

Jana LABUDKOVÁ¹, Radim ČAJKA²**COMPARISON OF EXPERIMENTALLY MEASURED DEFORMATION OF THE PLATE
ON THE SUBSOIL AND THE RESULTS OF 3D NUMERICAL MODEL****Abstract**

The purpose of this paper is to compare the measured subsidence of the foundation in experiments and subsidence obtained from FEM calculations. When using 3D elements for creation of a 3D model, it is, in particular, essential to choose correctly the size of the modelled area which represents the subsoil, the boundary conditions and the size of the finite element network. The parametric study evaluates impacts of those parameters on final deformation. The parametric study is conducted of 168 variant models.

Keywords

Foundation structure, soil – structure interaction, interaction models, contact stress, 3D FEM element.

1 INTRODUCTION

Because calculated subsidence and real subsidence of foundations do not correlate well, a site survey is needed and experimental measurements are carried out in order to determine subsidence of foundation soil under structures, deformation of foundation slabs and characteristics of stress in foundation slabs which depend on parameters of subsoil. Using results of such experiments, the methods used for calculation of subsidence are modified and become stricter. The interaction of foundation–subsoil is dealt with in such [5, 6, 8, 9, 16, 19].

In 2012 an experiment was carried out at the Faculty of Civil Engineering, VSB – Technical University of Ostrava [3].

Values measured during the load tests were compared with values calculated by means of interaction FEM models with 3D element of subsoil [1, 2, 18]. The calculations were carried out for several sizes of the subsoil and for different boundary conditions.

2 EXPERIMENTAL MEASUREMENTS

The model comprises the loading test which has been performed using test equipment in the Faculty of Civil Engineering, Technical University of Ostrava (VŠB – TUO). The test equipment can be used for experimental measurements of strain and state of stress. In case of interaction of the foundation structures and subsoil, it is possible to monitor stress-strain relations there [3].

A sample used for the experiment was a prefabricated concrete tile. Concrete tile was chosen for simplicity in the implementation of an experiment aimed at verifying the test methods and

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equipment. The dimensions of the plate were 500 x 500 x 48 mm. The upper layer of subsoil consists of loess loam with F4 consistency. Thickness of that layer is about 5 meters. During the test, the concrete slab was loaded in the centre by the pressure applied by a hydraulic press. Dimensions of the area under load were 100 x 100 mm. The load at the moment of failure was 18.640 kN. Measurements regarding to the interaction of foundation–subsoil is dealt with in such [4, 7].



Fig. 1: Test sample and load test

3 CREATING A COMPUTATIONAL MODEL IN ANSYS

The computational model was created using a 2D element SHELL 181 for the slab and a 3D element SOLID 45 for the model of subsoil.

SOLID 45 is an element which is used for linear and non-linear analyses of the structure with much deformation, creeping or plastifying. The sizes of network elements are different for the subsoil under study and for the slab surface where the network is more dense. The FEM analysis of contact problems is dealt with in such [14, 17].

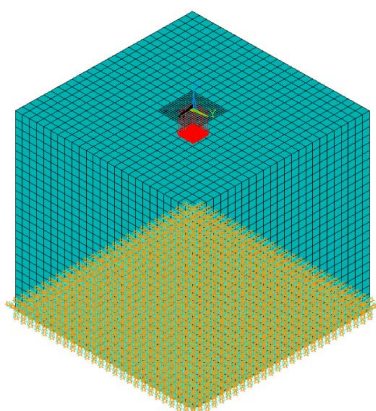


Fig. 2: 3D Model created in ANSYS

In order to transfer effects of the load, which is applied on the foundation slab, into the subsoil it is essential to create a mutual contact and define a contact surface. The contact surface is the place where the slab is in contact with the subsoil. The contact surface transfer compression force only.

Because this effects one side only, structural non-linearity should be introduced into calculations - it requires an iteration and the analysis is automatically non-linear. The contact is made using a contact pair: TARGE 170 – CONTA 173. The contact exists once elements from one surface enter into the other surface. Numerical solutions to contact tasks are also described in [10, 11, 12, 13,

15]. Friction between the slab and subsoil is not taken into account for the contact surface. This means, the friction coefficient is zero. Own weights of earth massif and concrete slab have not been taken into account either. The own weight of the earth should influence the final value of absolute quantities (the settlement). This influences the relative quantities only in a non-linear analysis.

3.1 Parametric study

The final deformation in 3D tasks is considerably influenced by the size of the modelled area which represents the subsoil and by boundary conditions.

The comparison was made for four different boundary conditions - see Fig. 3. All variants have been compared, attention being paid to the influence of the boundary conditions on the final quantities - this means, on the deformation resulting from the slab-subsoil interaction, internal forces and contact stress [1, 2, 18].

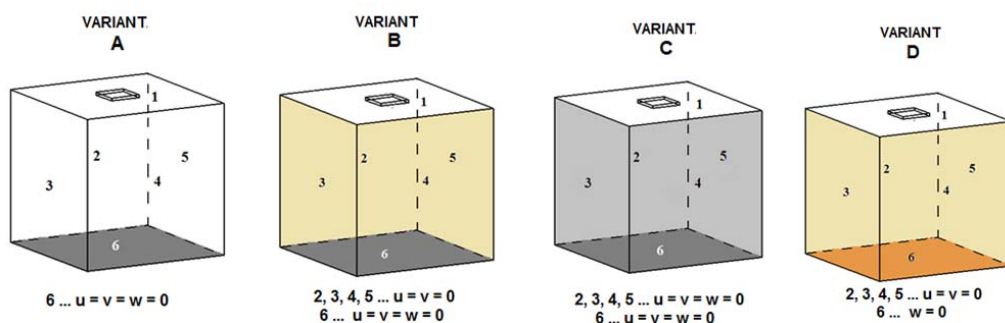


Fig. 3: Different types of boundary conditions

Four aspects were considered when comparing different models. The first aspect is dependence of deformation on the variant boundary conditions (variants A, B, C, D).

The Fig. 4 (on the left) shows impacts and relevance of the boundary conditions for the vertical deformation. The biggest difference in the vertical deformation for the increasing depths has been reached for A. In case of C, the boundary conditions of subsoil's external walls play such a key role that the deformation almost does not depend on the depth [1, 2, 18].

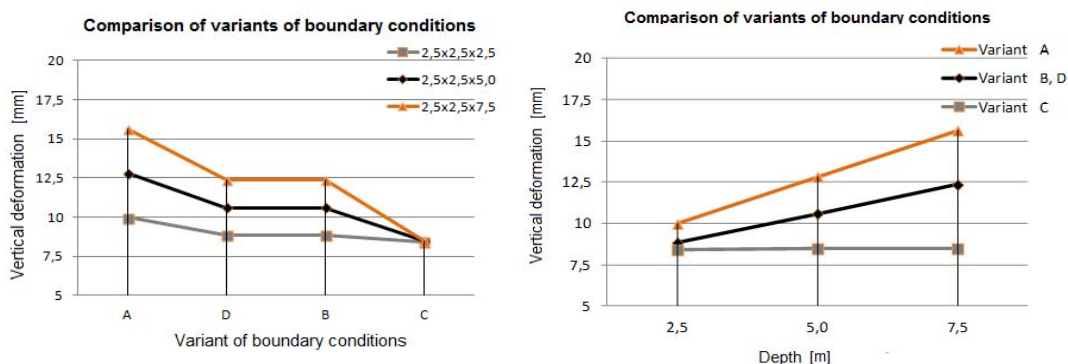


Fig. 4: Comparing the variants of boundary conditions: the vertical deformation vs. boundary conditions (on the left); the vertical deformation vs. depth (on the right)

The second aspect is dependence of deformation on variable depth of the subsoil, while keeping the same ground plan of the subsoil.

The Fig. 4 (on the right) shows that the higher the depth of the subsoil model is, the bigger the difference is between deformations calculated for the variants of boundary conditions. With the

increasing depth of the subsoil model, the selection of boundary conditions is becoming a more important criterion which influences the final vertical deformation [1, 2, 18].

The third aspect is dependence of deformation on variable size of ground plan of the subsoil, while keeping the same depth. The Fig. 5 (on the left) shows that the influence of any boundary condition is becoming weaker with the increasing ground plan of the subsoil. Using the chart in Fig. 5 (on the left) it can be concluded that the boundary conditions play no role at all, if the ground plan of the subsoil model is big enough.

The last aspect is dependence of deformation on the total size of modelled area. The Fig. 5 (on the right) shows that the bigger is the modelled area, the higher is the deformation. This is valid irrespective of the fact whether the primary reason for deformation is the depth or ground dimensions of modelled area [1, 2, 18].

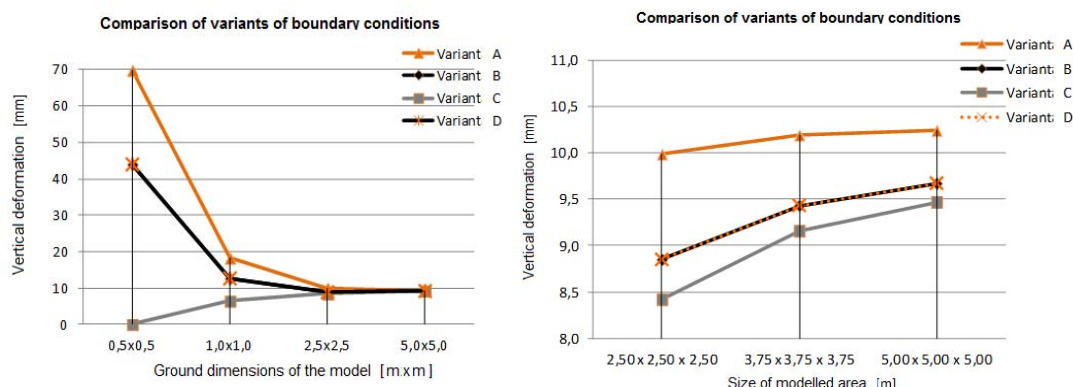


Fig. 5: Comparing the variants of boundary conditions: the vertical deformation vs. ground plan of the model (on the left); the Vertical deformation vs. the area size (on the right)

3.2 Vertical deformation vs. ground-plan dimensions and depth of the subsoil model

The A variant of the boundary conditions have been used to show the vertical deformation versus the ground-plan dimensions and depth of the subsoil model.

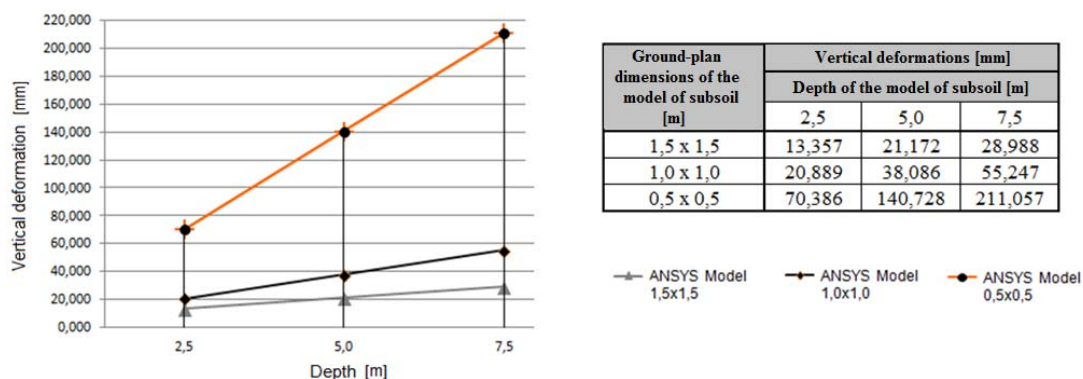
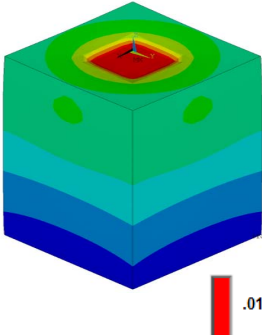
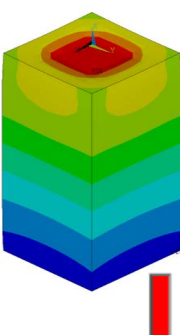
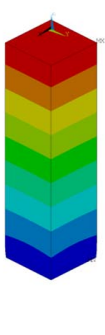
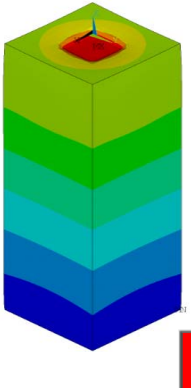
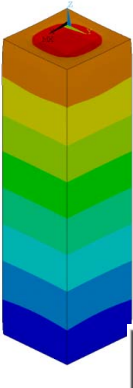
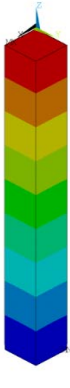
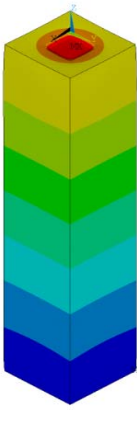
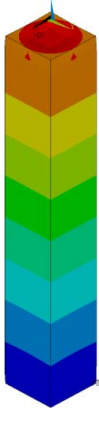



Fig. 6: Vertical deformation vs. ground-plan dimensions and depth of the subsoil

The vertical deformation increases, depending on the depth, most if the ground-plan dimension of the subsoil is same as the size of the slab. In that case, effects of the surrounding earth are not taken into account and the vertical deformation changes in the same proportion as the depth there. The bigger is the ground plan area, the more important is the role of the surrounding earth. This means, the vertical deformation changes less, as the depth changes. And the depth-deformation ration

is not maintained (see Fig. 6, Tab. 1). When modelling in ANSYS following elements have been used: 0.1 x 0.1 x 0.1 m [18].

Tab. 1: Vertical deformation vs. ground-plan dimensions and depth of the model of subsoil

Depth [m]	Ground-plan dimensions of the model of subsoil [m]		
	1.5 x 1.5	1.0 x 1.0	0.5 x 0.5
2.5			
5.0			
7.5			

3.3 Final state of stress and deformation of the slab

Based on the parametric study of effects of each 3D model parameter on the total deformation a model of subsoil has been chosen. Its dimensions are 2.5 x 2.5 x 2.5 m and the network size is

0.05 x 0.05 x 0.05 m. The boundary conditions are those from the D variant. The final state of stress and deformation are shown in the figures below.

Fig. 7 shows total deformation with clear effects of the boundary conditions which prevent enclosing walls of the model from dislocating horizontally and the base of the subsoil model from dislocating vertically. The figure shows a vertical section through the center of the subsoil model [18].

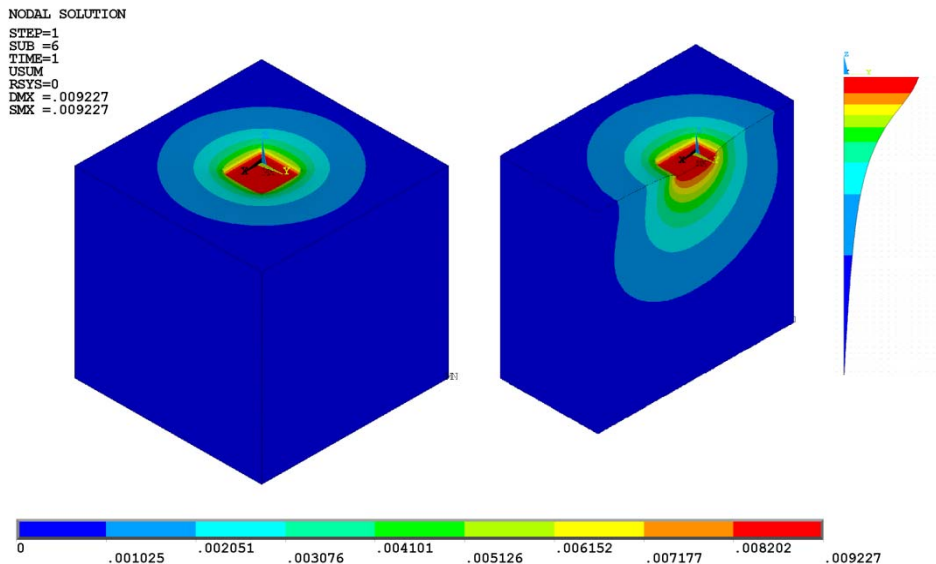


Fig. 7: ANSYS model: Total deformation – a vertical section through subsoil [m]

Fig. 8 through 10 show distribution of the contact stress. As expected, the contact stress is concentrated along the perimeter of the contact slab and in corners where the stress increases dramatically [18]. This is also visible in a transverse and inclined section through a concrete slab. In ANSYS it is possible to restrict peaks representing the increasing contact stress.

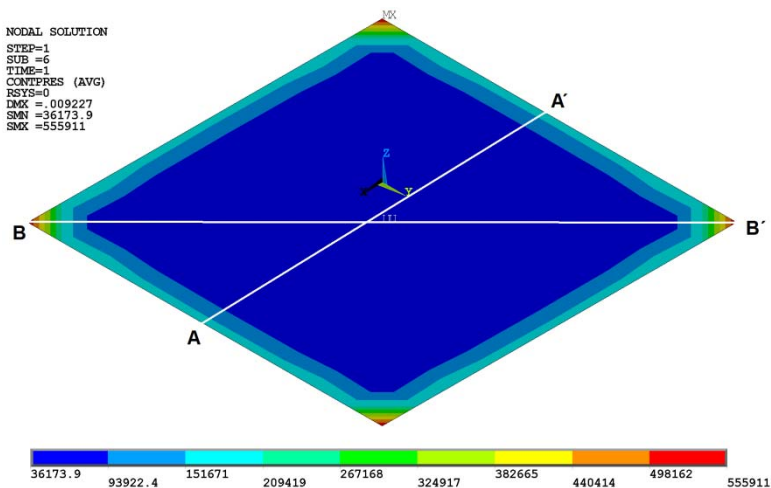


Fig. 8: ANSYS model: contact stress and cross-sections [Pa]

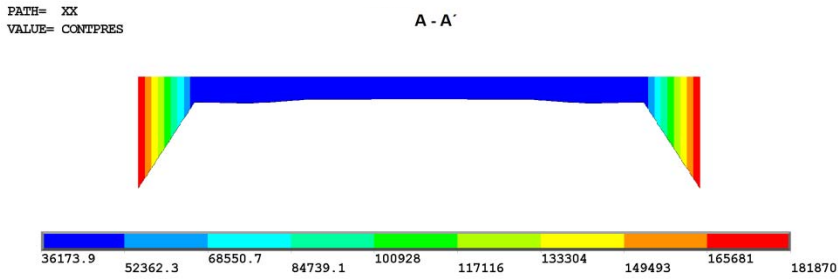


Fig. 9: ANSYS model: contact stress and A – A' cross-section [Pa]

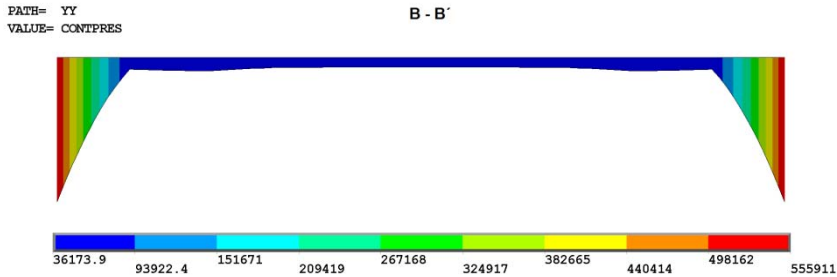


Fig. 10: ANSYS model: contact stress and B – B' cross-section [Pa]

Fig. 11 shows a vertical component of the stress in subsoil: σ_z . The red colour represents tensile stress in the soil under an area of subsidence.

When modelling a structure, it is very important to choose a correct material model and to enter correct parameters of the soil Fig. 11 compares the linear and non-linear material models. The linear calculation does not take into account the area and possible failures there. The non-linear model has been prepared using a Drucker – Prager model which makes it possible to describe properly behaviour of the soil and a difference between tensile strength and compressive strength.

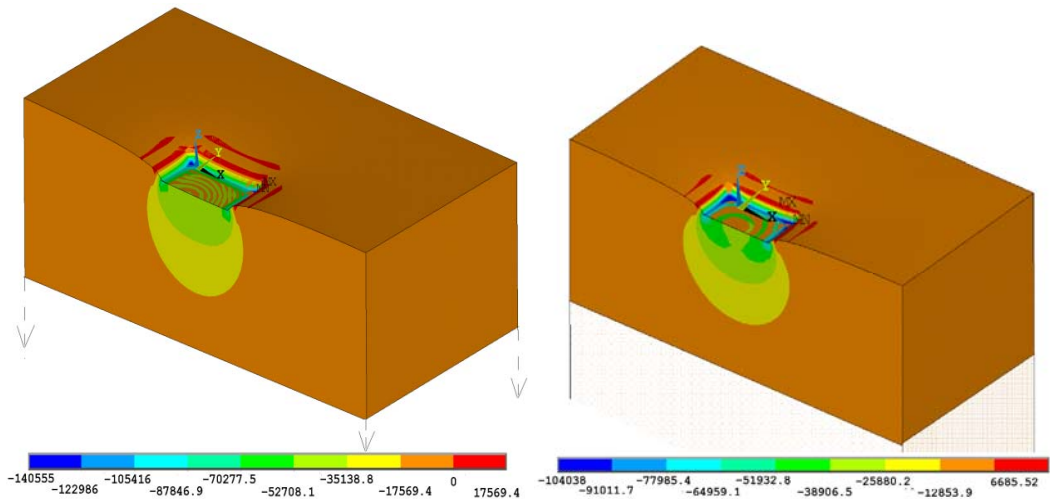


Fig. 11: ANSYS model: comparing the σ_z stress in linear and non-linear material models

In a non-linear analysis, permanent deformation appears once the parameters go beyond the plasticity limits. No deviations have been found between the linear and non-linear models for the subsoil with the size of 2.5 x 2.5 x 2.5 m with 0.1 x 0.1 x 0.1 m mesh. If the finite element network in

the same model become more dense – $0.05 \times 0.05 \times 0.05$ m – extreme values of the compression and tension reach almost double values. In that case, plasticizing occurred (Fig. 12) and the linear and non-linear material models were different (Fig. 11). After the plasticizing, the tensile and compressive stress in soil decreased. In reality, the soil is able to transfer, in a lesser extent, tensile stress as well. This is in line with the used condition of plasticity where the tensile stress is possible – see Fig. 11.

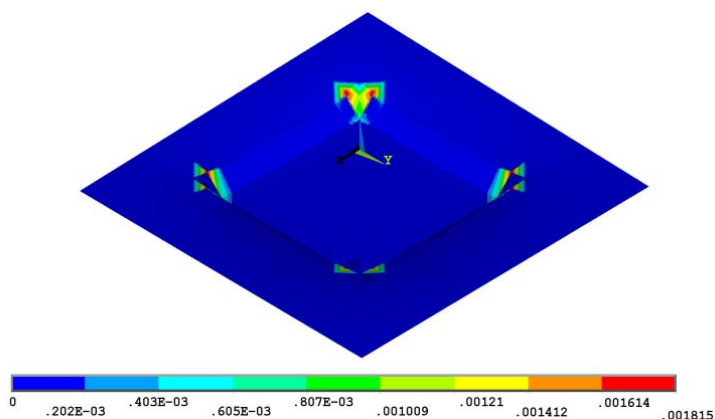


Fig. 12: Model ANSYS: Plastic deformations

4 CONCLUSION

Values of deformation resulting from the 3D model with 3D elements in ANSYS are very dispersed, the reason being the individual parameters. (Fig. 13)

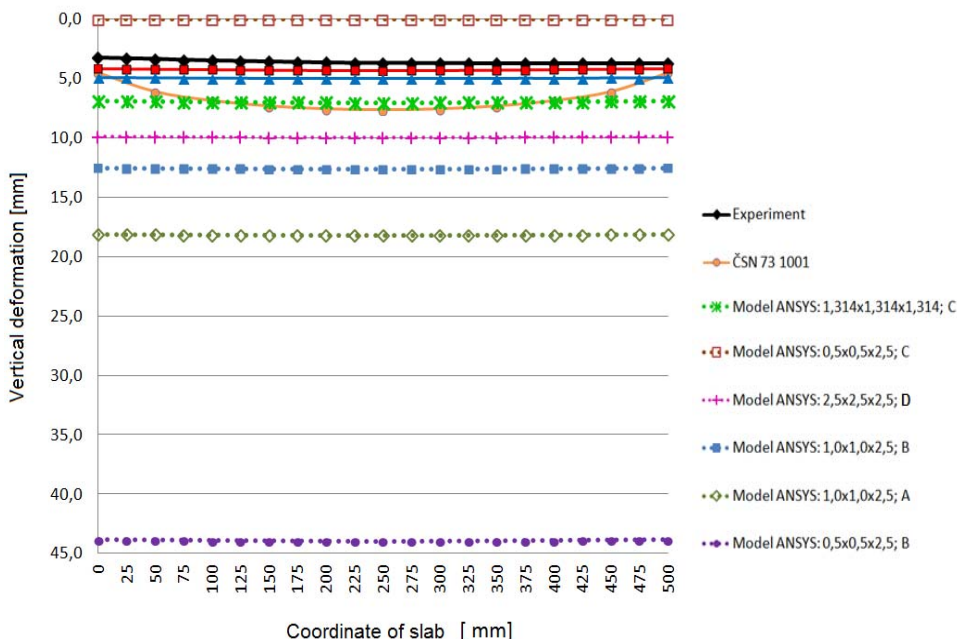


Fig. 13: Comparing the measured vertical deformation and some 3D models created in ANSYS

The deformation resulting from the ANSYS models are bigger than those measuring during the experiment. One of the reason is that the ANSYS model do not take into account the strength of the earth. Properties of a 3D subsoil model are in line with those of a linear elastic mass. If the size of the area is estimated using a known depth of the deformation zone obtained by means of a corrective coefficient of additional load, m , the 3D model includes indirectly effects of resistance which the additional load earth applies against deformation. Coefficient m being the corrective coefficient influences the structural strength of the soil. At the same time, the less the corrective coefficient m is, the more the deformation behavior of the soil approaches the behavior of the linearly elastic mass. If m is approaching zero, the results converge towards the results of the 3D finite element models. The maximum subsidence of subsoil obtained from subsidence of an elastic half-space modified by means of structural strength in line with ČSN 73 1001 was 7.612 mm under the center of the slab. The calculation calculated the subsidence of the subsoil down to the z_z depth of the deformation zone.

An important parameter in 3D models is the degree of discretizing. Division of the model into finite elements influences both the results and the number of degrees of freedoms, being thus important for the calculation time and quantity of processed data.

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