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THE CALIBRATION PROGRAM FOR THE HYPOPLASTIC SAND MODEL

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Abstract: *The present paper is concerned with the development of calibration program for the Von Wolffersdorff hypoplastic model, often referred to as the hypoplastic model for sand, and as such to bring this model to the point of practical applications. The proposed methodology combines standard laboratory measurements with their numerical simulations at a material point to address, apart from experimentally derived data, those model parameters which can be inferred from theses laboratory tests only indirectly. As an example, the entire calibration process is presented for a sand sample collected from a construction pit of the Komořany tunnel.*

Keywords: Coarse sand, Hypoplasticity, Model calibration, Von Wolffersdorff model.

1. Introduction

Although the well-known elastoplastic Mohr-Coulomb (MC) model offers a good estimation of failure criterion, it still suffers from several shortcomings. Not only that the strength parameters c and φ and Young's modulus E of this model are valid only for a certain range of stress, but the response below the yield stress is linear elastic both in loading and unloading. To overcome these shortcomings the MC model can be enhanced to include the dependence of strength parameters on the deviatoric plastic strain and thus to simulate hardening and softening or to include the evolution of Young's modulus with depth.

Another option is to adopt advanced soil models such as the elastoplastic CamClay model or a relatively new theory of hypoplasticity. Even in their basic form, the hypoplastic soil models well simulate the fundamental characteristics of soils such as the stiffness dependency on soil density and the nonlinear response in both the primary loading and unloading. When enhanced with the concept of so called small strain stiffness they allow for reflecting a relatively high stiffness at very small strains. Although these models have proved useful in many practical applications, see e.g. (Mašín, 2009), (Kadlíček, et al., 2016) and their reliability has been repeatedly verified, they are still mostly employed for the academic purposes only. This is perhaps attributed not as much as to the lack of theoretical knowledge but more to the exhausting process of their calibration.

Thus, to stimulate interest of practical engineers in advanced constitutive models, we have been recently focusing our attention on developing a suitable methodology and tools for their calibration. As for the calibration procedure of the Mašín hypoplastic model for clays (Mašín, 2013) we refer the interested reader to (Kadlíček, et al., 2015). In the present contribution, we concentrate instead on the essential steps associated with the calibration of the Von Wolffersdorff hypoplastic model, which is also referred as the hypoplastic model for sand (HS), (Wolffersdorff, 1996).

2. Hypoplastic model for sand

The advanced soil models define in the void ration and stress $e \times q \times p$ space the so called State Boundary Surface (SBS), see Fig. 1. This surface surrounds all admissible states. A significant advantage

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of the HS model can be found in the fact that its parameters can be determined on the basis of standard laboratory tests, i.e. the oedometric and triaxial tests.

The HS model is defined by eight parameters, namely φ_c, h_s, n, e_{d0}, e_{c0}, e_{i0}, α and β (Herle, et al., 1999). These parameters can be divided into two groups according to the procedure needed for their determination. The first group consists of parameters that can be determined directly from the available experimental measurements. The second group represent parameters that have to be determined by means of a parametric study, thus by matching numerical simulations with experiments. Individual parameters are described in the following sections.

Initial void ratios e_{d0}, e_{c0} and e_{i0}

These parameters control the positions of the limiting void ratio curves as seen in Fig. 2. The void ratio e_{d0} represents the void ratio in the densest possible state, e_{c0} represents the void ratio of the soil at the critical state and e_{i0} is introduced as a theoretical value of the initial void ratio for the state that occurs in the loosest possible state. This value can be represented by the spheres formed in a rectangular grid. The value of e_{c0} can be determined directly from the oedometric. The triaxial test is also an option. The recommended mutual relations between all three parameters is given by Eqs. (1) and (2). (Herle, et al., 1999)

$$e_{d0} = 0.5\, e_{c0} \tag{1}$$

$$e_{i0} = 1.2\, e_{c0} \tag{2}$$

The critical friction angle φ_c

The critical friction angle φ_c represents the value of a friction angle at the moment when the soil specimen exposed to the shearing maintains a constant rate of volumetric deformation. This parameter can be evaluated based on the triaxial tests. However, in case of coarse grained soils it is advantageous to associate the value of with the so-called angle of repose. It has been shown that the angle of repose and the critical state friction angle are nearly identical. (Herle, et al., 1999)

Parameters h_s and n

These parameters control the slope (h_s) and curvature (n) of the normal compression line (NCL) in the $ln\,p \times e$ plane. Fig. 3 compares the simulations of the oedometric tests provided by the calibrated hypolastic model (full line) with experimental measurements (dotted line). For the sake of clarity the simulations associated with a higher value of the parameter n (dashed) and a higher value of the parameter h_s (dash-dotted) in comparison to their optimal (calibrated) values are also presented. The evaluation of these parameters can be performed based on the results of the isotropic compression test. However, the oedometric test is recommended as it is easier to execute, but more importantly it allows for achieving higher pressures. (Herle, et al., 1999)

Parameters α and β

Calibration of these parameters requires conducting a triaxial test as they influence the peak friction angle. The parameter α influences the dependency of the model on the soil density and consequently the overconsolidation ration and the value of the peak friction angle. Parameter β influences the overall stiffness depending on the density and the relative position of the overconsolidation peak in the $\varepsilon \times q$ plane. The influence of these parameters is evident from Fig. 4 showing a nearly perfect match between simulation (bold solid line) and the triaxial test (narrow solid line). The two other lines shows HS model performance when setting the parameters α and β to differ from the original calibrated values. (Herle, et al., 1999)

Further details can also be found in (Kadlíček, et al., 2015)

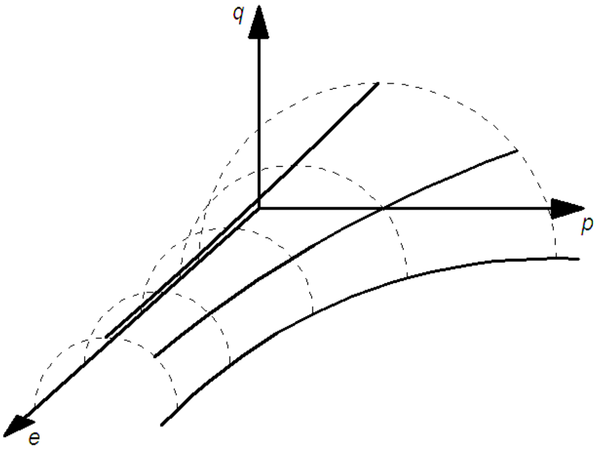

Fig. 1: State boundary surface.

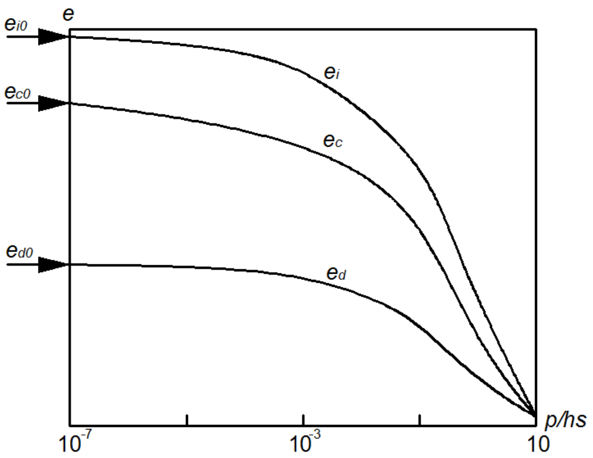

Fig. 2: The limiting void ratio curves in $\ln p \times e$ *plane.*

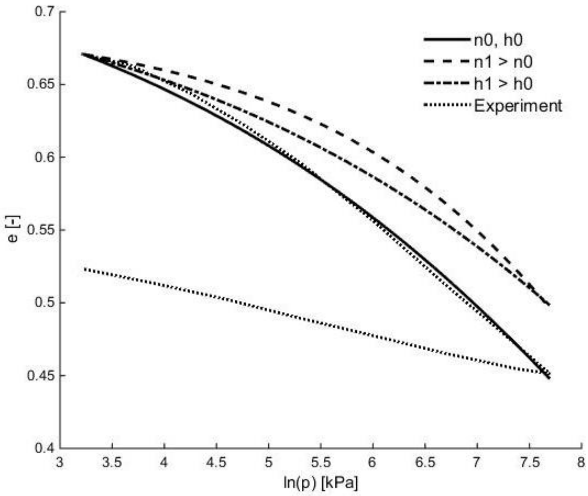

Fig. 3: Oedometric test in $\ln p \times e$ *plane.*

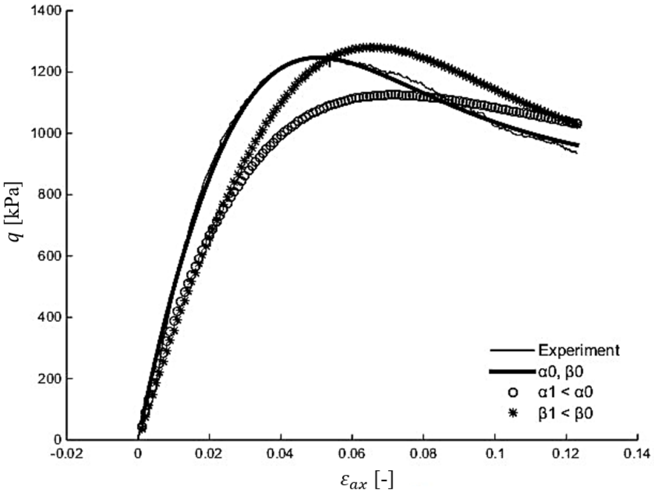

Fig. 4: Triaxial test in $\varepsilon_{ax} \times q$.

3. Calibration software

The calibration softwares have already been developed for two advanced soil models for fine grained soils, namely the elastoplastic CamClay model and the Masin hypoplastic model. This third calibration program thus completes the set of the calibration programs for advanced soil models.

To run program successfully, the laboratory test data has to be ordered in a predefined form consisting of oedometric and triaxial tests. While parameters h_s, n, e_{d0}, e_{c0} and e_{i0} are calibrated for every oedmetric test included in the input file, parameters φ_c, α and β are determined for the whole set of triaxial tests. Once the calibration is finished, results of the calibration are saved to the well-arranged MS Excel file. This file includes comparison of the conducted laboratory tests with the HS model and a table of values of all parameters. The comparison charts are shown in Figs. 5 and 6, which represent a drained triaxial test and an oedometric test, respectively. Tab. 1 stores the values of calibrated parameters. The laboratory tests used for the calibration were performed on the sand specimen which was acquired from a construction pit of the Komořany tunnel. (Tichovká, 2012) An example of the input file with further instructions on how to successfully run the beta version of the calibration program is available on https://mech.fsv.cvut.cz/TA04031603.

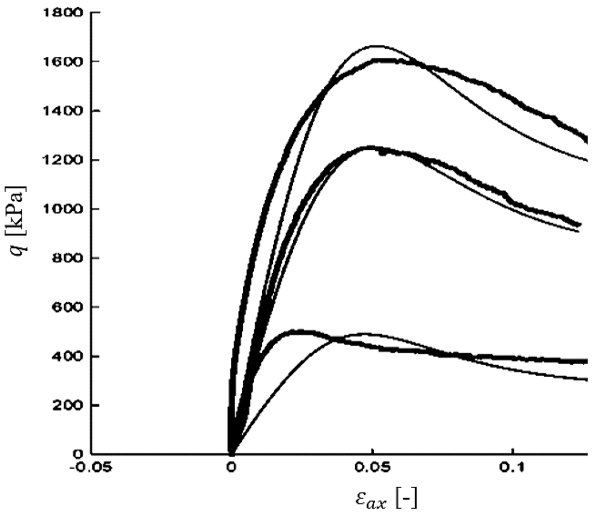

Fig. 5: Triaxial test with HS model.

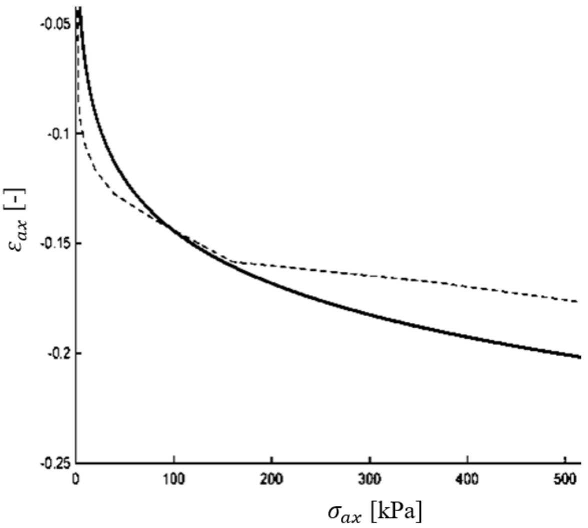

Fig. 6: Oedometric test with HS model.

Tab. 1: The calibrated parameters of the HS model for the Komořany specimen.

Parameters	n	h_s	e_{c0}	e_{i0}	e_{d0}	φ_c	α	β
Values	0.112	15092	0.919	1.102	0.459	35.1	1.022	1.571

4. Conclusion

This calibration software enables a prompt evaluation of the HS model's parameters and together with calibration programs for the CamClay model and the hypoplastic model for clay represents an effective tool when employing the advanced soil models for large scale engineering analyses. Apart from the calibration programs our effort is also directed to the search for suitable cporrelations between the advanced soil model parameters and standard index characteristics of soils. This should allow us to create calibration tables that would provide estimates of parameters of the selected model based on standard soil classification. This should make the advanced soil models even more accessible to practical engineers. Some preliminary results on this study can be found in (Kadlíček, et al., 2016).

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