INDEX COPERNICUS INTERNATIONAL

ORIGINAL ARTICLE

Bulletin of the Maritime Institute in Gdańsk

Variability of undrained shear strength c_u within one organic soil layer

Zmienność wytrzymałości na ścinanie bez drenażu c_u w obrębie jednej warstwy gruntu organicznego

Krzysztof Załęski, Patryk Juszkiewicz, Paweł Szypulski

Samodzielne Laboratorium Geotechniki Instytutu Morskiego w Gdańsku, Polska

Article history: Received: 15.08.2016 Accepted: 10.11.2016 Published: 15.01.2017

Abstract: For the purpose of this article, a program of geotechnical laboratory tests was performed on organic soil (mud) samples from one geological layer. All undisturbed samples were taken within the same excavation in a square grid with a side about 30 cm. Differences between specimen parameters were found at basic test results and at shear strength tests results. Based on all performed tests, authors suggest carefulness in assuming geotechnical parameters of organic soil layers because of their spatial variability, even in close vicinity.

Keywords: undrained shear strength c_u, unconsolidated undrained triaxial test UU, laboratory vane shear test, organic soil layer.

Streszczenie: Dla potrzeb niniejszego artykułu został przeprowadzony program geotechnicznych badań laboratoryjnych na próbkach gruntu organicznego (namułu) pochodzących z jednej warstwy geologicznej. Wszystkie próbki o nienaruszonej strukturze zostały pobrane z dna jednego wykopu w siatce kwadratów o boku ok. 30 cm. Różnice w parametrach próbek stwierdzono na podstawie wyników badań podstawowych jak również badań wytrzymałości na ścinanie. Bazując na wszystkich przeprowadzonych testach, autorzy sugerują ostrożne przyjmowanie parametrów geotechnicznych gruntów organicznych ze względu na ich przestrzenną zmienność nawet w bardzo bliskim sąsiedztwie.

Słowa kluczowe: wytrzymałość na ścinanie bez drenażu c_u, badanie bez konsolidacji i bez drenażu w aparacie trójosiowego ściskania UU, badanie ścinarką laboratoryjną, warstwa gruntu organicznego.

INTRODUCTION

Every modern geotechnical design process requires high-quality parameters to model soil behaviour under construction load. Parameters can vary a lot within the same geological soil layer. Geotechnical investigation programs are often limited because of their high costs. The number of boreholes and laboratory tests is reduced to minimum, required by local law and standards. Statistical analysis of soil layer properties is difficult in these cases.

One of the most important parameters of sensitive, organic soils is shear strength in undrained conditions c_u. Visually homogenous samples taken in 0,5 m distance sometimes can have shear strength difference by 20 percent. When samples are taken in 50 or 100 m distance, this difference can be much bigger. For this article, a complex analysis of one organic soil layer was made, including determination of shear strength, basic and classification tests.

SAMPLING

To perform shear strength comparative tests, undisturbed samples of organic soil were needed. There is a lot of organic soils at shallow depths around Gdansk. The main part of them is fluvial because of the close neighbourhood of Vistula River and its mouth. For the needs of this article, sampling was made on the land owned by Maritime Institute in Gdansk (MIG).

Fig. 1. Map with marked boreholes locations (www.maps.google.pl)

Location

During preliminary geological investigation for building of the new MIG's headquarters, a series of boreholes and soundings was made. Terrain for this investment is situated directly by the Dead Vistula River bed [Fig. 1].

Based on geological documentation, the point no. 4 (BH4), situated less than 20 meters from the riverbank, was chosen. In this point under 2,70 m of anthropogenic uncontrolled clayey embankment, organic soil (mud) layer with over one meter thickness was found. This area has a specific geological structure. Layers of organic soils are alternately separated by sands [Fig. 2].

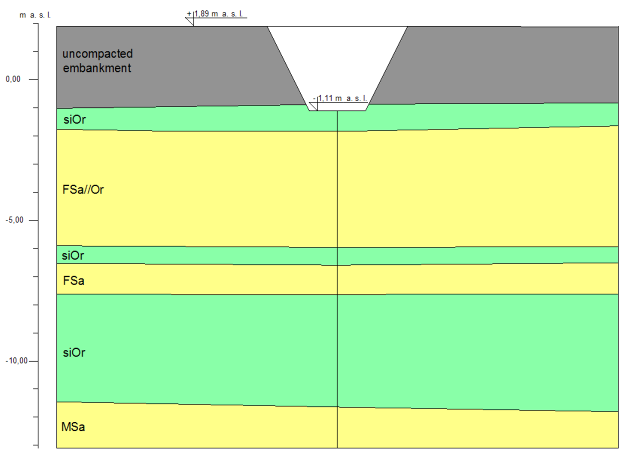

Fig. 2. Cross section with designed excavation

Procedures

To get to the organic layer, an excavator was used. First, all anthropogenic embankment had to be removed. The excavation of 2,70 m depth and 2:1 slopes was designed and performed [Fig. 2]. During mechanical works, a lot of brick fragments and concrete was found. When the top of the organic soil appeared, the first 5 - 10 cm of disturbed layer was removed manually. After that, soil was ready for sampling.

Cylinders of 100 mm internal diameter were pushed into the soil. First, this operation was made manually until soil resistance became too big. Then the wooden plate was placed on partially pushed cylinders and statically tightened using excavator. The distance between cylinders was about 20 cm. Thirty samples were taken this way.

On the same level, near the part of excavation where cylinders were pushed, undisturbed block samples were taken. This operation was made solely manually, using only hand tools. After cutting, the blocks were protected with foil and put into a tube. Five almost cubical block samples of about 30 x 30 x 30 cm were collected.

Transport and storing

The sampling location is situated only ca. one kilometre from MIG's Geotechnical Laboratory. All samples taken from excavation were placed in a car and protected against movement and vibrations. To limit samples' exposure to disturbing factors, the shortest way with ferry was chosen. In twenty minutes, samples were transported to the laboratory and placed in a refrigerated container with constant temperature of 4 °C. All samples were stored vertically with orientation as in situ.

LABORATORY TESTS

Laboratory tests program realized in Geotechnical Laboratory of Maritime Institute in Gdansk comprised two parts.

Tab. I. Basic and classification tests results

	DIAMETER D [mm]	CONFINING PRESSURE σ_3 [kPa]	PARTICLE DENSITY ρ_s [g/cm³]	BULK DENSITY ρ [g/cm³]	WATER CONTENT w [%]	PLASTIC LIMIT w_P [%]	LIQUID LIMIT w_L [%]	ORGANIC CONTENT I_{OM} [%]	CONSISTENCY INDEX I_c [-]
Specimen no. 1		27	2.68	1.650	53.750	30.132	59.830	5.417	0.20
Specimen no. 2	38	54	2.67	1.640	51.550	30.631	61.670	5.530	0.33
Specimen no. 3		108	2.66	1.670	56.500	30.887	64.120	5.694	0.23
Specimen no. 4		27	2.70	1.680	52.400	27.814	61.790	5.402	0.28
Specimen no. 5	50	54	2.68	1.750	56.450	27.620	61.710	5.352	0.15
Specimen no. 6		108	2.68	1.660	51.740	27.688	56.590	5.136	0.17
Specimen no. 7		27	2.72	1.680	55.030	31.256	61.580	5.580	0.22
Specimen no. 8	70	54	2.70	1.680	54.960	30.103	63.190	5.556	0.25
Specimen no. 9		108	2.71	1.680	52.500	30.186	58.530	5.319	0.21
		Average	2.69	1.68	53.88	29.59	61.00	5.44	0.23
		Median	2.68	1.68	53.75	30.13	61.67	5.42	0.22
		Standard deviation	0.02	0.03	1.83	1.38	2.19	0.16	0.05

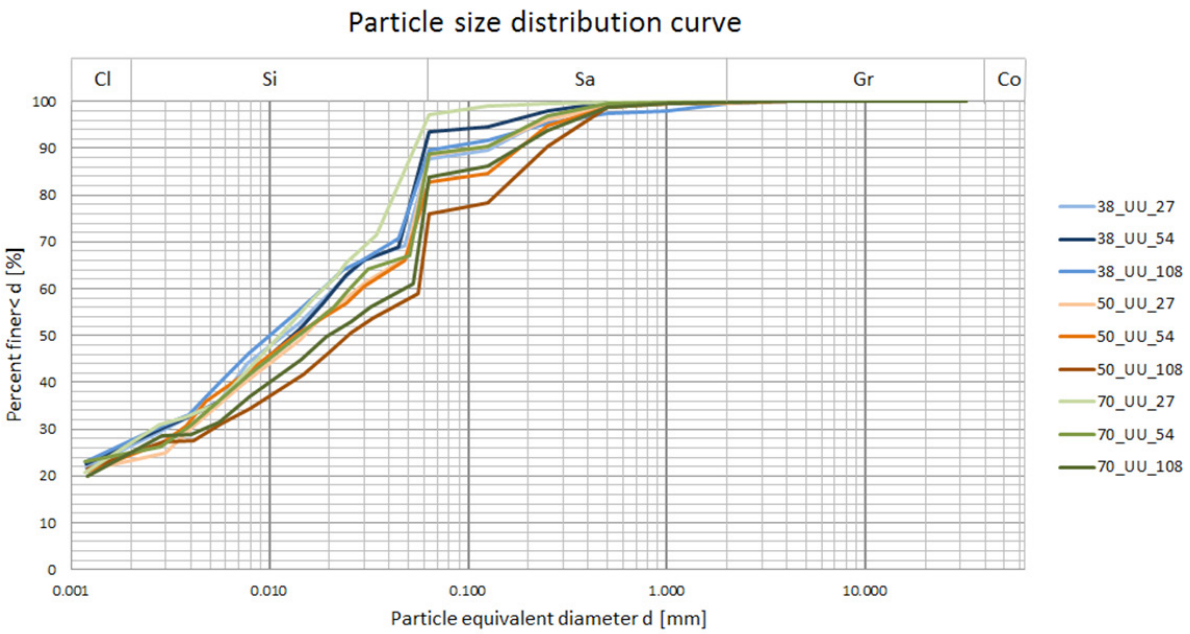

Fig. 3. PSD results

First part contained simple, basic tests. In this part, tests such as: water content, plastic limit, liquid limit, particle density, organic content, bulk density, and hydrometer test with wet sieving, were performed.

Second part of laboratory tests program contained shear strength tests in two devices. First, after preparation of triaxial samples, the laboratory shear vane test LV were performed. Parallel to vane tests, the unconsolidated undrained triaxial tests UU were being carried out. They were done on samples of three diameters: 38 mm, 50 mm, 70 mm in 3 levels of confining pressure: 0,5 σ_v, σ_v and 2σ_v according to BS [7] and ISO [12] standards, where σ_v means total vertical stress at the sampling depth z.

$$\sigma_v = z \cdot \gamma \quad (1)$$

Where:
$z -$ *sampling depth* [m]
$\gamma -$ *soil unit weight* [kN/m³]

Nine independent UU tests and nine LV tests were done. All tests were made on specimens cut from block samples.

Classification tests

Water content

Water content specifies the quantity of water in a soil. Test was performed in accordance to PKN-CEN ISO/TS 17892-1 [8].

BMI, 2017; 32(1): 8-13 DOI: 10.5604/12307424.1224045 www.bullmaritimeinstitute.com

Bulk density

Test is performed to designate bulk density of cohesive soils, using cutting ring method in accordance to PKN-CEN ISO/TS 17892-2 [9].

Particle density

Particle density plays an important role in understanding and determination of other physical properties, including bulk density and porosity. Test was performed in accordance to PKN-CEN ISO/TS 17892-3 [10].

Atterberg limits: plastic (w_p) and liquid (w_L) limits

Atterberg limits: liquid limit and plastic limit stand on the boundaries of fine - grained soils states. The first one (w_L) is empirically established water content at which a soil passes from a liquid state to a plastic state. The plastic limit (w_p) is empirically established water content at which soil becomes too dry to be plastic. Tests were performed in accordance to PKN-CEN ISO/TS 17892-12 [13].

All results of tests mentioned above are summarized in table [Tab. 1].

Particle size distribution (PSD)

A particle size distribution analysis (PSD) is performed to determine the percentage of all the individual fractions of tested sample. There is a variety of techniques used; each has advantages and disadvantages, depending on the sample properties. Here, a wet sievings combined with hydrometer tests were performed in accordance to PKN-CEN ISO/TS 17892-4 [11]. The PSD curves are presented on figure [Fig. 3].

Undrained shear strength tests:
Laboratory vane shear test (LV)

The test with application of laboratory shear vane apparatus is performed to determine undrained shear strength. Vane is pushed into the soil specimen to a specific depth and sheared at constant rotation speed forwarded to the vane through the calibrated spring. Test is continued to failure, which can be observed as a rapid decrease in torque transmitted into the sample. Based on stiffness of spring and angle of vane rotation, undrained shear strength can be calculated. In this test, unlike triaxial test, there is no confining pressure applied to the specimen. Tests were performed in accordance to BS 1377-7 1990 [7] and undrained shear strength was calculated using equation:

$$c_u = \frac{M}{K} \cdot 1000 \quad (2)$$

Where:

M – *torque applied to shear the soil* $[N \cdot mm]$

K – *constant which depends on the dimension of the vane* $[mm^3]$

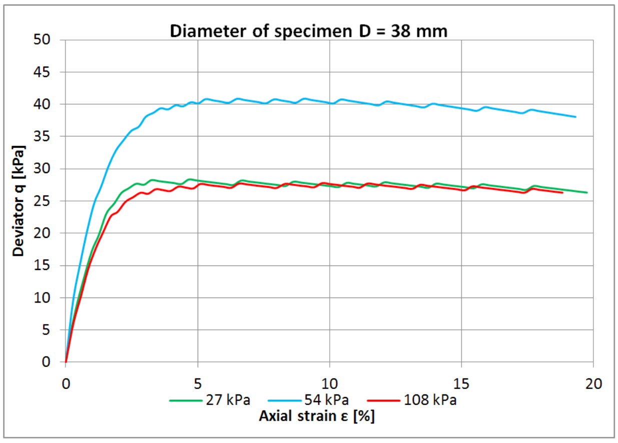

Fig. 4. Triaxial UU test curves. Specimen of 38 mm diameter tested in three levels of confining pressure.

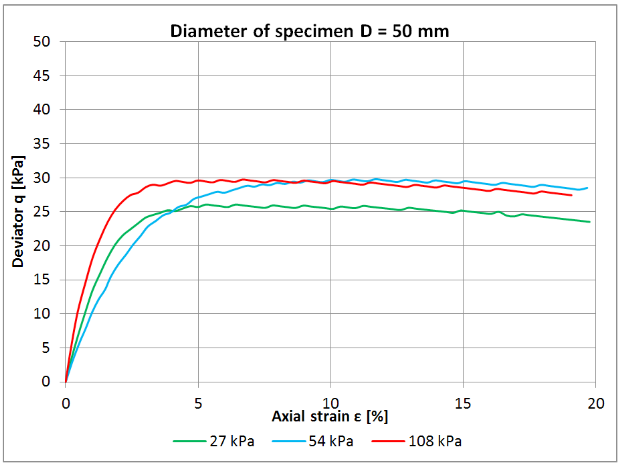

Fig. 5. Triaxial UU test curves. Specimen of 50 mm diameter tested in three levels of confining pres

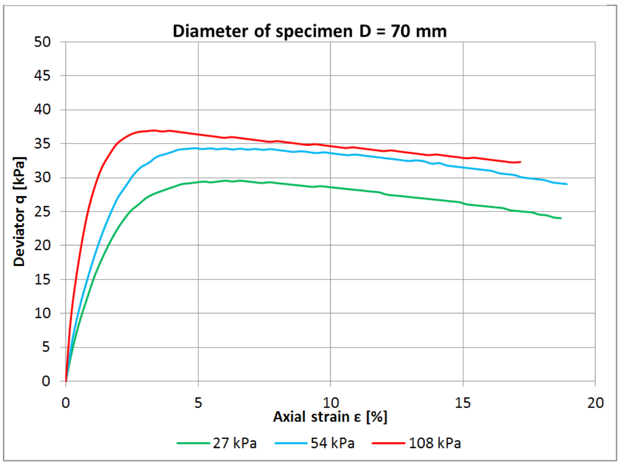

Fig. 6. Triaxial UU test curves. Specimen of 70 mm diameter tested in three levels of confining pressure.

Tab. II. Summary of shear strength test results

	DIAMETER D [mm]	CONFINING PRESSURE σ_3 [kPa]	UNCONSOLIDATED UNDRAINED TEST c_u [kPa]	AVERAGE VALUE [kPa]	STANDARD DEVIATION [kPa]	COEFFICIENT OF VARIATION [-]
Specimen no. 1		27	14.17			
Specimen no. 2	38	54	20.40			
Specimen no. 3		108	13.86			
Specimen no. 4		27	13.04			
Specimen no. 5	50	54	14.90	16.30	3.48	0.21
Specimen no. 6		108	14.87			
Specimen no. 7		27	14.78			
Specimen no. 8	70	54	17.17			
Specimen no. 9		108	23.49			

Unconsolidated, undrained triaxial tests (UU)

The test is performed to determine undrained shear strength (c_u) of soil. Test is carried out at constant isotropic pressure and strain – controlled axial loading.

After specimen preparation test is carried out at isotropic, confining pressure equal to 0.5, 1.0 and 2.0 of total vertical stress „in situ." Water table was below 3.0 m, so unit weight of soil above sampling level was assumed to be equal . Considering this, the total „in situ" stress σ_v was calculated 18 kN/m^3, and the tests were carried out at 27, 54 and 108 kPa confining pressures.

Diameter of specimen was equal to 38, 50, and 70 mm, with height 76, 100, and 140 mm, respectively. During the tests, axial strain speed was 1,5 %/min and tests were continued until 20% of specimen axial strain was achieved. Tests were performed in accordance to BS 1377-7 1990 [7] and undrained shear strength was calculated using equation:

$$c_u = \frac{(\sigma_1 - \sigma_3)_f}{2} \quad (3)$$

Where:
$\sigma_1 - vertical\ stress\ at\ failure\ [kPa]$
$\sigma_3 - cell\ pressure\ at\ failure\ [kPa]$

All result curves are presented on figures [Fig. 4], [Fig. 5] and [Fig. 6].

Results

Water content and bulk density were designated directly before triaxial tests to provide the most reliable results possible. Difference in these parameters results only from specimens' inhomogeneity. The specimens were sampled in direct vicinity, with distance from each other approximately equal to 20 cm. Similar situation is observed for Atterberg limits. Theoretically, soil specimens taken in close vicinity should have the same values of plastic and liquid limit. However, as presented in table [Tab. 1], parameters values vary up to 10%.

Small variability is observed in all basic and classification tests results. Authors of this papers expect the differences in geotechnical strength parameters should also be observed.

The curves obtained from PSD analysis are similar in shape. The most significant differences can be observed near the border between the sand and silt. This is probably because of fragments of organic matter. In this area, the difference between the highest and the lowest curve exceeds 20%.

Results of unconsolidated, undrained tests

All the curves presented above in perfectly homogeneous material should be plotted in the same order as the confining stress level, whereas this situation is presented only on Fig. 5. For samples of smaller diameters curves and shear strength, values are random. This is because of inhomogeneity observed first in classification tests and PSD tests results. The biggest difference in c_u parameter based on all UU tests summarized is in table [Tab. 2] is 10,45 kPa with the average value about 16,29 kPa. It is up to 64 percent of the mean value.

The maximum value of undrained shear strength is determined for specimen of 70 mm in diameter at 108 kPa confining pressure, as expected. However, the second maximum value is for specimen of 38 mm diameter at 54 kPa confining pressure. It can lead to the conclusion that diameter or confining pressure has limited influence on test results in case of soft organic soils.

Maximum values of undrained shear strength, determined by laboratory vane [Tab. 3], are for different specimens that maximum values from triaxial apparatus. For example, specimen no. 5, shear strength in laboratory vane was 20.19 kPa, but in triaxial apparatus, only 14.90 kPa. There is no possibility to perform both test on the same specimen because of technical reasons.

CONCLUSIONS

Soil samples from testing site macroscopically had similar properties. Sampling was made in one excavation at the same depth to provide the same or possibly the most similar specimens for testing in geotechnical laboratory. Classification tests gave an opportunity to see that specimens, even in close vicinity, have different physical parameters. This can lead to a simple conclusion – it is difficult to get the same specimen of cohesive, organic soil, even since they are from the same geological layer specified based on CPTu tests and drillings. The geotechnical strength tests results were only confirmation that specimens differ from each other.

In designing practice, often the same, average geotechnical parameters for whole specified layer are assumed, even when CPTu tests or drilling are far from each other. This assumption can lead to inappropriate calculations, for example, of structure settlements and stability.

Hopefully, in actual standards, a big range of safety factors exists. They are used in specific cases of geotechnical designing to provide safe projects of foundations and other structures. There is a need to be careful with assuming the parameters of organic soils.

Authors of this paper recommend performing as many tests as possible to gain most reliable parameters, because it allows to optimize geotechnical project and reduce costs.

References:

[1] Myślińska E.: Laboratoryjne badania gruntów i gleb. WUW, Warszawa 2010.

[2] [2] Wiłun Z.: Zarys Geotechniki. WKŁ, Warszawa 1976, 2005.

Publications

[3] [3] Zhao H.F., Zhang L.M., et al.: Variability of geotechnical properties of fresh landslide soil deposit. Engineering Geology 166 (2014).

[4] [4] Omar T., Sadrekarimi A.: Effect of triaxial specimen size on engineering design and analysis. International Journal of Geo-Engineering (2015) 6:5.

[5] [5] Omar T., Sadrekarimi A.: Specimen size effects on behavior of loose sand in triaxial compression tests. Canadian Geotechnical Journal 52: 732-746 (2015).

[6] [6] Kjell Karlsrud et al.: Strength and deformation properties of Norwegian clays from laboratory tests on high-quality block samples. Canadian Geotechnical Journal 50: 1273-1293 (2013).

Standards

[7] [7] BS 1377-7 1990; Methods of test for Soils for civil engineering purpose - Part 7: Shear strength tests (total stress)

[8] [8] PKN-CEN ISO/TS 17892-1; Badania geotechniczne - Badania laboratoryjne gruntów – Część 1: Oznaczanie wilgotności;

[9] [9] PKN-CEN ISO/TS 17892-2; Badania geotechniczne - Badania laboratoryjne gruntów – Część 2: Oznaczanie gęstości gruntów drobnoziarnistych;

[10] [10] PKN-CEN ISO/TS 17892-3; Badania geotechniczne - Badania laboratoryjne gruntów – Część 3: Oznaczanie gęstości właściwej – Metoda piknometru;

[11] [11] PKN-CEN ISO/TS 17892-4; Badania geotechniczne - Badania laboratoryjne gruntów – Część 4: Oznaczanie składu granulometrycznego;

[12] [12] PKN-CEN ISO/TS 17892-8; Badania geotechniczne - Badania laboratoryjne gruntów – Część 8: Badanie gruntów nieskonsolidowanych w aparacie trójosiowego ściskania bez odpływu wody;

[13] [13] PKN-CEN ISO/TS 17892-12; Badania geotechniczne - Badania laboratoryjne gruntów – Część 12: Oznaczanie granic Atterberga;

Word count: 2030 Page count: 6 Tables: – Figures: 6 References: 13

Scientific Disciplines: Geoscience

DOI: 10.5604/12307424.1224045

Full-text PDF: www.bullmaritimeinstitute.com/fulltxt.php?ICID=1224045

Cite this article as: Załęski K., Juszkiewicz P., Szypulski P.: Variability of undrained shear strength c_u within one organic soil layer.: BMI, 2017; 32(1): 8-13

Competing interests: The authors declare that they have no competing interests.

Corresponding author: Krzysztof Załęski, Samodzielne Laboratorium Geotechniki Instytutu Morskiego w Gdańsku, Polska; e-mail: kzaleski@im.gda.pl

Ministerstwo Nauki i Szkolnictwa Wyższego The goals are financed according to the agreement 591/P-DUN/2017 from the funds of the Ministry of Science and Higher Education for science promotion.