plate of a heavy rack. The Model was concreted beneath a "STAND" outdoor testing device [4]. The basic dimensions of the experimental model were 2000 x 2000mm, meaning that the model was a square- shaped 150mm thick concrete slab. The type of concrete used for concreting was C35/45 XF1. The experimental model was post tensioned by six fully threaded pre-stressing thread bars. The materials of the thread bars were made of low relaxation steel with the designation Y 1050, and the diameters of these thread bars were 18mm. The thread bars were anchored by domed nuts and recessed anchor plates. Each thread bar was pre-stressed using a hollow hydraulic cylinder with a force of 100kN. The deployment plan of the pre-stressing thread bars is shown in Figure 1.

The model was laid on homogenous subsoil with known parameters. A sliding joint was placed between the contact surface of the concrete floor model and the subsoil. This sliding joint was made of a combination of PVC foil and geotextile [5]. The experiment was realized in the "STAND" outdoor testing device which is situated within the area of the Faculty of Civil Engineering, VŠB –Technical University of Ostrava.

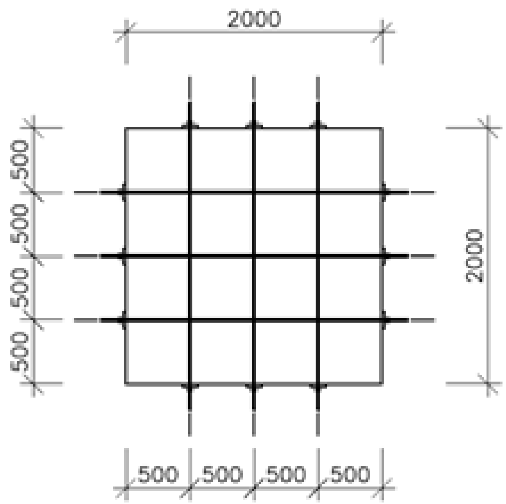


Figure 1 Ground plan of the experimental model

2.0 DESCRIPTION OF THE "STAND" TESTING DEVICE AND MEASUREMENTS

The "STAND" outdoor testing device consists of two frames. Crossbeams enable variability of the press machine location. The frames are anchored with screws into a steel grate based in the reinforced concrete strip foundations. The construction is anchored with 4m long micropiles. The greatest possible vertical load is 1 MN [4].

The experimental static loading test consisted of the assembly of a set of measurements (Figure 2):

- Vertical deformation measurement (potentiometric position sensors)
- Measurement of the vertical load (built-in pressure sensors)
- Strain measurement on the surface of the slab (strain gauges)
- Strain measurement inside the slab (strain gauges)
- Measuring the stress on the interface of the slab and soil (geotechnical pressure cells)
- Temperature inside and on the surface (temperature sensors)
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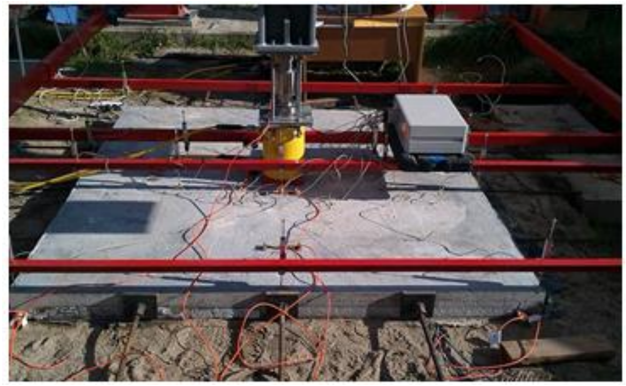

Figure 2 The complete assembly for static load test

3.0 DESCRIPTION OF THE SUBSOIL ATTRIBUTES

The experimental model was implemented on a compacted gravel bed. The gravel bed layer thickness was 300mm and was compacted on prime clay subsoil without greensward. The subsoil characteristics were determined by standard geotechnical measurements.

Subsoil attributes:

- Subsoil consists of loess loam with F4 consistency
- Thickness of the subsoil layer was approximately 5 meters
- Volumetric weight of soil γ = 18.5 kN.m-3
- Poisson coefficient ν = 0.35
- Measuring the stress on the interface of the slab and soil (geotechnical pressure cells)
- Static Young's modulus EDEF = 2.65MPa

4.0 PROCESS OF STATIC LOAD TEST

The vertical load was generated by an ENERPAC CLRG high tonnage hydraulic cylinder. The loaded equipment was placed between the experimental model and the steel extension fixed on the "STAND". The hydraulic system was equipped with a pressure sensor. Potentiometric position sensors were installed on the surface of the concrete floor model. These gauges were connected to the same sensor station with automatic scanning and recording. The shape and size of the load area simulated the base plate of a heavy loaded rack. The dimensions of the load area were 200 x 200mm. A fixed interval of loading - 75kN / 30 min was chosen for this experimental testing.

5.0 THREE-DIMENSIONAL NUMERICAL MODEL

The interaction between the subsoil and the foundation slab was solved using numerical modeling and simulation with ANSYS 15.0 software. The data for the example were taken from the measurements of the experimental model during the load test.

5.1 Creation of the Model

The concrete slab was modelled as a two-dimensional structure using a SHELL 181shell element. Uniform thickness was set to 150mm for the shell elements. The subsoil was modelled with a SOLID 45 three-dimensional solid element. A regular finite element mesh was generated on both the plate and the subsoil. The dimensions of elements representing the modelled area of subsoil were 0.1 x 0.1 x 0.1m. The area of the plate was meshed using elements with a size of 0.1 x 0.1m.

A nonhomogeneous half-space was used for the analysis of the interaction between the loaded pre-stressed slab and the subsoil. The concentration of vertical stress in the axis of the foundation differs from the homogeneous half-space and the static Young's modulus varies smoothly with depth. This material model can describe the deformation behavior of heterogeneous substances such as soil more accurately.

The contact area between the concrete slab and the subsoil can typically transfer only compressive force and the transfer of compressive force depends on whether the two surfaces are in contact or not. The solution is an iterative process and the calculation automatically includes changing-status nonlinearity. The contact is realized using the contact element pair TARGE170 – CONTA173. The friction between the concrete slab and the subsoil in the contact area is neglected. The self-weight of the subsoil and the pre-stressed floor slab are also neglected in the calculation.

Vertical load, which was generated by a hydraulic press, was divided into nodes situated in the 200 x 200mm loading area. The load in the point of failure was approximately 525 kN. Loading of 100 kN from pre-stressed bars was placed in quarters of all edges of the plate (Figure 3).

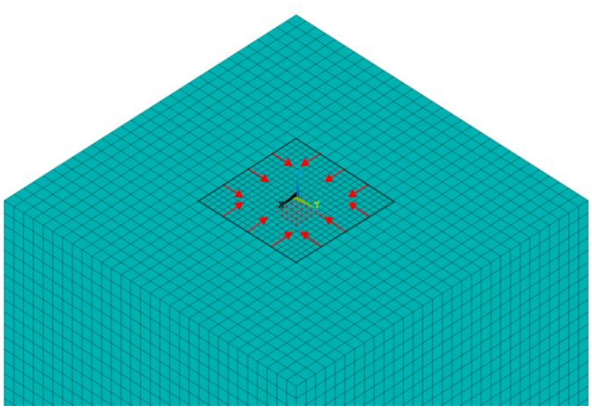

Figure 3 Total vertical displacement of the subsoil model [m]

The boundary conditions were set to restrain horizontal displacement of the nodes in the peripheral walls, which forms the boundary of modelled area of subsoil and vertical displacement of the base plane of the subsoil. There were no boundary conditions restraining any degrees of freedom of the nodes on the level of the top plane representing the terrain surface.

5.2 Stress and Deformation Results of the Model of Pre-Stressed Slab

The size of the modelled area of subsoil and boundary conditions significantly affect resulting deformations in the three-dimensional numerical simulations. Based on a parametric study [6, 7] and the effect of the parameters of the 3D model on deformations, the dimensions of the modelled area of subsoil were chosen to be 6.0 x 6.0 x 6.0m with the boundary conditions set as mentioned above.

Figure 4 shows the total vertical displacement of the subsoil model. As assumed, the maximum subsidence is located in the middle of the slab and its value is 5.514mm. The deformed shape of the model is symmetrical, which indicates that the symmetrical load and especially the symmetrical pre-stressing were specified correctly. Figure 4 also shows vertical displacement in the vertical section through the middle of the subsoil model.

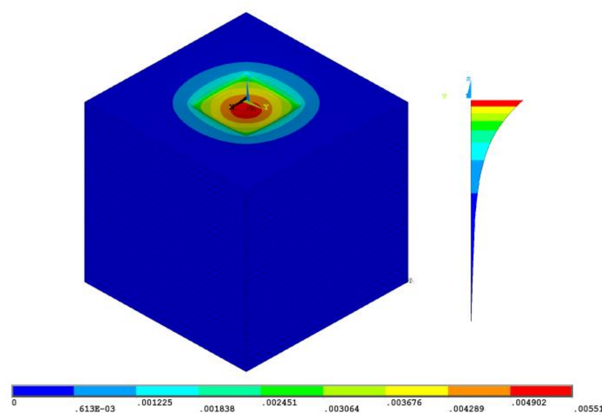

Figure 4 Total vertical displacement of the subsoil model [m]

Horizontal deformation of the subsoil model is displayed in Figure 5. The shape of deformation is symmetrical (in the x and y axis direction) and for presentation of results only deformation in the y axis direction is shown. The deformation in the x axis direction has the same shape only rotated 90 degrees around the vertical middle axis of the subsoil model. The deformation in the y axis direction is symmetrical around the origin, which is placed in the middle point of the plate. Horizontal deformation in the y axis direction pointing to the middle of the plate has the same value but opposite orientation as shown in Figure 5.

Horizontal deformations of the plate (in both x and y axis direction) are affected by introducing pre-stress in the plane of the model of the pre-stressed concrete slab. In Figure 5 the position of the pre-stressing bars in the y axis direction is shown. Sections in these positions are labelled A-A, B-B and C-C. In Figure 6 horizontal displacement v is displayed in all sections.

The effect of pre-stress force on deformations in the mid-plane of the slab is noticeable from sections through positions of the pre-stressing bars shown in Figure 6. The most affected areas are beneath the anchors of the pre-stressing bars and the effect grows weaker towards the center of the plate. The deformation in the y axis direction is fully symmetrical around the origin, which is placed in the middle point of the plate. Horizontal deformation in the y axis direction pointing to the middle of the plate has the same value but opposite orientation as shown in Figure 6.

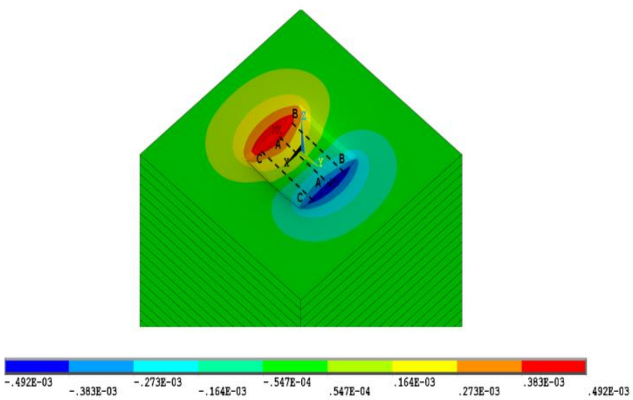

Figure 5 Horizontal deformation [m]

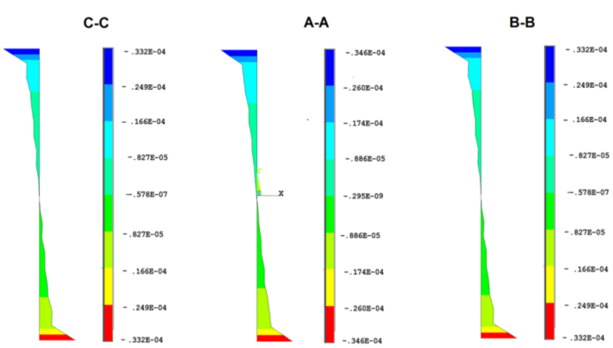

Figure 6 Horizontal deformation of sections A-A, B-B, C-C in the y axis direction [m]

The vertical component of normal stress σ_z in the subsoil is displayed in Figure 7. The red indicates areas with the greatest tension in the settlement trough with a value of 1000 to 14178.3 Pa. The yellow in Figure 7 indicates minor tensile stress with a value of 0 to 1000 Pa.

The level of stress σ_z with increasing depth illustrates the vertical section through the middle of the subsoil model in Figure 7.

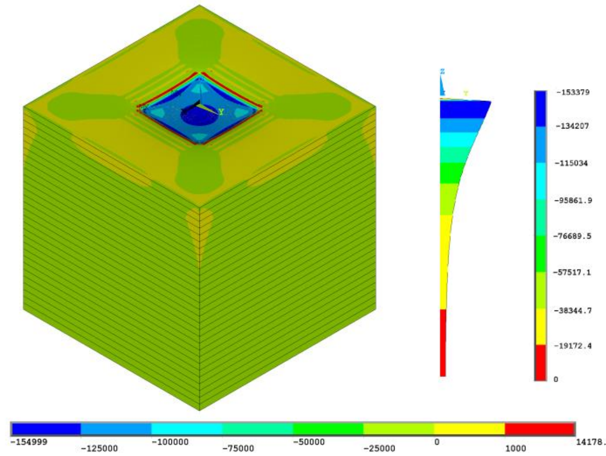

Figure 7 Distribution of normal stress σ_z, vertical section through the subsoil model [Pa]

The contact stress distribution is shown in Figure 8. As assumed, the stress is concentrated on the periphery of the plate and rises sharply in corners. This is illustrated in the transverse section A-A and diagonal section B-B through the pre-stressed concrete slab in Figure 8. Stress peaks can be reduced in ANSYS software.

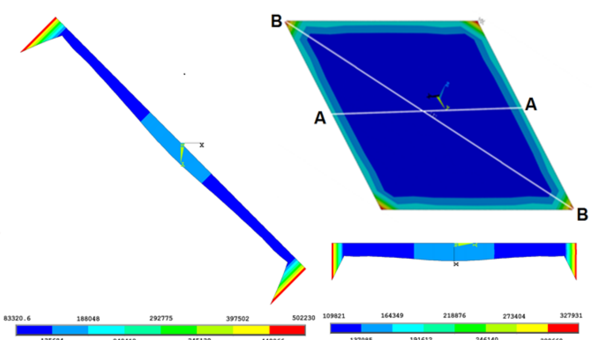

Figure 8 Distribution of contact stress, transverse and diagonal section [Pa]

6.0 CONCLUSION

The experimental post-tensioned concrete industrial floor model resisted the loads exerted after seven loads cycles and induced a maximal load level 525 kN. The first significant cracks were detected after the fourth cycle when the load reached 300 kN. These cracks were located near the anchors of the thread bars. Data collected from measurements during the experiment were used in the creation of the numerical model.

A nonhomogeneous half-space was used for the analysis of the interaction between the loaded pre-stressed slab and the subsoil. The concentration of vertical stress in the axis of the foundation differs from the homogeneous half-space and the static Young's modulus varies smoothly with depth. Using this material model, the deformation behavior of heterogeneous substances such as soil is described more accurately.

The contact area between the concrete slab and the subsoil can typically transfer only compressive force and the transfer of compressive force depends on whether the two surfaces are in contact or not. An iterative process is applied and the calculation automatically includes changing-status nonlinearity. Vertical displacement measured during the experiment and the displacement calculated in the numerical analysis differs by 320% in the center of the slab where the maximum displacement is located. Specifically the subsidence of the experimental model reached 17.8mm, whereas the calculated vertical displacement from the numerical model reached only 5.5mm.

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