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STRESS AND DEDFORMATION STATES IN STRUCTURES AND STRUCTURAL ELEMENTS USING COUPLED MODELLING

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ABSTRACT
In this grant project the techniques of the method of the coupled modelling was substantially extended for various material and appropriate structural systems. In principle, a combination of linear effects of the external loading and material and time-dependent nonlinear change in structures was considered. Assessment of rock behaviour in surrounding of utility tunnels, solution of the structural strength below foundation, back analysis of reinforced soil slopes and studies of slopes endangered by groundwater were carried out.

KEYWORDS: physical and numerical modelling, stability, slopes, tunnels, inverse analysis

1. INTRODUCTION

Numerical methods seem to be the cheapest tool for assessing different types of structures. If the theory of damage should be involved into the formulation of the problem to be solved, special treatment is required. The test experiments have been carried out to get knowledge about a reasonable approach for solving the problem.

The scope of the grant was the development of constitutive equations for inelasticity and damage of heterogeneous materials that benefit from some specificities of a special boundary element method. On one hand side, we need to obtain better approximations of the local stress and strain fields than in the standard approaches based on experience, especially when considering damage and failure conditions. We tend to simplify sufficiently the numerical techniques of overall homogenization in order to obtain a treatable system of equations that could recover the status of a constitutive equation.

Models are considered for application to plasticity, viscoelasticity and damage in soil/rock material. Model by (Kachanov, 1992) is mostly used. The method proposes a continuation and development of Desai's DSC which has formerly been used for saturated soils and then extended to solid materials. The extension by Desai consisted in inclusion of skeleton into the consideration and solution of such problems, which were coupled (mutual interaction of water and skeleton was studied). Procházka and Trčková (Procházka and Trčková, 2000) introduced previously piecewise uniform eigenstrains in each material phase and précised the properties of the phases. Standard applications of the method to a two-phases rock material (stone, clay) are considered in this study, it means only one sub-volume per phase is considered. A typical application of coupled modelling (experimental and numerical) to special case of patterns was published in (Trčková and Procházka, 2001; Trčková and Procházka, 2006).

Coupled modelling was used to assess rock behaviour in surrounding of utility tunnels, solution of the structural strength below foundation, back analysis of reinforced soil slopes and studies of slopes endangered by groundwater. Three examples of coupled modelling utilization are described in this article.

2. ASSESSMENT OF ROCK MASS BEHAVIOUR IN SURROUNDING OF UTILITY TUNNELS

The fundamental ideas of a numerical procedure leading to overall plastic and damage behaviour of rock matrix in a rock – tunnel lining aggregate is presented. Based on the numerical models and mechanical laws it is possible to obtain the strain and stress from results of experimental scale models. Very important property of the above procedure is the non-linearity of the problem, which, when using some

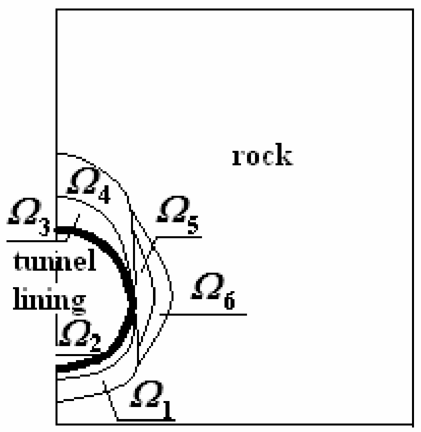

Fig. 1 Distribution of eigenstrain zones.

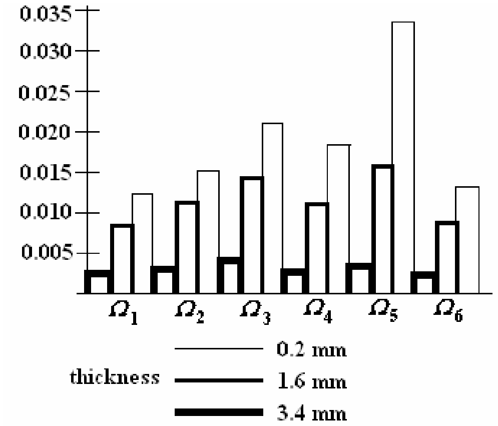

Fig. 2 Spectral values of eigenstrain tensors in the zones; various thicknesses.

smart algorithm, can be solved by very powerful iterative process.

Underground utility tunnels and other technological and specific tunnels constructed in small depths under the surface occur often under building foundations especially in an urban area. These tunnels and foundations of the ground structures can interact mutually and influence their stability and cause adverse reaction. Redistribution of the stress around the tunnel depends not only on properties of environmental soils, and tunnel size and location, but also on tunnel lining stiffness (Jao and Wang, 2000). This study focuses on coupled modelling of this problem. On experimental and numerical models distribution of stress around horizontally located circular tunnel with diameter about 1.6 m under the strip footings in dependence on the lining stiffness was carried out. Experiments were performed on a scale of 1:20 in modelling stand. The analysis was focused on determining stress distributions due to construction of strip footing above existing tunnel lined by lining of various thicknesses.

On the basis of experiment results, internal parameters for numerical models were determined. In numerical models Desai´s Distinct State Concept (Desai, 1994) was combined with Transformation Field Analysis (Dvorak, 1992; Dvorak and Procházka, 1996). The procedure may be considered as a special case of inverse analysis.

It has been shown that the strength of the equivalent of the concrete lining, depth of the tunnel under surface and location of the strip footing principally influence distribution of the stress. Some range of relative stiffness was considered in our study for a typical location of small tunnels.

The reason, wherefore first of all described scale physical models were carried out, was to use results from physical scale models in numerical modelling.

In the same way as experiments, numerical examples were prepared. Six zones, Ω_1, Ω_2,…, Ω_6, were selected according to Figure 1. The Unified model started from the thickness 3.4 mm, and plastic behaviour together with damage was created. The tunnel linings changed in the sense of experimental models.

Additional eigenstrains are depicted in Figure 1. It is seen that if the thickness is weaker, the effect of opening (concentration of plastic strains) appears in zone Ω_5, while in other zones eigenstrain slightly increases (Fig. 2). They can be lowered after more precise selection of the Unified model.

3. SOLUTION OF STRUCTURAL STRENGTH BY FREE HEXAGON METHOD

The free hexagon method seems to be one of very promising (Cundall, 1971; Moreau, 1994). In comparison with previous methods, this method involves time-dependent problem with Newtonian forces, which are caused by contact forces of moving particles. It simplifies the body of the earth (soil) to a set of hexagons, which are, or are not in a mutual contact. The material properties of the hexagons are determined from the state of stresses. Adjusting the idea of PFC (particle flow code), which starts with balls instead of hexagons and dynamical equilibrium, while in our case the static equilibrium is considered. The hexagons represent a typical shape of grains the earth consists of. A cut from arrangement of hexagonal elements that are in mutual contacts is seen from Figure 3. The method was used to assess structural strength below foundation.

The behaviour inside each element is either linear or non-linear (plastic, viscoelastic, viscoplastic, etc). To describe such behaviour, boundary elements are applied. The static equilibrium is used in formulation of free hexagon method. This method has been established in middle 90-ties and the fundaments can be found in Procházka and Válek, 2000.

The experimental models are based on physically equivalent materials and scale modelling. Physical

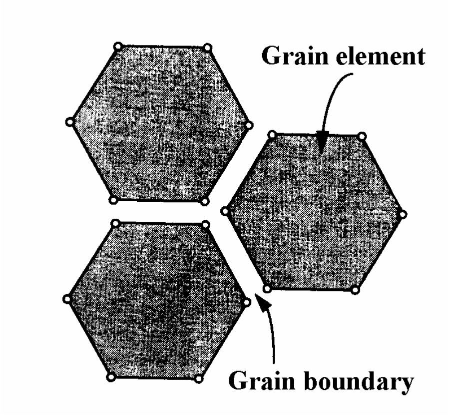

Fig. 3 Sample decomposition - three adjacent particles in mutual contact.

model on a scale of 1 : 25 was prepared. In our case similar modelling was used with such an exception that very particular materials were used.

The proposed model, in contrary to modern numerical methods (FEM, BEM, etc.), is enable one to disconnect the medium described by the balls, when needed (e.g. providing certain requirement on tensile strength). The most natural contact conditions - Mohr-Coulomb hypotheses - may be simply introduced and, after imposing all such contact conditions.

4. BACK ANALYSIS OF REINFORCED SOIL SLOPES

Among the most popular reinforcement in soil mechanics of slopes is anchoring and nailing. In our experiments nails are applied; they are penetrated into the slope, it is loaded only by its volume weight. The material of nails as well as that of the slopes is known from laboratory tests. This circumstance influences the distribution of stresses along the length of the body of the nail. Moreover, position of the nails to the stability of the reinforced slopes is observed. As the experiments are carried out in scale models, similarity conditions have to be obeyed. Slope 1 : 1.5 (length : height) was considered in the scale of 1 : 100. The technology of construction of experimental models is very important. Similarity rules are applied, but in this case no additional tests on physically equivalence of materials (real and that in the scale model) are necessary. Physically equivalent material was selected to be in compliance with selected real slope. As is well known, slopes stability is phenomenon which underlies the softening material behaviour, i.e. the nonlinear behaviour is concentrated along the slip curve. All kinds of nails are fully active after their mobilization. Different position of nails is considered to obtain the influence of this effect.

In numerical analysis a priori integration method is fully used (Koudelka and Procházka, 2001). Its application enables one to decide relatively very quickly if the slope is stable or the measure of stability, the safety margin. The nails have been prepared from a chip of bamboo, unified in the shape and dimensions, their shear strength is known, so that the resistance force due to a nail is also given. Influence of load to the safety margin is depicted in Figure 4.

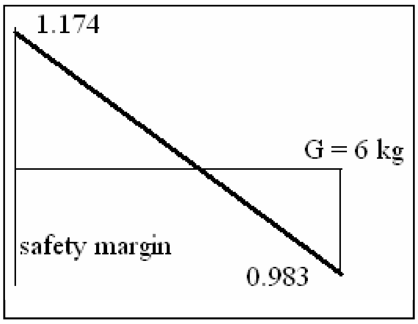

Fig. 4 Relation load and safety margin.

Two basic positions is horizontal set of nails were prepared. The first is seen in Figure 5, it should help to stiffen the upper part of possible slip surface (curve). As is well known, this is the most advantages position, since the slopes in general start their damage along the ridge. The first loading step is also seen from this picture.

In Figure 6 the second position of reinforcement is depicted together with obvious movement of the ridge. Also in the upper right part of the slope partial damage is highlighted and according to the assumed shape of the slip curve the safety margin is derived.

It is worth noting that this approach for the identification of appropriate structure of slopes with reinforcement by nails can be applied to various types of slopes, even in non-homogeneous mediums. For this case and the AIM see (Procházka, 1990).

5. CONCLUSIONS

Three examples of utilization of the coupled modelling method have been mentioned. Coupled modeling of behavior of structures (mutual comparison of experimental and numerical models) becomes very powerful tool for assessment and design. The results of the experimental model tests served to formulate constitution relations for numerical modelling. On the basis of experiment results, internal parameters for numerical models can be determined. The procedure may be considered as a special case of inverse analysis. An experimental modelling is limited by the fact that the results are valid only in the frame of conditions characterizing experiment. Therefore it is advantageous to combine the experimental modelling with numerical methods and utilize of their positive features, the flexibility and high performance of numerical solutions where the input parameters can be change very fast.

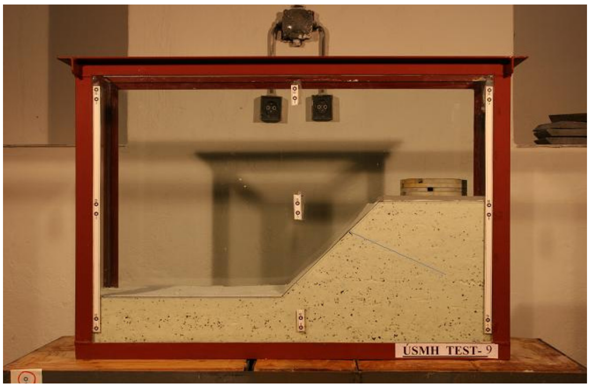

Fig. 5 View of stand with the slope loaded from above and with the first position of a nail.

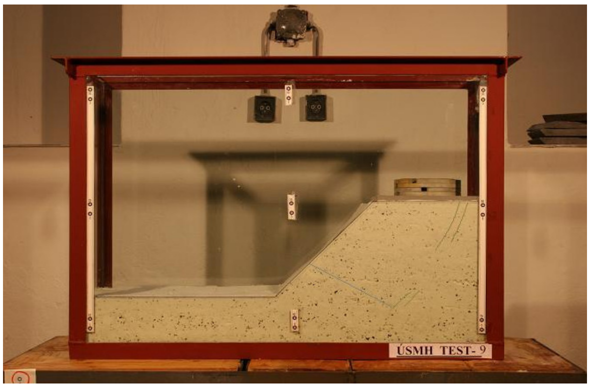

Fig. 6 The second type of reinforcement, slip curves highlighted.

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STAVY NAPĚTÍ A DEFORMACE V KONSTRUKCÍCH A KONSTRUKČNÍCH PRVCÍCH UŽITÍM SDRUŽENÉHO MODELOVÁNÍ

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ABSTRAKT:
Metodika sdruženého modelování byla podstatně rozšířena pro využití k řešení širšího spektra problémů. V zásadě se vycházelo z myšlenky kombinace lineárního vlivu vnějšího zatížení a materiálově a časově nelineárních změn v konstrukcích. Pro ověření možnosti využití navržených postupů bylo hodnoceno chování horninového prostředí v okolí tunelů ražených v přípovrchových vrstvách, sledovány deformace podloží pod základovou patkou a změny rozložení napětí kolem výkopu pro patku, provedena zpětná analýza vyztužených zemních svahů a stability svahů ohrožených spodní vodou.