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Parameter identification for constitutive models based on pressuremeter test

Identification des paramètres pour les modèles constitutifs basés sur test pressiométrique

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ABSTRACT: The application of numerical methods for performing SLS and ULS design of complex geotechnical structures requires the usage of appropriate advanced constitutive models. Determination of input parameters for these models becomes a key aspect. The logical choice of parameter determination based on laboratory experiments may suffer from effects of sample disturbance and therefore the in-situ behaviour may not be captured with sufficient confidence. Alternatively, in-situ measurements such as CPT or pressuremeter test provide information of the in-situ behaviour but this approach has the disadvantage that parameters cannot be directly identified. Therefore, the in-situ test has to be modelled as a boundary value problem and parameter identification has to be based by applying appropriate parameter identification procedures or by simple curve fitting approaches. In this paper pressuremeter tests are numerical simulated and parameters for the well-known Plaxis Hardening Soil Small model are derived based on these analyses. The authors believe that this is a promising way forward for obtaining realistic input parameters for advanced constitutive models and thus improve the prediction capabilities of numerical methods in geotechnical engineering.

RÉSUMÉ: L'application de méthodes numériques pour la conception SLS et ULS de structures géotechniques complexes nécessite l'utilisation de modèles constitutifs avancés appropriés. La détermination des paramètres d'entrée de ces modèles devient un aspect essentiel. Le choix logique d'une détermination des paramètres basée sur des expériences en laboratoire peut souffrir des effets de la perturbation de l'échantillon et, par conséquent, le comportement in situ peut ne pas être capturé avec suffisamment de confiance. D'autre part, les mesures in situ telles que les essais CPT ou pressiométriques fournissent des informations sur le comportement in situ, mais cette approche présente l'inconvénient de ne pas permettre l'identification directe des paramètres. Par conséquent, l'essai in situ doit être modélisé comme un problème de valeur limite et l'identification des paramètres doit être basée sur l'application de procédures appropriées d'identification des paramètres ou sur des approches simples d'ajustement de courbes. Dans cet article, les essais pressiométriques sont simulés numériquement et les paramètres du célèbre modèle Plaxis Hardening Soil Small sont dérivés sur la base de ces analyses. Les auteurs pensent qu'il s'agit d'une voie prometteuse pour obtenir des paramètres d'entrée réalistes pour les modèles constitutifs avancés et améliorer ainsi les capacités de prédiction des méthodes numériques dans le domaine de l'ingénierie géotechnique.

Keywords: SBPMT; Parameter determination; numerical modelling; nonstitutive model calibration.

1 INTRODUCTION

Over the past years, there has been significant progress in the development of soil constitutive models. Advanced models are able to represent soil behaviour much better than simpler models. However, the more advanced the model, the more parameters are required. The proper determination of these parameters is one of the key factors for carrying out numerical analyses successfully. It is often the case that these parameters are determined based on laboratory tests (e.g., triaxial and oedometer tests), which are not always available on all projects (especially in the early design stages).

Alternatively, constitutive model parameters can be determined from in-situ tests. In-situ testing is faster, cheaper and causes (often) less soil disturbance than laboratory testing. However, it is not possible to determine the parameters directly from field results (measured data). Recommendations on how to interpret results from pressuremeter tests (PMT) are given e.g., in (Mair and Wood 1987; Yu 2010; Clarke 2023).

This paper presents an approach for deriving Plaxis HS Small model (Benz 2007) parameters by modelling the self-boring pressuremeter test (SBPMT) as a boundary value problem and comparing the results of the analysis with field measurements.

2 SELF-BORING PRESSUREMETER TESTS

2.1 Test site

SBP tests were conducted in Vienna, Austria for a construction project. The testing programme included 18 tests performed in three boreholes at depths ranging from 7 to 50 m. This paper focuses on three tests from the same borehole conducted at depths of 15.8, 30.95, and 36.5 m, respectively.

The stratification is deduced from the borehole log and is illustrated in Figure 1. Beneath the ground level lies a layer of backfill with a thickness of 0.6 m. Below the backfill, a 3.7 m layer of gravel is present. Silt was first encountered at a depth of 4.3 m below the surface.

The groundwater level is located at a depth of around 8.3 m below ground level in this borehole. According to the borehole log, the soil tested in all three tests was mainly silt. Within the silt, a small amount of clay was encountered at the depth of the first test (at 15.8 m), while some fine sand was present at the depth of the second test (at 30.95 m) and some dense to fine sand was found at the third test depth (at 36.5 m). The results of those tests are presented in Figure 2.

In addition to the SBP tests, laboratory tests were conducted. Those tests were used to assess the strength parameters and the unit weight of the silt layers.

2.2 Test interpretation

The tests were performed employing a 6-arm probe with an 88 mm diameter. The field measurements were used to determine the total in-situ horizontal stress (σ_{h0}) and yield stress (P_{yield}). Theoretically, the SBP is drilled into the soil with no disturbance. Consequently, the in-situ horizontal stress could be determined directly. Nevertheless, there is always some minor disturbance to the ground around the probe. Therefore, it is essential to assess this disturbance to ensure accurate determination of the total in-situ horizontal stress. There are several methods to interpret the in-situ horizontal stress from SBP results. In this analysis, the lift-off method has been used to assess the total in-situ horizontal stress.

According to Marsland and Randolph (1977), the behaviour of the soil is elastic in the vicinity of in-situ horizontal stress. For undrained conditions the onset of yield is represented by reaching the undrained shear strength (s_u) of the soil in the cavity wall. The yield stress is determined as follows:

$$P_{yield} = \sigma_{h0} + s_u \tag{1}$$

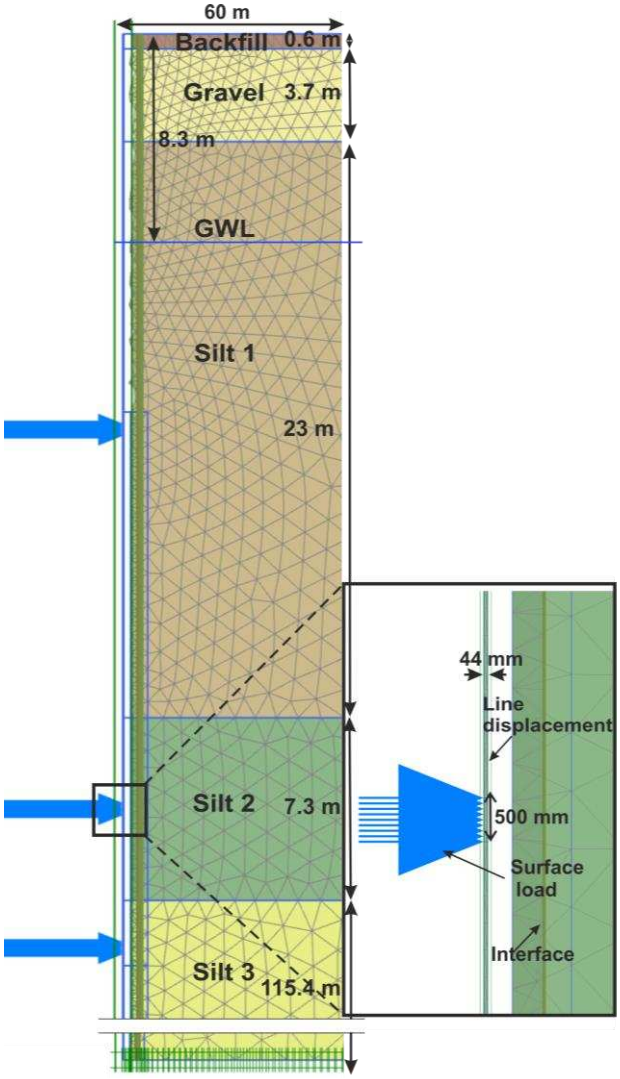

Figure 1. 2D FE model – SBPMT and soil stratification.

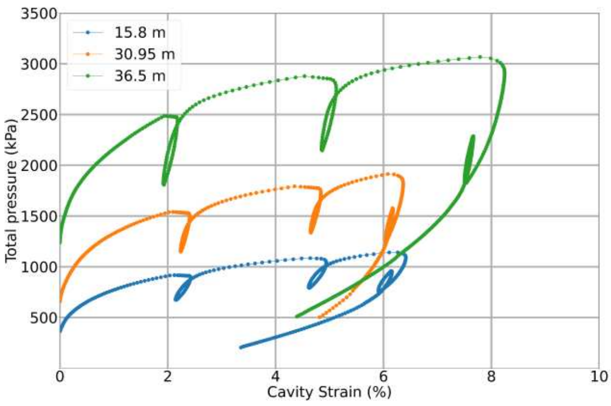

Figure 2. Pressure – strain response for the three selected tests.

The effective in-situ horizontal and yield stress were used to calculate the coefficient of earth pressure at rest (K_0) and the overconsolidation ratio (OCR), as elaborated in the following section.

3 NUMERICAL ANALYSIS

In literature, several attempts have been made to model the SBP tests as a boundary value problem, such as (Tschuchnigg and Schweiger 2016; Gaone at al. 2019). A 2D axisymmetric finite element model was created to model the field SBP tests and the obtained results were compared with field measurements. SBP tests were modelled in Plaxis 2D V21 (Plaxis 2021). The model is presented in Figure 1, it consists of 9630 15-noded elements.

3.1 Finite element model

The model has a width and a depth of 60 m and 150 m, respectively. A parametric study was performed to examine the effect of the boundaries on the simulations. The thickness of each layer is displayed in Figure 1; layer Silt 3 extends all the way to the bottom boundary of the model. The left boundary is positioned at a distance of 0.044 m (equal to the radius of the SBP membrane) from the vertical axis of symmetry. At the left boundary, a line displacement (which is fixed in horizontal direction and free in vertical direction) and an impermeable interface are created.

The total horizontal stresses were determine based on the lift-off method and were obtained from the SBPMT report. Afterwards, the vertical stresses were computed. From the vertical and horizontal effective stresses, K_0 values for the three tests were identified. Furthermore, the “effective” yield stresses were computed using the yield stresses provided in the SBPMT report through Eq. 1 for the three silt layers to calculate OCR. As different values for K_0 and OCR were obtained for the three tests, the silt layer was divided into three layers (Silt 1, Silt 2, and Silt 3). The values of K_0 and OCR for the respective layers are presented in Table 1.

3.2 Constitutive model and soil parameters

The silt layers were simulated using the Hardening Soil Small model (HSS) (Benz 2007). It is an elasto-plastic constitutive model characterized by the ability to account for both deviatoric and volumetric hardening while considering stress-dependent stiffness. The HSS model is an extension to the Hardening Soil model (HS) (Schanz et al. 1999), where it incorporates the high stiffness at very low strains. Compared to the HS model, the HSS model requires two additional parameters to describe the small-strain stiffness. These parameters are the initial shear modulus (G_0) and the shear strain level ($\gamma_{0.7}$), which denotes the amount of shear strains where the secant shear modulus is reduced to 70% of its initial value. The parameters of the HSS model are presented in Table 1.

The strength parameters ($c'$and φ') were determined from consolidated undrained triaxial tests. K_0 and OCR were calculated based on the total horizontal stress and yield stress values obtained from the SBPMT report. The stiffness parameters were calibrated through back analyses of the SBP tests. Additionally, the unit weight (γ_{unsat}) was determined from the laboratory tests.

Table 1. HSS model parameters used for the 3 silt layers.

Parameter	Silt 1	Silt 2	Silt 3
$\gamma_{unsat}(kN/m^3)$	20	20	20
$E_{50}^{ref}(kPa)$	13000	16500	18000
$E_{oed}^{ref}(kPa)$	13000	16500	18000
$E_{ur}^{ref}(kPa)$	39000	49500	54000
$m(-)$	0.8	0.8	0.8
$c'(kPa)$	8	8	8
$\varphi'(°)$	28	28	28
$\gamma_{0.7}(-)$	0.0001	0.0001	0.0001
$G_0^{ref}(kPa)$	60000	70000	120000
$p^{ref}(kPa)$	100	100	100
$K_0(-)$	1.17	1.08	2.12
$OCR(-)$	1.73	1.77	2.76

4 RESULTS

The three tests presented in Section 2 and Figure 2 were modelled and the simulation results were compared with field measurements. As the SBP tests were executed in silty soil, undrained material behaviour was considered.

The simulations were carried out in five calculation steps. Following the initial phase (K_0 procedure), the vertical line displacement (refer to Figure 1) is activated. In the subsequent step, the vertical line displacement corresponding to the membrane’s height (500 mm, refer to Figure 1) is deactivated and a linear load (equivalent to the effective horizontal stress) is applied. Afterwards, the loading phase takes place by applying a uniform load that corresponds to the maximum horizontal pressure obtained from the field results. Finally, the unloading phase commences by applying a uniform load lower than the maximum horizontal pressure.

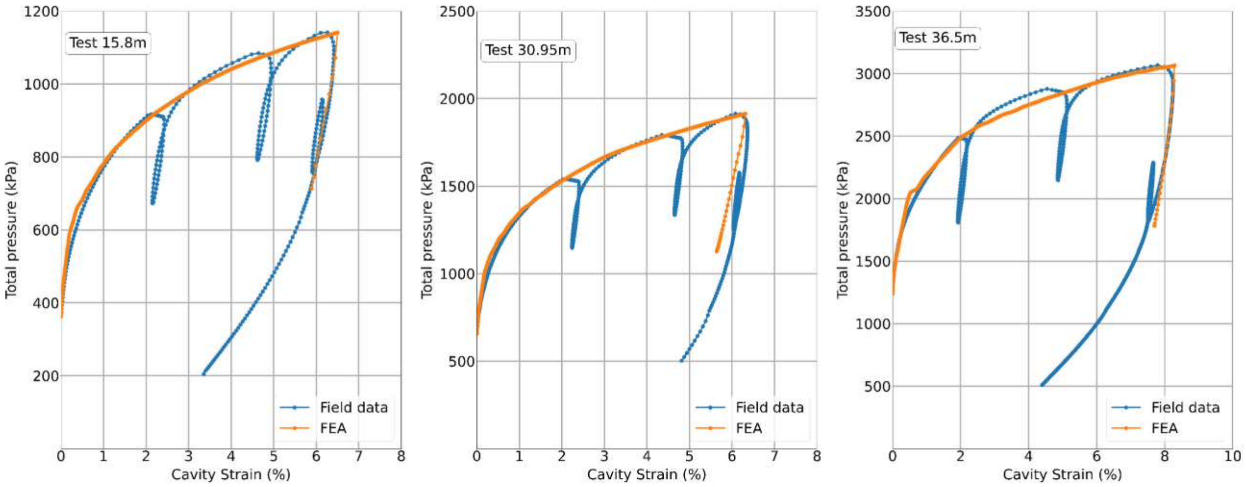

Figure 3. Comparison between field measurements and simulated tests.

The results of the simulations are presented in Figure 3. It can be seen that the HSS model produces a good agreement with the field measurements. It is worth noting that the third test (36.5 m) shows a slightly softer behaviour compared to the field data at cavity strains between 2.8% and 4.8%. Nevertheless, the calibrated stiffness parameters produced very good match with the field data.

5 CONCLUSIONS

There are various benefits to deriving soil parameters from in-situ tests. However, the primary constraint lies in the interpretation of the results as it is not possible to assess the parameters directly. Several attempts have been made to automate the process of parameter determination and to increase the confidence in the parameters derived from in-situ tests, such as (Marzouk et al. 2023a, 2023b).

In the present contribution, an efficient and practical approach to derive constitutive model parameters from SBP tests was illustrated. The numerical results show that it is possible to calibrate constitutive model parameters based on field measurements. The automated optimization of the parameters to accelerate the parameter determination process is part of ongoing research.

REFERENCES

Benz, T. (2007). *Small-strain stiffness of soils and its numerical consequences*. PhD thesis, University of Stuttgart, Germany.

Clarke, B. G. (2023). *Pressuremeters in geotechnical design*, 2nd ed., Boca Raton: CRC Press.

Gaone, F. M., Doherty, J. P. and Gourvenec, S. (2019). An optimization strategy for evaluating modified Cam clay parameters using self-boring pressuremeter test data. *Can. Geotech. J.* 56 (11), pp. 1668–1679. DOI: 10.1139/cgj-2018-0385.

Mair, R. J. and Wood, D. M. (1987). *Pressuremeter Testing. Methods and Interpretation*. Kent: Elsevier Science.

Marsland, A. and Randolph, M.F. (1977). Comparison of the results from pressuremeter tests and large in situ plate tests in London Clay. *Géotechnique*, 27, (2), 217-243. DOI: 10.1680/geot.1977.27.2.217

Marzouk, I., Tschuchnigg, F. and Brinkgreve, R.B.J. (2023a). Expansion of an automated system for determining soil parameters using in-situ tests. *In: Proc 10th European Conference on Numerical Methods in Geotechnical Engineering 2023.*

Marzouk, I., Oberhollenzer, S. and Tschuchnigg, F. (2023b). An automated system for determining soil parameters: Case study. *In: Proc 8th International Symposium on Deformation Characteristics of Geomaterials 2023.*

Plaxis bv. (2021). *PLAXIS 2D Reference Manual*. Bentley Systems, Incorporated, Netherlands.

Schanz T., Vermeer P.A. and Bonnier P.G. (1999). The hardening-soil model: formulation and verification. *In: Beyond 2000 in computational geotechnics,* Rotterdam: Balkema, p. 281-90.

Tschuchnigg F. and Schweiger H.F. (2016). Embankment and footing prediction by means of 2D and 3D finite element analyses. *In: Proc embankment and footing prediction symposium 2016,* p. 366–90.

Yu, H-S (2010). *Cavity Expansion Methods in Geomechanics, 1st ed*. Dordrecht: Springer.

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