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Small-strain stiffness of fine-grained soils from Poland based on a laboratory test database

Rigidité à la petite contrainte des sols à grain fin de Pologne basée sur une base de données de tests en laboratoire

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ABSTRACT: A proper characterization of behavior of fine-grained soils has significant practical implications for a number of geotechnical design problems. While laboratory tests are often preferred for the assessment of geotechnical parameters in controlled conditions, their statistically representative quantity is seldom available as they are relatively expensive and time-consuming. Therefore, the use of a database, as a complementary source of information, may be an interesting alternative for implementation in engineering practice. Although it cannot be treated as a substitute for the site-specific tests, it can significantly increase the reliability of parameter estimation and offer an additional guidance in selection of their characteristic values. The paper presents the summary of the database, currently composed of the results from 322 triaxial tests conducted at confining pressures ranging from 15 kPa to 2000 kPa, for overconsolidated clays and glacial tills from Poland. The impact of the soil type on the obtained results is the main focus of this paper; furthermore, the distributions of selected basic parameters are presented as well as their relation to shear stiffness at small strains.

RÉSUMÉ: Une caractérisation appropriée du comportement des sols cohérents a une influence significative pour un certain nombre de problèmes de dimensionnement d'ouvrages géotechnique. Bien que les tests en laboratoire soient souvent préférés pour l'évaluation des paramètres géotechniques dans des conditions contrôlées, leur faible quantité ne permet pas une représentative statistique, car ils sont relativement coûteux et prennent beaucoup de temps. Par conséquent, l'utilisation d'une base de données, en tant que source d'informations complémentaire, peut constituer une alternative intéressante pour la mise en œuvre dans la pratique de l'ingénierie. Bien qu'il ne puisse pas être traité comme une alternative aux tests spécifiques à un site, il peut considérablement augmenter la fiabilité de l'estimation des paramètres et offrir une aide supplémentaire dans la sélection de leurs valeurs caractéristiques. Cet article présente le résumé de la base de données, actuellement composée des résultats de 322 essais triaxiaux conduits à des pressions de confinement allant de 15 kPa à 2000 kPa, pour des argiles sur-consolidées et des moraines argileuses en Pologne. L'impact du type de sol sur les résultats obtenus est l'objet principal de cet article. De plus, les distributions des paramètres de base sélectionnés sont présentées ainsi que leur relation avec la résistance au cisaillement pour de petites déformations.

Keywords: glacial tills; clays; small-strain stiffness; database.

1 INTRODUCTION

A triaxial apparatus is used as one of the preferred laboratory methods for obtaining soil strength and stiffness parameters of the soil. However, as such tests are relatively expensive and time-consuming, especially tests conducted for fine grained soils in drained conditions, the scope of testing program is often limited in the case of standard geotechnical investigation. As a consequence, a statistically representative number of tests may not be available to offer sufficiently reliable prediction of soil parameters without a reference to prior knowledge and comparable experience. In geotechnical practice, this is often done implicitly; however, a use of a database of previous test results can allow explicit comparison, and it is justified when parameter variability assessment is needed. Therefore, in limit state design framework, it can help in the selection of characteristic values based on derived ones (Orr 2017). Whereas, establishing databases for different types of parameters and various geographical locations can be used for benefit of probabilistic analysis in reliability based design (RBD) framework (Lacasse and Nadim 1998; ISSMGE 2017).

In the case of overconsolidated fine grained soils, a number of studies have been conducted to characterize various aspects of their behavior and variability; majority of them focused on the area of the United Kingdom (Atkinson 2007; Clarke et al. 2008; Gasparre et al. 2007; Chandler 2010; Simpson 2010; Clayton 2011; Vardanega and Bolton 2011; Pineda et al. 2016; Brosse et al. 2017, Ku et al. 2017). In Poland, these soils have been investigated to some extent, mostly based on a limited number of data points or based on various in situ tests, however (Lipiński and Tymiński 2011; Godlewski and Szczepański 2012; Godlewski and Wszędyrówny-Nast 2016; Młynarek et al. 2018). Majority of these studies aimed to establish new or validate existing transformation models used for parameter estimation.

The paper focuses on the presentation of the overview of the database of triaxial test results conducted for soil samples taken in various regions of Poland. Two main soil types were investigated, namely: clays and glacial tills. Due to limitations of the paper, the presentation and the analysis of the results contained in the database has been limited mainly to small-strain stiffness; other parameters and their variability will be investigated and presented in the future.

2 THE DATABASE

The compiled database comprises of triaxial test results conducted for cohesive soils from Poland. Pleistocene glacial tills and Pliocene clays were used; these soils can be encountered in most areas of Poland and they often are the main subject of investigation and laboratory tests conducted during standard geotechnical investigations. The geographical and geomorphological distribution of sampling locations is related to geological history of the investigated strata and the three major glaciation periods that resulted in their significant preconsolidation (Fig. 1).

The thickness of the ice overburden at its maximum is estimated to have reached 800-1000 m, for a duration of approx. 160 000 years during South-Polish glaciation. During subsequent glaciations, ice thickness has reached approx. 700 m and 300 m, respectively.

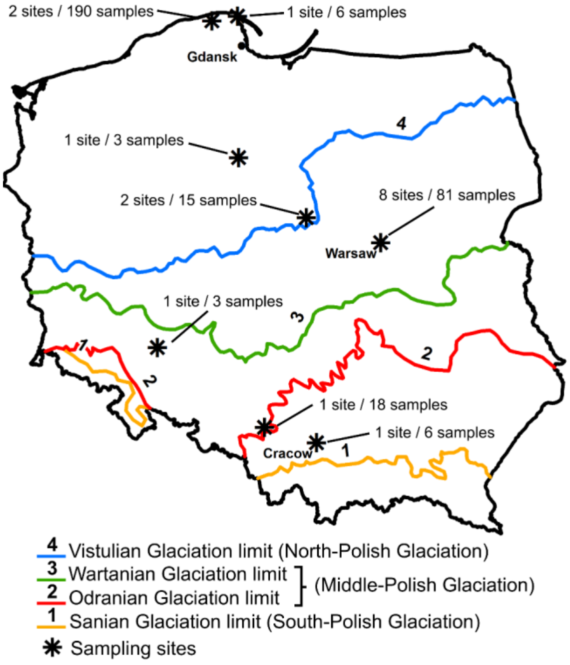


Figure 1. Sampling locations in Poland

This resulted in the overconsolidation ratios (OCR) for Warsaw clays varying from 12 to 50 (Kaczyński 2003); for glacial tills, these values are generally lower.

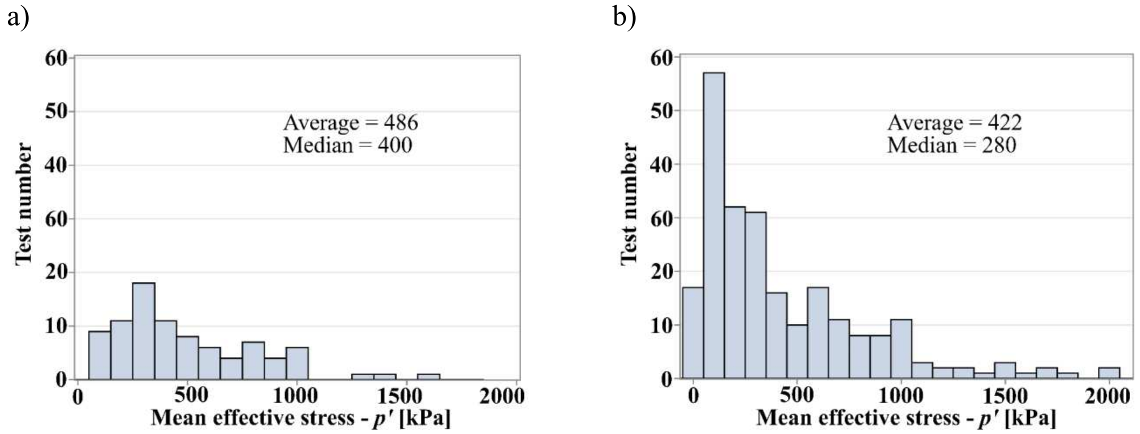
The tests were carried out using two triaxial testing devices. At the time of the paper preparation, the database comprised of 322 test results, 235 for glacial tills and 87 for clays, almost twice the number of tests that were used for the earlier, preliminary study (Bogusz and Witowski 2018). The tests were conducted on undisturbed soil samples, either 70 mm in diameter and the height of 140 mm, or the diameter of 38 mm and the height of 75 mm.

The samples were saturated with an automatic pressure control algorithm, until B coefficient reached a value greater than 0.95. After the saturation phase, the isotropic consolidation stage was carried out, followed by the S-wave transition measurements with bender element tests (BET). In the case of 38 mm diameter samples, both the shear wave and the compressional wave (P-wave) velocities were measured. The measurements of the P-wave velocity were conducted with one pair of piezoelectric elements according to the solution proposed by Lings and Greening (2001).

In the analysis of the signal, a method of visual interpretation of the signal was applied, where the main signal "peak" transition measurement was focused on the major first peak method (Dyvik and Madhus 1985; Lee and Santamarina 2005).

Together with the use of local displacement transducers developed in-house (Witowski 2018), during shearing, detailed results over the entire range of stiffness degradation were obtained for each sample. However, despite the availability of such detailed data, at this stage, basic soil parameters and obtained wave velocities are the primary concern of the current study, in relation to resulting small-strain stiffness characterization. More detailed analysis of other parameters (e.g. shear strength, stiffness at intermediate strains and its degradation) will be a subject of future studies when more data points become available.

The dataset presented in the paper consists primarily of the measured shear wave velocities in relation to the stress-state and the basic parameters of the soil. The properties expected to significantly affect the obtained results are: the effective confining pressure, natural water content (w_n), initial void ratio (e_0), plasticity index (PI) and bulk density. The statistical information concerning selected parameters contained in the database is shown in Fig. 2–5, in relation to the number of test results available at specified intervals.


a)

b)

Figure 2. Statistical information on the distribution of mean effective stress: a) clays; b) glacial tills.

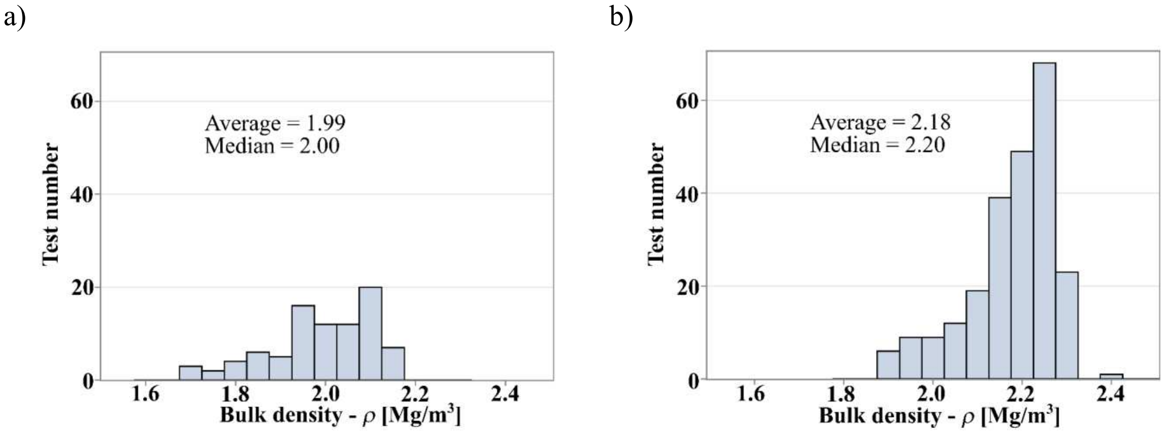


Figure 3. Statistical information on the distribution of bulk density: a) clays; b) glacial tills.

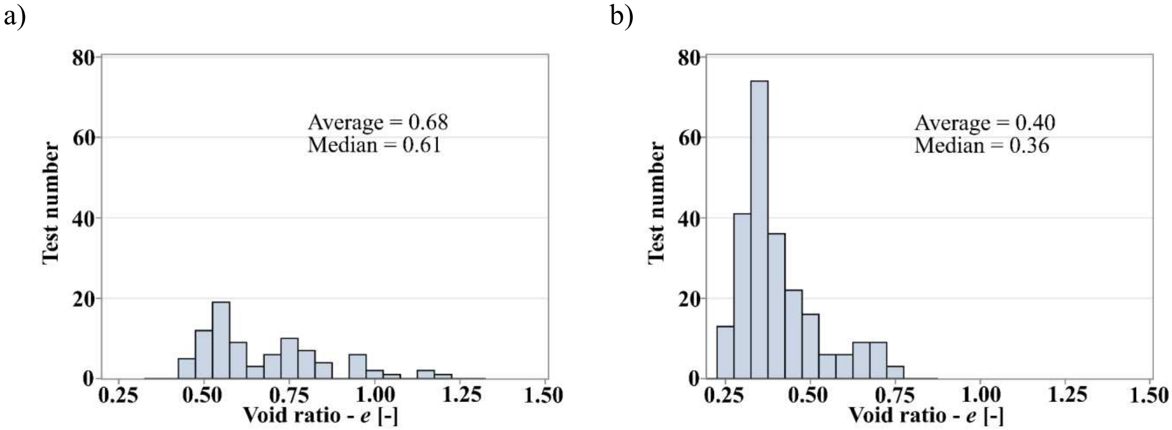


Figure 4. Statistical information on the distribution of void ratio: a) clays; b) glacial tills.

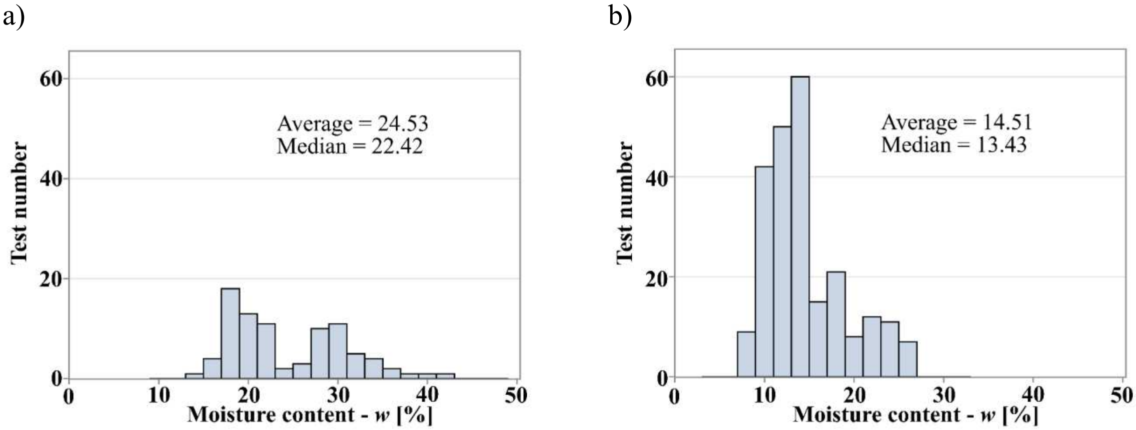


Figure 5. Statistical information on the distribution of natural moisture content: a) clays; b) glacial tills.

The tests were conducted at the confining pressures between 15 kPa and 2000 kPa, with data up to 500 kPa dominating the distribution over the tested range (Fig. 2). The deepest test samples were taken from a depth of approx. 160 m below ground level. In the case of clays, no clear distribution pattern can be observed in regard to presented basic parameters (Fig. 3a-5a). However, noticeable bimodal distribution, especially of moisture content (Fig. 5a), can be attributed to site-specific distributions at sampling locations. On the other hand, for glacial tills, the observed distribution with significant skewness can be observed in the case of all presented parameters: bulk density (Fig. 3b), initial void ratio (Fig. 4b), and natural moisture content (Fig. 5b). A significant variability has been observed for distributions at all sites, as well. This suggests that the resulting regional distributions are not affected by test site locations in a significant way.

3 SUMMARY OF THE RESULTS

The obtained results were summarized in graphs (Fig. 6-13). The relations between measured basic parameters, namely: moisture content, bulk density, and initial void ratio, are presented in Fig. 6-8. As expected, they show satisfactory linear cross-correlations, as well as noticeable clustering distinction between results obtained for clays and glacial tills.

Furthermore, the relationships between initial void ratios and shear wave velocities (Fig. 9) as well as primary wave velocities (Fig. 10) are presented. In the case of glacial tills, noticeable level of clustering can be observed. For clays, the trend is less visible, which may be associated with the smaller number of samples present in the database. Moreover, a distinction between results obtained for these two analyzed types of soil can be seen. The same observation can be made in regard to dynamic (undrained) Poisson's ratio (Fig. 11) derived based on measured wave velocities. For both types of soils, the estimated values of this coefficient range from 0.24 to 0.48. However, these values are generally lower compared to the results obtained by other researchers (Marjanovic 2015); this is probably due to a relatively large spread of P-wave velocity measurements, which is likely to be affected by the pore fluid and the mineralogy, while the S-wave is more dependent on mechanical behavior and grain contacts (Marjanovic 2015).

The relation between shear wave velocity and mean effective stress is presented in Fig. 12, both in linear (Fig. 12a) and logarithmic scale (Fig. 12b). As expected, the increase in V_S velocity is visible along with the increase in effective stresses. Data showing V_S velocities for glacial tills are generally in line with published data for similar soils from Poland as well as other regions (Lipiński and Tymiński 2011; Ku et al. 2016). Furthermore, Fig. 13 presents the relation between initial (small-strain) shear modulus, calculated based on the measured shear wave velocities, and initial void ratio. Results obtained for glacial tills exhibit larger scatter than in the case of clays. Such results are to be expected considering the variability of soils classified as glacial tills.

Finally, Fig. 14 presents the log-log relationship between small-strain shear stiffness and confining pressure normalized by atmospheric pressure p_a (without accounting for cohesion), based on the identification algorithm presented by Obrzud and Truty (2018). Obtained gradients of linear regression lines represent the stiffness exponents at small-strains, which can be used to approximate stiffness-dependence of non-linear constitutive laws, e.g. parameter m for Hardening Soil model (Benz 2007). Values obtained for both, clays ($m = 0.490$) and glacial tills ($m = 0.516$), are in line with values observed for clays of various origins (0.400-0.850), which were summarized by Obrzud and Truty (2018). Obviously, for calculation purposes, such generalized values should be used with caution and only as a first approximation.

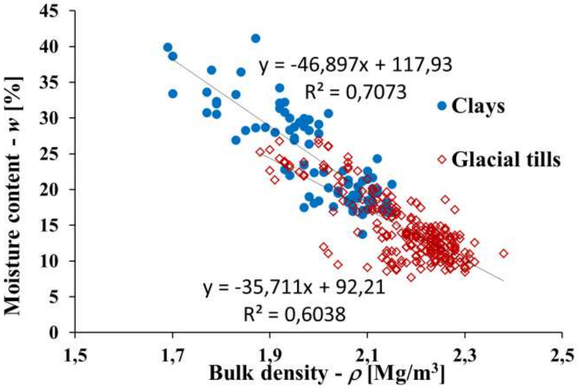


Figure 6. Relation between moisture content and bulk density

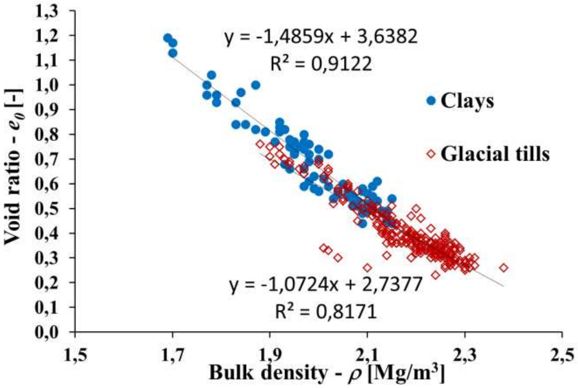


Figure 7. Relation between initial void ratio and bulk density

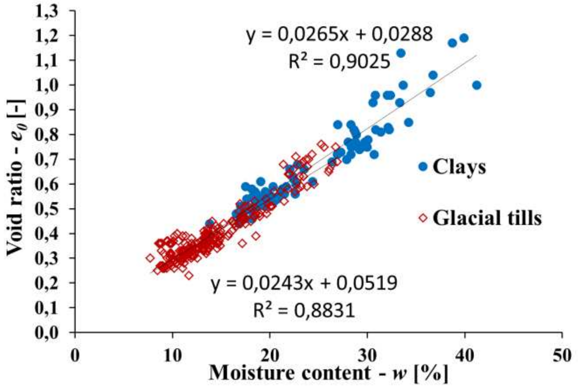


Figure 8. Relation between initial void ratio and moisture content

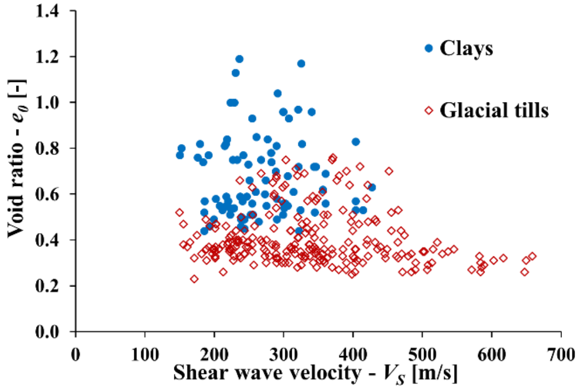


Figure 9. Relation between initial void ratio and shear wave velocity

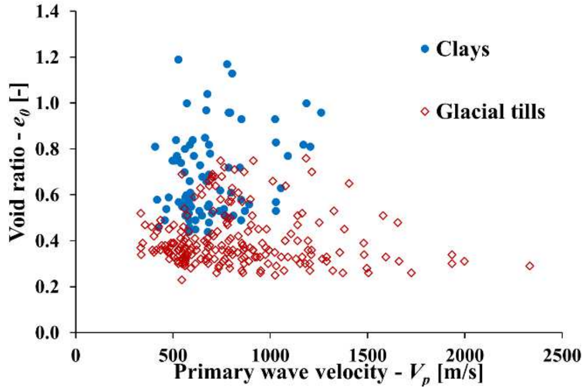


Figure 10. Relation between initial void ratio and primary wave velocity

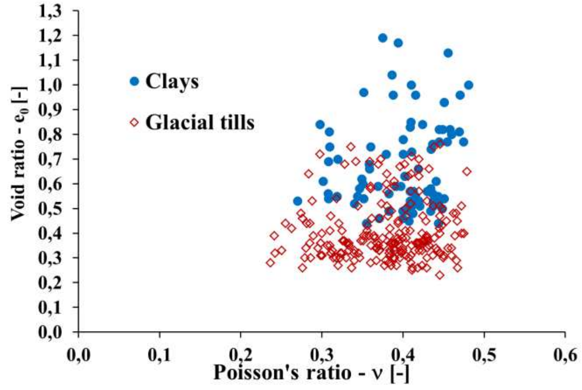


Figure 11. Relation between initial void ratio and dynamic (undrained) Poisson's ratio

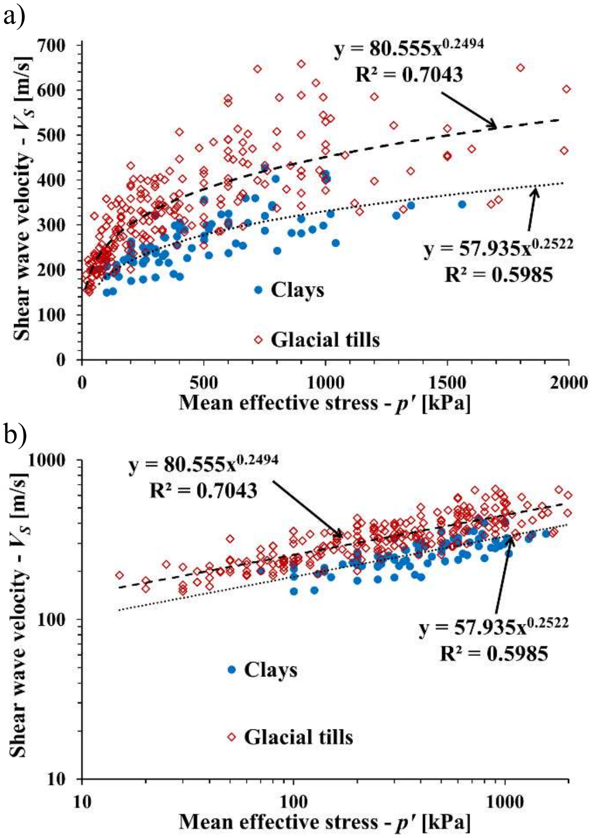


Figure 12. Relation between shear wave velocity and mean effective stress: a) normal scale; b) logarithmic scale.

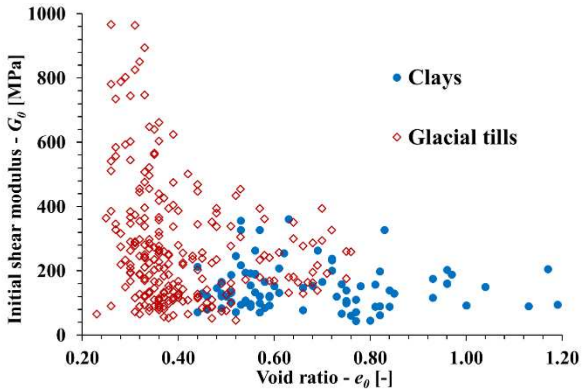


Figure 13. Relation between initial shear modulus and void ratio

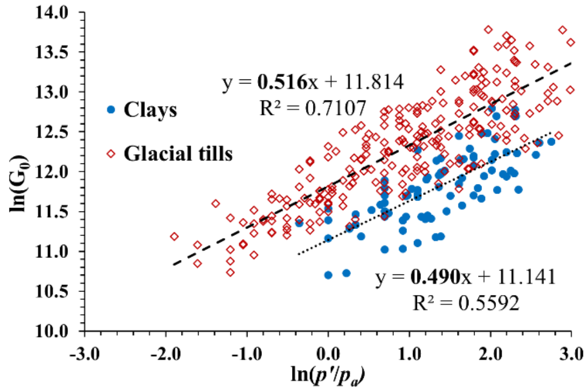


Figure 14. Determination of stiffness exponent.

4 CONCLUSIONS

The paper presented the overview of a database containing advanced laboratory test results obtained for clays and glacial tills from various locations in Poland. The statistical information on some of the parameters contained in the database were presented as well as relations between selected results. Due to the limitation of the paper and still preliminary stages of the analysis, the presented results are focused on small-strain shear stiffness and its stress-dependence.

Observed higher variability in initial shear stiffness for glacial tills can probably be attributed to broader definition of those soils than in the case of clays. Conversely, its stress-dependence, when defined as a power-law exponent, shows unexpected similarity.

Generally, the soil parameters presented in databases should not be used as a substitute for proper geotechnical investigation; they can be referenced as a baseline for comparison or used as a supplementary knowledge in the process of parameter selection. As the number of data points in the database considered herein will increase, further analysis will be a subject of future studies.

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