Change of soil mechanical properties due to triaxial sample size

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Abstract. Triaxial test is widely used to determine the behaviour and strength parameters of soil. Several consolidated drained triaxial compression tests were performed on two specimen sizes of sand and clay. This article investigate and compares the influence of specimen size and scale effect on the soil shear strength. The tests results show that the shear strength parameters are influenced by the clay specimen size. The results indicate that the effect of triaxial clay sample size is more significant with higher confining pressures. The second type of tests carried out on sand samples shows that sample size doesn't influence the results of the shear strength. Author's show that clay analyses can be significantly affected by the choice of the specimen size used to determine shear strength parameters.

Keywords: triaxial test, effect of specimen size, shear strength, angle of internal friction, cohesion.

Introduction

Triaxial tests are often used to determine the behavior and strength characteristics of soils (Omar & Sadrekarimi, 2015). The results of triaxial tests can be influenced by various experimental conditions such as confining pressure, shearing rate, end constraint, and specimen size (Park & Jeong, 2015). In this study the effect of specimen size on the drained shearing behavior of dense sand and dense clay was investigated using specimens 5 and 10 cm in diameter. Specimen size can have a significant impact on the measured shear strength (Hu, Dano, Hicher, Le Touzo, & Derks, 2011; Cerato & Lutenege, 2006). Literature analysis shows the difference between an effective friction angle from undrained tests and drained tests was up to 7° for loose sand, but was negligible for dense sand using different specimens sizes. There the effect of specimen size on the undrained and drained shearing behavior of Nakdong River sand was investigated using loose and dense specimens 5 and 10 cm in diameter (Park & Jeong, 2015). The higher compressibility of smaller specimens during isotropic compression and drained shearing could be due to the larger volumetric fraction of the sand particles near the specimen's sides (Omar & Sadrekarimi, 2015).

The literature analysis shows that for the same clayey silt sample size, as the over-consolidation ratio increases, the deviator stress increases. This behavior is more significant on the samples which had been initially consolidated at smaller consolidation pressure. The results indicate that the effect of sample size is more significant at higher confining pressures. It was found that the total and effective peak friction angles decreases with increasing sample size (Sivadass, Lee, & Karim, 2013).

A small diameter sample may not truly represent the “fabric” and “structure” of the soils at the site (Chew & Bharati, 2011). Testing bigger samples sizes gives better representation of field shear and deformation behaviour, so buildings are safer. The reason for different results for larger and smaller is mainly due to the presence of non-uniformity and non-homogeneity in the field which can be captured in large size sample but not in small size sample. Furthermore, the small diameter sample is affected to more sample disturbance during sampling, transportation and sample testing.

The undrained shear strength of marine clay obtained from large diameter triaxial sample is lower than that obtained from small diameter sample, although both samples are obtained from large diameter sampler. The triaxial tests results shows that larger sample size results are 20–70% lower than that of conventional sample size results (Chew & Bharati, 2011).

Many laboratories perform triaxial tests on sand or clay to determine the shearing strength of the soil sample. However, there are different size triaxial cells in use today (D. Li, C. C. Li, & X. Li, 2011; Kuwano & Mulmi, 2008) and the effect of the varying specimen size (Amšiejus, Dirgėlienė, Norkus, & Žilionienė, 2009) and soil type (sand or

over consolidated moraine clay) on the resulting friction angle used in foundation design has never before been investigated in Lithuania thoroughly. The main reason of such a tests lack – very difficult to provide triaxial tests with over consolidated moraine clay. During these experiments it can appear problems with saturation (Kadkhodaie & Rezaee, 2016; Dong, Kong, & Zhe, 2016; Glover, 2017), big particles appearance in shearing plane (Zhang, Baudet, Hu, & Xu, 2017; Vangla & Latha, 2015), long term investigations (Suzuki, Dyvik, & Schmertmann, 2017; Liu, Xie, Shao, & Conil, 2018) and etc. Specimen size effect on the shear strength parameters can affect the design and analysis of many geotechnical constructions. The optimum design of foundations involves a better understanding of the behaviour of the used materials in order to guarantee the safety of its structural behaviour during its lifetime. Soil strength parameters and using them determined soil bearing resistance usually are defined with some errors. If we know the reasons of errors, shortcomings of testing apparatus could be eliminated, method of data evaluation could be developed, soil parameters could be determined more precisely and foundation designed more economically.

This paper presents the shearing strength results of experimental triaxial tests on sand and over consolidated moraine clay samples with different diameters and heights. In this study the effect of specimen size on the drained shearing behavior of dense sand and dense clay was investigated using specimens 5 and 10 cm in diameter.

Experimental analysis

Identification of tested soil

This research work analysing clay, which belongs to the glacial formations of the Middle Pleistocene Medininkai glacial period (gt II md) laying in the eastern part of Lithuanian territory (Lekstutytė, Gadeikis, Žaržojus, & Skuodis, 2018). An other soil type – sand, which deposited on the Lithuanian coast of the Baltic Sea have been formed during the Quaternary (Skuodis, Markauskas, Norkus, Žaržojus, & Dirgėlienė, 2014). The investigated area of sand is located in the southern part of the Lithuanian mainland area of the Baltic Sea. Lithuanian standard sand for scientific testing can be Baltic Sea Klaipėda sand, due to granulometry composition and particles shape (Skuodis, Karaman, & Dirgėlienė, 2017). This is the reason, why Klaipėda sand was chosen for investigations as standard soil, according to which results it is provided comparison of over consolidated moraine clay triaxial tests results.

In the triaxial experiments clay and sand were tested in this work. First type of soil according to granulometric curve is sandy silty clay (see Figure 1). The properties of prepared samples are as follows: density $\rho = 2.28\text{--}2.30\text{ g/cm}^3$, particles density $\rho_s = 2.72\text{ g/cm}^3$, void ratio $e = 0.29\text{--}0.31$, moisture $w = 9\text{--}10\%$, Atterberg liquid limit $W_L = 0.245$, Atterberg plastic limit $W_P = 0.139$, plasticity index $I_p = 0.1$, liquidity index $I_L = -0.215$. The undisturbed samples were taken from borehole of 12.5–13.1 m depth.

Figure 1. Grain size distribution for clay

The next investigated soil according to granulometric curve is even-graded sand, uniformity coefficient is $C_U = 1.47$ and coefficient of curvature is $C_C = 0.93$ (see Figure 2). Soil granulometric composition is of 1.34% fine, 96.38% medium and 2.28% coarse particles, respectively. The particles of this soil are mostly of the same shape, because it is sampled from Klaipėda seashore, where a surface of particles is polished by the waves. The tested sand samples of low water contents ($w = 6\%$) have been performed by compacting. The triaxial tests have been performed for samples of density $\rho = 1.69\text{ g/cm}^3$ and the void ratio $e = 0.49\text{--}0.51$.

Figure 2. Grain size distribution for sand

Triaxial testing

The consolidated drained (CD) tests were performed for the specimens of height/diameter ratio of $H/D = 2$. For investigation of scale effect the triaxial compression tests were performed on two specimen sizes of sand and clay: first, samples of 50 mm diameter and 100 mm height (50/100); second, samples of 100 mm diameter and 200 mm height (100/200). The saturation wasn't performed.

Sand compaction was performed in six layers of equal thickness by tamping the top of each layer with a tamper to reach the target density for each specimen.

Each type of the prepared samples has been cut leastwise three times. The tested clay samples have been sheared under three horizontal pressure $\sigma_3 = 150$ kPa, 250 kPa, 350 kPa. The sand samples have been cut under $\sigma_3 = 100$ kPa, 200 kPa, 300 kPa. An axial strain rate of 0.02%/min was used for clay and 0.95%/min for sand. Each of the tests was continued up to deformation, which is equal to 15%. The circles representing the state of stress in the triaxial samples at failure are drawn (see Figures 3–6).

Figure 3. Mohr circles and strength envelope of clay 50/100

Figure 4. Mohr circles and strength envelope of clay 100/200

Figure 5. Mohr circles and strength envelope of sand 50/100

Figure 6. Mohr circles and strength envelope of sand 100/200

Comparison of shear strength

The first type of tests carried out on over-consolidated moraine clay demonstrates that the angle of peak internal friction in term of effective stress shows variation with sample size. It was determined $\phi' = 26.87^\circ$ for samples of 50 in diameter and $\phi' = 24.50^\circ$ for samples of 100 in diameter (Table 1). It was found that the effective peak friction angle decreases with increasing sample size. These results are similar to the results determined by other authors (Sivadass et al., 2013).

From all experiments, it is found that the max deviator stress decreases as the sample size increases. In a drained test the deviator stresses at failure were 371 kPa, 501 kPa, 695 kPa for small samples and 384 kPa, 498 kPa, 659 kPa for large samples under three horizontal pressure $\sigma_3 = 150$ kPa, 250 kPa, 350 kPa. The maximum deviator stress increases as the confining pressure increases. The results indicate that the effect of triaxial sample size is more significant with higher confining pressures. Whereas effective cohesion shows rise from 34.42 kPa to 56.48 kPa with sample size increment. For clay exhibiting peak stress behavior in the small size samples, axial strain corresponding to peak stress are higher, differing by ± 45 –100% from big samples.

Table 1. The peak values of shear strength from triaxial tests

Type of soil	Cohesion c' , kPa		Internal friction angle, ϕ' °	
	50/100	100/200	50/100	100/200
clay	34.42	56.48	26.87	24.50
sand	0	0	40.51	40.77

The second type of tests carried out on sand samples shows that sample size effect doesn't influence the results of drained triaxial compression tests (Table 1). The cohesion is $c' = 0$ (kPa) for both type of samples. The comparison of test data on samples 50 and 100 mm in diameter, for which the slenderness is the same, does not reveal any difference in the peak angle of internal friction. It was determined $\phi' = 40.51^\circ$ and $\phi' = 40.77^\circ$ respectively. Therefore, we can

conclude that there is no obvious sample size effect in the sand strength behavior. A similar studies on coarse granular materials show comparable results (Hu et al., 2011).

While using small size samples for determining clay shear strength parameters, may result in un-conservative design, the choice of a large sample size is consequently a more accurate representation of soil strength conditions and field deformations.

Conclusions

1. It was found that the clay effective peak friction angle decreases with increasing sample size from 26.87° to 24.50°.
2. The results indicate that the effect of triaxial clay sample size is more significant with higher confining pressures.
3. The effective cohesion shows rise from 34.42 kPa to 56.48 kPa with sample size increment.
4. The triaxial experiments does not reveal any difference in the peak angle of internal friction and cohesion of dense sand.

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