https://doi.org/10.1051/e3sconf/20199215004

Preliminary assessment of variability of selected Hardening Soil model parameters for glacial tills and clays from Poland

Witold Bogusz[1,*] and *Marcin* Witowski[1]

[1]Building Research Institute, Warsaw, Poland

Abstract. Typical ranges of variability of basic soil parameters are relatively well known. Such knowledge is important to aid engineers in the selection of characteristic values for design or as a basis for conducting sensitivity analyses for more complex soil-structure interaction problems. However, for application of advanced non-linear constitutive models, which often are defined by model-specific parameters, such variability is rarely known. To improve parameter estimation, as well as to provide a basis for the choice of realistic variability range, a database of high quality laboratory tests can be used. The paper presents the results of preliminary assessment of variability of selected Hardening Soils model parameters for overconsolidated glacial tills and clays from Poland, based on a local database of triaxial test results.

1 Introduction

Advance numerical methods like finite element method (FEM) are now routinely used not only by research community but also in design practice. The complexity of many geotechnical problems (e.g. deep excavations) requires consideration of non-linear soil behaviour with the use of constitutive models which can account for stress- and strain-dependence of the soil. Although their availability in commercially available FEM codes as well as their understanding among designers increased, a proper choice of parameters is still challenging.

One of the main factors affecting the spread of innovations is the relative advantage they can offer in reference to their ease-of-use and the cost of implementation. In the case of advanced constitutive models, this relates to the number and the type of input parameters. The advantage of non-linear models lies predominantly in the increased accuracy of prediction and a wider range of application. However, some of the parameters used in non-linear constitutive models may not be easily derived from results of standard geotechnical investigation or even they may lack a clear physical meaning.

In recent years, the use of Hardening Soil (HS) model, with its extension to account for small strain stiffness [1], has become a popular choice among practicing designers. Some of the reasons behind its implementation success are the intuitive understanding of its fundamental parameters as well as the guidance on obtaining them, which is offered in literature and by the software developers [2]. Although the HS model parameters generally can be derived from a standard geotechnical investigation report, either directly or indirectly, the range of variability of these parameters is still not well known. Such knowledge could be used for further improvement of parameter selection, and it could give a more rational basis for conducting sensitivity analyses by designers.

This paper aims to preliminarily evaluate the variability for selected HS model parameters based on the database of triaxial test results for glacial tills and clays from Poland. Although these soils have been investigated extensively in the past [3-4], their characterization towards application of advanced constitutive models is still insufficient.

2 Hardening Soil model parameters

The HS model, with small strain stiffness extension, accounts for non-linear behaviour of the soil in regard to stress- and strain-dependence. Generally, input parameters for this model should be derived primarily from drained triaxial test results. However, some of its parameters can be also derived from undrained tests as well as estimated from in-situ test results by using empirical correlations.

Based on the triaxial test results, following parameters can be obtained [2]:

- From stress paths in p'-q plane:
  - Effective strength parameters: φ', c'
- Relationships $\varepsilon_1 - q$:
  - secant modulus: E_{50}
  - unloading-reloading modulus: E_{ur}
  - stiffness stress dependency parameter: m
  - failure ratio: R_f
- Relationships $\varepsilon_1 - \varepsilon_v$
  - dilatancy angle: ψ'
  - maximum void ratio: e_{max}

Furthermore, from results of Bender Element Test (BET), an initial (small-strain) modulus of deformation E_0 or an initial shear modulus G_0 can be estimated. The

* Corresponding author: w.bogusz@itb.pl

representation of the three moduli are presented in Figure 1. Based on a triaxial test results from a good quality sample, a relatively accurate representation of non-linear behaviour and strain-dependent stiffness degradation characteristic of the soil can be then modelled.

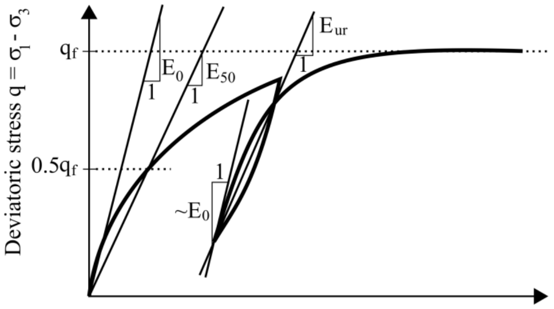

Fig. 1. Non-linear stress-strain relationship in Hardening Soil model with definition of input moduli [2].

The second most important aspect of soil nonlinearity, namely, stress dependence, can be evaluated based on series of triaxial tests. The stress-dependence relationship in HS model is described by a parameter *m*, which is a power-law exponent. The deformation modulus used in the calculations is related to the reference input value by a following function (1):

$$E_{50} = E_{50}^{ref} \left(\frac{\sigma_3 + c \cdot cot\varphi}{\sigma_{ref} + c \cdot cot\varphi}\right)^m \quad (1)$$

Similar relationship exists for other stiffness parameters, E_0 and E_{ur}. In HS model, a single value of parameter *m* is used, while in reality, it is not exactly the same for all three of abovementioned moduli.

In the paper, parameter *m* has been assessed, following the identification algorithm described in [2], using a linear regression of the function in Figure 2.

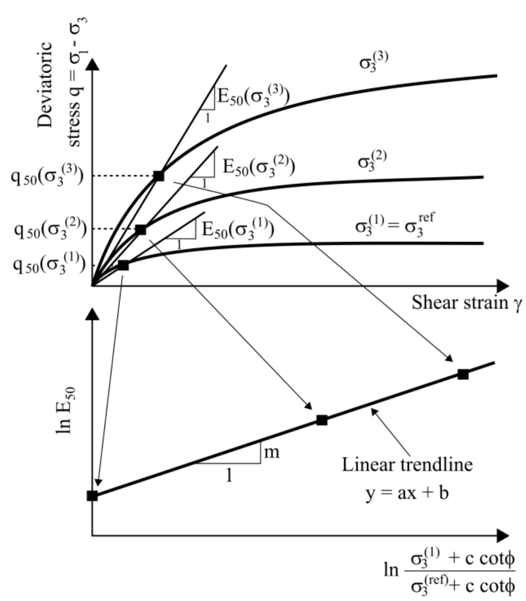

Fig. 2. Determination of the stiffness stress dependency parameter from triaxial tests, based on [2].

The graph presents, in a log-log scale, the relationship between secant stiffness moduli (2) and the ratio (3) of corresponding confining stress in relation to its assumed reference value.

$$y = lnE_{50} \quad (2)$$

$$x = ln\left(\frac{\sigma + c \cdot cot\varphi}{\sigma_{ref} + c \cdot cot\varphi}\right) \quad (3)$$

The value of the power exponent *m* is based on the inclination parameter of the resulting linear approximation.

3 The database

The results presented in this paper are based on the database compiled from 114 triaxial test results obtained for glacial tills and clays from Poland [5].

Analysis was based on 27 triaxial tests (9 series) conducted in drained conditions (CICD) and 60 tests (20 series) in undrained conditions (CICU) for glacial tills, as well as 6 CICD tests (2 series) and 21 tests (7 series) for clays.

4 Results

Due to the preliminary character of the analysis, only results for some of the HS model parameters are considered in this paper. In this section, results concerning shear strength parameters, deformation moduli, as well as stiffness exponents are presented.

Figure 3 presents the relation between obtained effective angle of internal friction and effective cohesion for each sample, for both glacial tills and clays. Due to small number of samples, results for clays exhibit a significant scatter without any clear correlation or clustering. In the case of glacial tills, the values of angle of internal friction present relatively small scatter while effective cohesion shows significant variability.

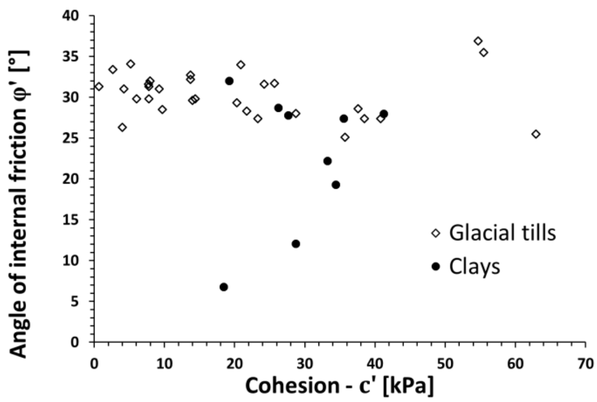

Fig. 3. Relationship between angle of internal friction and cohesion.

The relationship between secant stiffness moduli E_{50} and corresponding mean effective stresses is presented in Figure 4 for both tested soil types. Figure 5 presents the results obtained for glacial tills only, but with the distinction between drained and undrained test conditions. Although, theoretically, the secant modulus used in HS model should be obtained from drained triaxial tests only, obtained values which were based on undrained test results show similar distribution. In both cases, significant scatter of results can be observed.

Following figures present the results of stiffness exponent derivation. In Figure 6, parameter m is derived from the secant stiffness moduli E_{50} for clays ($m_{50} = 1.078$) and glacial tills ($m_{50} = 0.714$)). The latter soil type is further analysed in Figure 7, with distinction between drained ($m_{50} = 0.535$) and undrained ($m_{50} = 0.762$) testing conditions.

As some tests on glacial tills were also conducted in order to investigate unloading - reloading deformation characteristic of the soil, Figure 8 presents the results of the analysed stiffness exponent derived based on unloading-reloading moduli E_{ur} (m_{ur} = 1,235).

Finally, Figure 9 shows the results of stiffness exponent m_0 determination based on initial shear moduli G_0 for both glacial tills ($m_0 = 0.670$) and clays ($m_0 = 0.495$). These values are independent from assumed drainage conditions as they were obtained from BET.

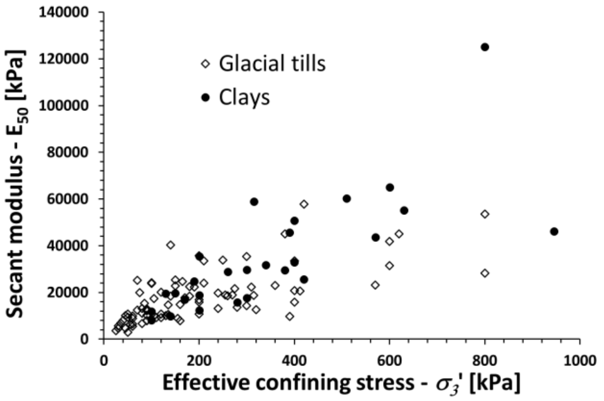

Fig. 4. Comparison of relationship between secant modulus E_{50} and effective confining stress for glacial tills and clays.

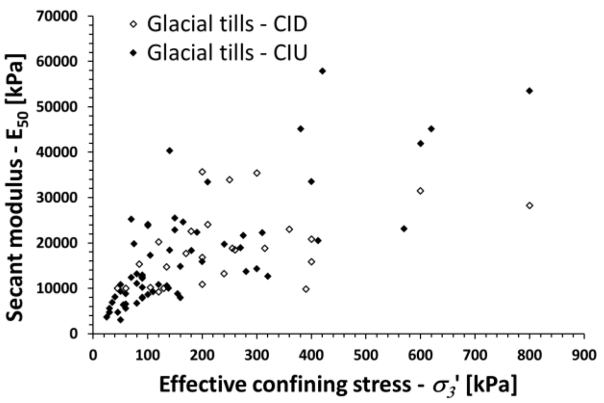

Fig. 5. Comparison of relationship between secant modulus E_{50} and mean effective confining stress from drained and undrained tests for glacial tills.

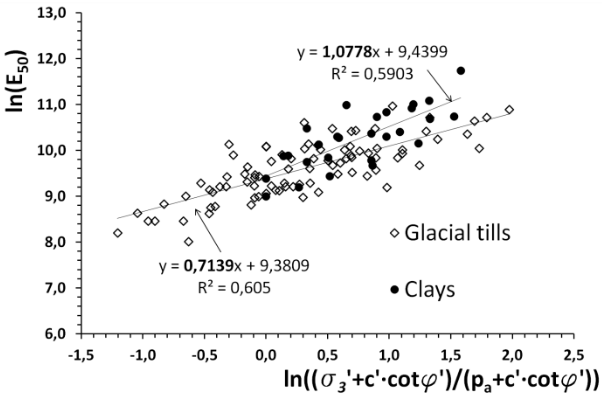

Fig. 6. Determination of stiffness exponent m based on E_{50} for glacial tills and clays.

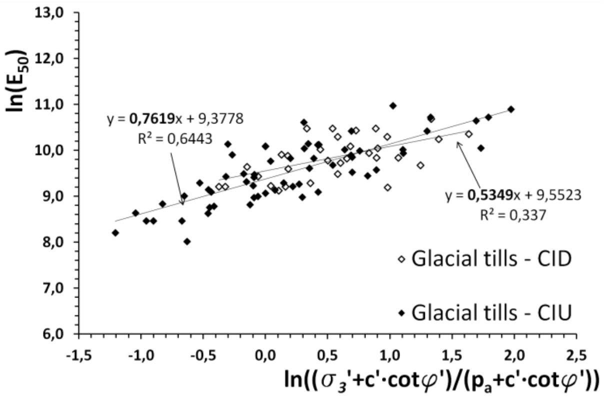

Fig. 7. Determination of stiffness exponent m based on E_{50} from drained and undrained tests for glacial tills.

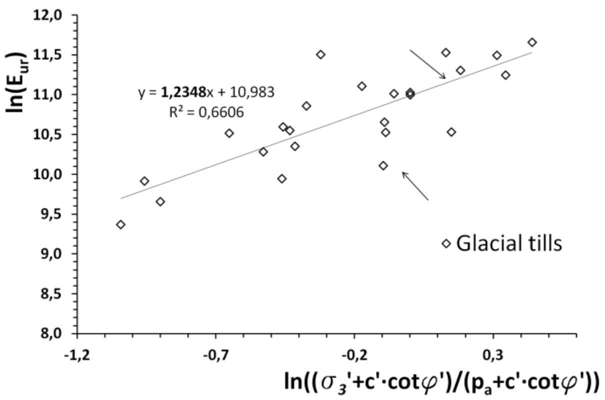

Fig. 8. Determination of stiffness exponent m based on E_{ur} for glacial tills.

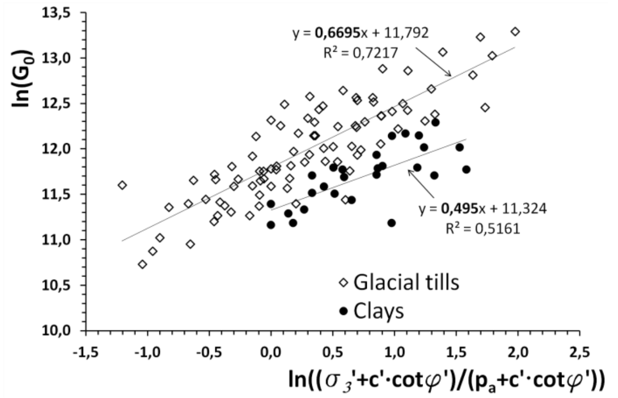

Fig. 9. Determination of stiffness exponent *m* based on G_0 for glacial tills and clays.

Table 1 presents the summary and comparison of the obtained stiffness exponent *m* values. Although definite conclusions cannot be made with certainty at this point, due to limited number of tests, a preliminary assessment is presented.

The value of m_0 for glacial tills can be considered as the most reliable due to relatively large number of samples considered as well as testing conditions (BET). For clays, probably a larger number of tests is still necessary to obtain more reliable assessment.

Furthermore, based on the data from unloading-reloading of the glacial tills, although the stress-dependence is easily observed, the scatter of results with relatively small number of data points limits the reliability of obtained result. Especially, in view of the fact that the *m* value exceeded 1.00, which is an upper boundary reported in literature [2], and usually obtained in the case of normally consolidated soft soils.

Finally, similar results as in the case of m_{ur} for glacial tills were obtained for m_{50} in the case of clays. For glacial tills, significant difference can be observed between results obtained from drained and undrained tests.

Table 1. Summary of obtained stiffness exponent *m* values.

Soil type	**Glacial tills**		**Clays**
Test type	CICD	CICU	CICU
m_{50}	0.714		1.078
	0.535	0.762	
m_{ur}	1.235		-
m_0	0.670		0.495

5 Conclusions

As reliability of prediction increases with the use of more advanced models, which often require a larger number of input parameters, it reduces as the uncertainty in parameter estimation increases. Availability of databases and characterization of variability can aid in the process of parameter selection.

The paper presents the results of preliminary analysis of parameters used as input in Hardening Soil model with small strain stiffness extension, which have been derived from the database of triaxial test results conducted for glacial tills and clays from Poland.

With a sufficient number of data points, the possibility of obtaining reliable prediction of the range of variability for analysed parameters exists. However, although some trends in the analysed parameters can be observed, quantitative assessment still cannot be reliably conducted at this time.

Future analysis, based on an increased number of results, will re-evaluate the obtained results as well as look into possible clustering due to other factors than the general soil type alone, e.g. specific location in reference to geological history.

References

1. T. Benz *Small-strain stiffness of soils and its numerical consequences* (Phd thesis, Universitat Stuttgart, 2007)
2. R.F. Obrzud, A. Truty, *The Hardening Soil model – a practical guidebook ZSoil.PC 100701 report*, Zace Services, Switzerland (2018)
3. C.R.I. Clayton, Geotechnique, **61**, 1 (2011)
4. A. Gasparre, S. Nishimura, N. Minh, M. Coop, R. Jardine, Geotechnique **57**, 33–47 (2007)
5. W. Bogusz, M. Witowski., Proc. XVI Danube – European Conf. on Geotech. Eng., 585-590 (2018)