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CALIBRATION PROGRAM FOR FINE GRAINED SOILS

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Abstract: *This paper is concern with an ongoing effort to introduce hypoplastic models into the engineering community. Attention is limited to the hypoplastic model for fine grain soils. Carefully selected samples of soils collected from various regions of the Czech Republic are examined to test the quality of the recently developed calibration software. The behavior of these soils is then compared by solving a simple example of a uniformly loaded strip footing. The results provided by the Mohr-Coulomb model are also exploited to identify some drawbacks of both models.*

Keywords: Hypoplastic model, Mohr-Coulomb model, calibration, fine grain soils

1. Introduction

During the last few decades, some advanced soil models such the Hypoplastic model for clays (HC) have underwent a significant development, see e.g. Mašín (2013). Despite an indisputable precision in the prediction of soil response, these models are still too far from being ordinary used in practice. Such a state is probably caused by theoretical and technical demands associated with tuning the material parameters of the model. We expect that robust calibration software combined with classification of soils represents the way of overcoming such obstacles. Some preliminary results of our current research effort are provided in this contribution.

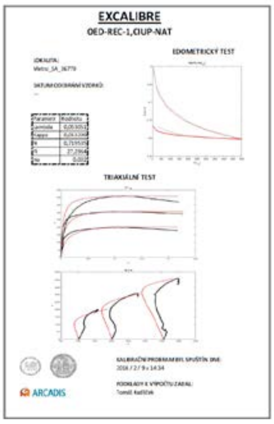

Fig. 1: Calibration report

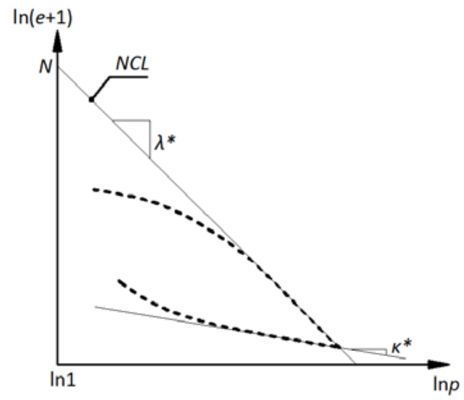

Fig. 2: Parameters of hypoplastic clay model

2. Calibration software

The calibration program is being developed to remove difficulties associated with time consuming calibration of the hypoplastic models and consequently broaden application of these advanced models in the engineering practice. The current version of the program is available free of charge at TAČR (2016) where particular details of model calibration, not listed here due to lack of space, are presented. For

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illustration we show in Fig. 1 a typical output of the program offering the calibrated data of the model together with the comparison of laboratory measurements and numerical simulations of given tests such as the oedometric test shown in Fig. 2. This figure also identifies some of the material data of the basic version of the model. Further details discussing also its extended version accounting for a high stiffness at initial stages of loading are described in Mašín (2005).

3. Soil samples

Six samples of fine grain soils were collected from various regions of the Czech Republic, see Fig. 3, and tested in the Arcadis CZ, a.s. laboratory. Soil classification according to the USCS accompanied by a brief description to identify some of the differences is presented in Tab. 1.

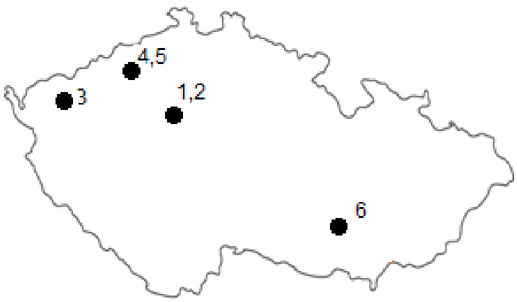


Fig.3: Locations of the tested samples

1,2 - Prague subway V.A,
3 - Odval Hajek – Karlovy Vary region,
4,5 - Bilina – dump slope
6 - Brno region

Tab. 1: Soil samples description

	USCS	DESCRIPTION
1	CL	Low plasticity clay with traces of sand, 65% passing 0.063mm sieve
2	CL	Low plasticity clay with traces of sand, 51% passing 0.063mm sieve
3	CL	Low plasticity clay, at least 55% passing 0.063mm sieve
4	CL	Low plasticity clay, with fraction of coal, 65% passing 0.063mm sieve
5	CH	High plasticity clay, 92% passing 0.063mm sieve
6	CH	High plasticity clay 90% passing 0.063mm sieve

The calibration software requires the knowledge of standard laboratory tests such as oedometric and triaxial tests. The basic parameters of the model seen in the 2nd to 6th column in Tab. 2 are found either directly from the experimental curves or by numerical simulations of these tests. Point out that the first three parameters have a direct link to the oedometric test in Fig. 2. The forth parameter stands for the angle of internal friction at critical volume and the 5th parameter controls the ratio of the shear and volumetric stiffness.

Tab. 2: Soil samples description

Sample number	$\lambda^*[-]$	$\kappa^*[-]$	$N[-]$	$\varphi_{cv}[°]$	$r[-]$	$E_0[\mathrm{MPa}]$	$k_d[\frac{\mathrm{MPa}}{\mathrm{m}}]$
1	0.047	0.010	0.662	27,3	0,235	14,73	0,099
2	0.042	0.007	0.611	32.4	0,304	14,40	0,120
3	0.039	0.006	0.677	32.6	0,385	4,41	0,172
4	0.023	0.006	0.497	25,9	0,627	5,18	0,307
5	0.051	0.011	0.891	24,2	0,731	2,84	0,138
6	0.103	0.018	1.327	25,6	0,521	10,08	0,053

In Tab. 3 we also present the parameters of the Mohr-Coulomb (MC) model for the first two soil samples as these were used in a comparative study in the next section. For details regarding the derivation of the shear strength parameters we refer the interested reader to Kadlíček et al. (2015).

Tab. 3: Soil samples description

Sample number	$E_0[\mathrm{MPa}]$	$k_d\left[\frac{\mathrm{MPa}}{\mathrm{m}}\right]$	$\upsilon[-]$	$c_{ef}[\mathrm{kPa}]$	$\varphi_{ef}[°]$
1	14,729	0,099	0,400	25	23,5
2	14,397	0,120	0,400	20	30

The last two parameters in Tab. 2, also listed in Tab. 3, deserve some special attention. These parameters are implemented in GEO5 FEM software, Fine-Ltd. (2016), to allow for the evolution of stiffness with depth. This becomes particularly important with application of classical constitutive models such as Mohr-Coulomb to properly reduce the dependency of the displacement profile on the size and boundary conditions of the computational model in finite element (FEM) simulations, see Šejnoha et al. (2015). The parameter E0 is the elastic modulus representing the soil stiffness at the terrain surface and the parameter kd shows how this modulus increases with depth h according to equation (1)

$$E(h) = E_0 + k_d h \qquad (1)$$

For this simple linear relationship the parameters E0 and h are typically derived from an oedometric test for the expected range of stresses. Therefore, they can be assumed as material properties independent of the computational model being solved. Nevertheless, the location of the bottom boundary must still be selected with caution.

4. Numerical example

A simple example of a uniformly loaded strip footing is presented to examine the behavior of relatively similar soils. The finite element mesh is plotted in Fig. 4. The computational model is 40 m long and 10 m deep. Only half of the model is analyzed due to symmetry. The strip footing is represented by a beam element with a finite stiffness. All calculations were performed adopting the GEO5 FEM software in the 2D environment assuming the state of plane strain. The results in terms of the maximum vertical displacements caused by a uniform loading of 100 kPa and measured at the center and edge of the footing are stored in Tab. 4. Note that these values are derived for the hypoplastic model assuming the basic formulation that requires only the first 5 parameters in Tab. 2. Qualitatively, these results agree well with a variable composition identified with individual soil samples.

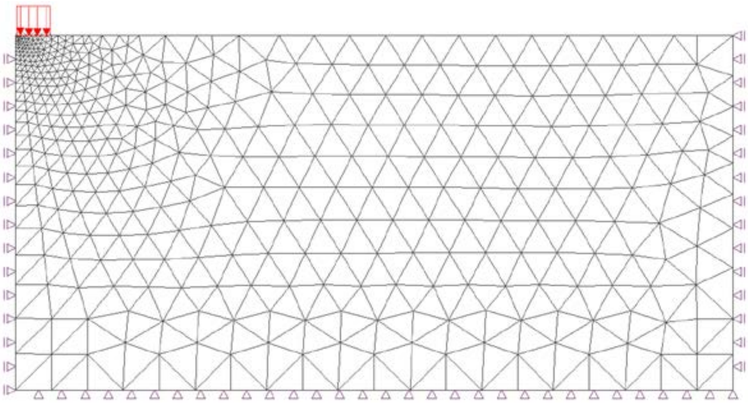


Fig.4: Finite element mesh and loading

Tab. 4: Maximum vertical displacements at edge and center of footing

Sample number	Edge [mm]	Center [mm]
1	40	53
2	44	57
3	33	43
4	28	38
5	66	87
6	83	110

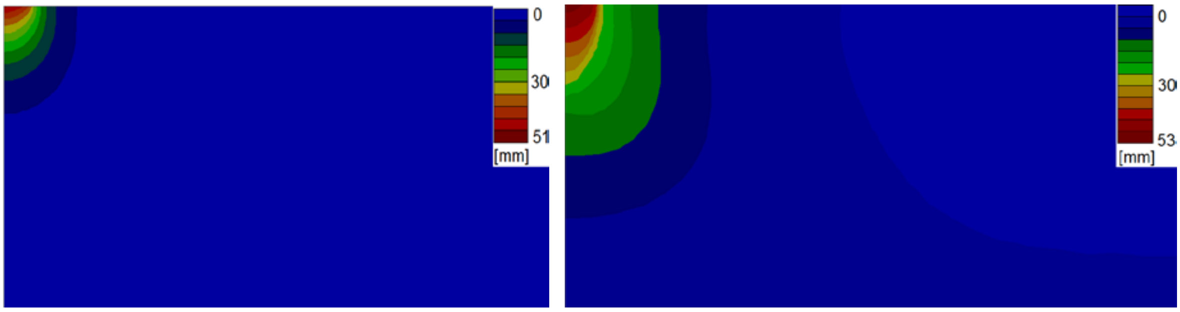
To compare the settlement prediction provided by HC and MC models we run the same analysis with the MC model adopting the variable soil stiffness and the strength parameters in Tab. 3. The resulting displacements are available in Tab. 5 suggesting some possible drawbacks of the HC model when used in its basic version only.

Tab. 5: Comparison of prediction provided by extended version of HC model and MC model

Sample number	HypoClay - SS / Total loading				MC / Total loading			
	100 kPa		200 kPa		100 kPa		200 kPa	
	Edge [mm]	Center [mm]	Edge [mm]	Center [mm]	Edge [mm]	Center [mm]	Edge [mm]	Center [mm]
1	18	28	36	51	16	22	43	53
2	18	28	37	53	17	22	38	48

Clearly, this yields the soil response much too compliant as evident when comparing the MC predictions in Tab. 5 with those listed in Tab. 4. To remedy this, an extended version has been developed that takes into account a relatively large shear stiffness of soil at initial stages of loading – the so called small strain stiffness, see e.g. Niemunis & Herle (1997).

The extended version of the HC models depends on additional 5 parameters. Their determination requires application of non-standard laboratory tests. This, however, goes beyond the present scope and we refer the interested reader to (Mašín (2015); Janda & Šejnoha (2013)). Here we just point out that using this extended version considerably improves the model performance as seen by comparing the settlements in Tab. 5.



a) *b)*

Fig.5: Displacement profile provided by a) extended HC model, b) MC model

At this point, we would like to warn the reader not fall into a false impression that using the classical MC model is sufficient and that there is no need for using more complex advanced models. To that end, we plot the overall displacement soil profile associated with the uniform loading of 200 kPa for both models. It is clearly seen that the MC model even if enhanced with a variable stiffness option, recall Eq. (1), predicts much deeper progress of vertical displacements. In general, this is largely influenced by the location of the bottom boundary of the model.

5. Conclusions

This contribution addresses some of our recent achievements towards development of the calibration software to provide data for some of the advanced constitutive models including the Cam clay and Hypoplastic models for fine and coarse grained soils. This should help to increase the interest in these models among practical engineers which in turn should lead to improved and more reliable design of geotechnical structures. Further support is expected by providing a classification methodology much similar to standard classification of soils.

Acknowledgement

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