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MATHEMATICAL MODELLING OF A CUT-AND-COVER CONSTRUCTION

Summary. Firstly, the replacement of the soil by two different kinds of plasticity models (Mohr-Coulomb model and Hardening-Soil model) is conducted. Secondly, the response of the numerical models without and with compaction process is analysed. Finally, several parametric studies are performed by means of the numerical model with the closest results to the field measurements to investigate the influence of the soil properties, on which the cut-and-cover construction is build, on lining displacements.

Keywords: *Back-calculation; Soil models; Numerical modelling, Parametric studies*

MATEMATYCZNE MODELOWANIE BUDOWY ODKRYWKOWEJ

Streszczenie. Po pierwsze, zastąpiono grunt dwoma różnymi modelami sprężystości (modele Mohra-Coulomba i ze wzmocnieniem). Po drugie, przeanalizowano reakcję modeli numerycznych z zastosowaniem procesu zagęszczania i bez niego. Przeprowadzono wreszcie szereg badań parametrycznych za pomocą modelu numerycznego, dającego wyniki najbliższe do badań terenowych, w celu zbadania wpływu własności gruntu, na którym prowadzona jest budowa metodą odkrywkową, na przemieszczenia obudowy.

1. Introduction

Cut-and-cover constructions have been successfully used in building underground structures mainly due to their low construction costs and low future maintenance cost. The arch-shaped concrete cut-and-cover constructions have economical advantages when compared with rectangular profiles, because of better interaction with surrounding soil to transfer the loading. An arch-shaped concrete cut-and-cover construction is the main interest of this paper. Two comprehensive computational models were developed using finite element package PLAXIS and validated by field measurements of tunnel profile at different stages of backfilling procedure.

2. Project of a cut-and-cover construction - tom2

The case study considered within this paper is a cut-and-cover construction built to underpass a small stream through a road embankment. The reinforced precast concrete arch tunnel tagged TOM2 belongs to the main project of the highway from Plzen (Czech Republic) to Nürnberg (Germany). The structure was constructed as a first example of this type of cut-and-cover construction within the Czech Republic in 1996. That is why detailed investigation was carried out in order to investigate behaviour of the structure in interaction with the soil at different stages of backfilling and also to get experience and information, which would be useful for economic as well as safe design in future. The TOM2 tunnel has single tube profile with the typical cross-section at area of $38m^2$, length 55m and 4.6m thick overly of soil at the crown of the arch.

3. Numerical modelling

Finite element analyses were carried out in plane strain conditions using a package known as PLAXIS version 7.2. The finite element package PLAXIS was chosen for developing comprehensive computational models of cut-and-cover construction TOM2, presented in this paper, because of its facility of modelling the soil itself as well as the structure and the inter iaction between the structure and the soil. For numerical modelling of cut-and-cover construction TOM2, the Mohr-Coulomb model (perfect plasticity) was used for a quick and simple first analysis of the problem. As a more sophisticated constitutive model for this case the Hardening-Soil model (deviatoric and volumetric hardening with plastic strains) was used.

4. Numerical model

For two dimensional plane strain analyses used in this project the soil was characterised by means of 6-node triangle finite elements. They provided a second order interpolation for displacement. The element stiffness matrix is evaluated by numerical integration using a total of three Gauss points called the stress points. The tunnel lining was taken into analyses as a curved beam. The beam is the one-dimensional structural object used to model slender structures in the ground with a significant flexural rigidity as a bending stiffness and a normal stiffness. The beams in PLAXIS represent real plates in the out-of-plane direction and can therefore be used to model tunnel linings.

The geometry dimensions of the numerical model were estimated due to the recommendations illustrated in literature (Potts & Zdravkovič, 2001). Finally, the dimensions of the numerical model were 60 x 32.6 m.

The mesh generation by PLAXIS was fully automatic and it took full account of the points and lines in the geometry model, so that the exact position of layers, loads and structures was accounted for in the finite element mesh. The generation process is based on a robust triangulation principal that searches for optimal triangles. The finite element mesh used in the analyses contained 2506 elements, 5099 nodes and 7518 stress points. Boundary conditions prescribed in the model are based on standard fixities.

In real case the construction process consists of many layers. Therefore simplifications had to be made in analyses and much fewer layers used. Two numerical models are adopted to approximate the actual construction process as closely as practically feasible. The first of used numerical models represented the construction process without compaction and the second of numerical models simulated the process with compaction procedure. The same input parameters for the numerical models were used within analyses. Difference between these two numerical models was in numbers of the structural construction stages. The analysis process of the numerical model represented compaction proceeds over total more or less twice construction phases compare to numerical model without compaction procedure.

5. Results

In this study the database of field data obtained during the construction of the cut-and-cover construction TOM 2 was used to compare the response of four constitutive models. The four models considered follow completely different approaches.

5.1. Output

Selected results of the constitutive models are examined, in order to achieve a better understanding of the cut-and-cover system behaviour using four different constitutive models:

Mohr-Coulomb model (without compaction process)

Hardening soil model (without compaction process)

Mohr-Coulomb model (with compaction process)

Hardening soil model (with compaction process)

Hardening soil model (with compaction process)The following plots see Fig. 1 – 4 presented relative shear stresses, which give an indication of the proximity of the stress points to the failure envelope

The pattern of relative shear stresses rapidly changed around the construction arch in all cases (Fig. 1 to Fig 4). The proximity of the stress points to the failure envelope near to the tunnel hinges, beneath the construction corners and on the interface between backfill below current landscape and first two layers of the original stratum is clearly visible.

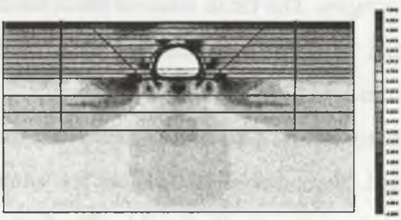

Fig. 1. MC model without compaction
Rys. 1. Model MC bez zagęszczania

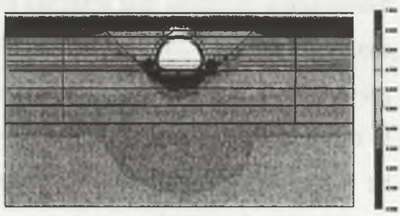

Fig. 2. HS model without compaction
Rys. 2. Model HS bez zagęszczania

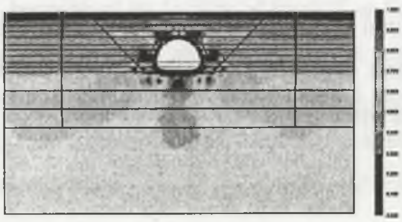

Fig. 3. MC model with compaction
Rys. 3. Model MC z zagęszczeniem

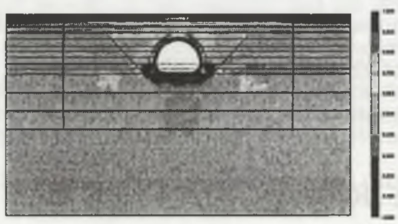

Fig. 4. HS model with compaction
Rys. 4. Model HS z zagęszczeniem

5.2. Comparison of computed results with observation

The finite element model used in the analyses was verified to horizontal and vertical displacements of construction and the development of earth pressures in time on the contact of tunnel lining and backfill at different stages of backfill procedure.

The displacements of the construction were observed by geodetic measurements at three particular points located on tunnel lining. The observation of total horizontal displacements refer only at one point signed as (G3=1).

The magnitude of contact pressure on the outside of lining was carried out by using of liquid-pressure-cells within three chosen points located on the contact of tunnel lining and backfill.

The results obtained by the Hardening – Soil model without compaction were found to give the best agreement with site measurement of deflection. On the other hand, the worst results were obtained using the Hardening – Soil model with compaction. By this analysis large vertical deformations were reached. The results from all finite element analyses were found to give poor correlation with site measurements of the development of earth pressures in time.

6. Parametric studies

The finite element analysis used the HS model without compaction was giving the closest results to the field measurements. That is why the analysis using HS model without compaction was chosen for further investigation. For simplicity the HS model without compaction is called in following text just a HS basic model.

The objectives of the parametric studies were to investigate the influence of individual subsoil layers with different stiffness parameters on displacements of the cut-and-cover construction and also to improve the understanding of the problem by examining the effect of varying individual parameters.

It has to be mentioned that the performance of the HS basic model is quite sensitive to parameter assumptions and therefore the analyses selected for the report have been made varying the stiffness parameters at the individual subsoil layers. The stiffness parameters were each time changed only in one subsoil layer and the stiffness parameters in rest of subsoil layers were kept the same as in case of the HS basic model.

Finally, the results obtained from parametric studies shown that the parameters used within the HS basic analysis were reasonably close to the field observation mainly in case of the total vertical displacements.

7. Conclusions

Within following lines several ideals of improvement of the numerical model are given. The improved model should be modelled by a finite element package able to model various shapes of tunnel lining as well as the compaction process by total multipliers as is for example possible with finite element code PLAXIS version 8. It should also be carried out by means of applications of advanced soil models and be oriented in the specific geotechnical features of the ground, in order to give an improved agreement between reality and numerical modelling. It has to be mentioned that in certain cases the performance of the Hardening-Soil model may be quite sensitive to parameter assumptions and therefore further sensitivity studies are recommended to give more insight in this problem.

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Omówienie

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