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Determination of geotechnical properties of marine clay from the Słupsk Bank

Parametry geotechniczne iłów z obszaru Ławicy Słupskiej

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Abstract: For the purpose of this paper, laboratory tests on clay samples, collected at the Słupsk Bank with the use of a vibrocorer, were carried out in the Geotechnical Laboratory of the Maritime Institute in Gdańsk. This study aims to determine the geotechnical properties of the above-mentioned soils. Oedometer and classification tests were conducted on the selected specimens. Strain properties, secondary compression index and undrained shear strength were determined for the material. The impact of vibrocoring as a sampling technique on the obtained results and recommendations for application of these results were also described.

Keywords: laboratory tests, oedometer, geotechnics, till, classification, properties, strength, density, clay, plasticity, liquidity, compressibility, vibrocorer, moisture content

Streszczenie: Na potrzeby niniejszego artykułu, w Samodzielnym Laboratorium Geotechniki Instytutu Morskiego w Gdańsku, przebadano próbki iłów pobranych za pomocą wibrosondy z obszaru Ławicy Słupskiej. Celem badań było określenie parametrów geotechnicznych wspomnianych gruntów. Przeprowadzono badania edometryczne oraz wykonano badania klasyfikacyjne. Dla wybranych próbek określono parametry odkształceniowe i wyznaczono współczynnik ściśliwości wtórnej oraz określono wytrzymałość na ścinanie w warunkach bez odpływu. Opisano również wpływ pobierania próbek wibrosondą na uzyskane wyniki oraz pewne zalecenia dotyczące wykorzystywania wyników.

Słowa kluczowe: badania laboratoryjne, edometr, geotechnika, gliny, klasyfikacja, parametry, wytrzymałość, gęstość, iły, plastyczność, płynność, ściśliwość, wibrosonda, wilgotność

INTRODUCTION

Due to negative changes in the environment and declination of the current natural energy resources, it is crucial to search for alternative and renewable energy sources. One of the most significant green energy sources is wind energy. In this case, electricity is produced by converting the wind's kinetic energy using wind turbines equipped with generators.

Wind farms can be located on the land (onshore) or in the sea (offshore). The benefit of offshore wind power is that the wind is much stronger and reliable off the coasts. Among the most essential advantages of offshore wind energy are large investment surface area, high profitability of investment, significant distance from human settlements and less negative environmental effects of the investment. Moreover, such projects enjoy public support as the society obtains energy without having to build burdensome eyesore power plants on the land. In recent years, the dynamic development of offshore wind energy has been observed, especially in the Western European countries, in the area of the North Sea. As a member state, Poland is obliged to implement the European Union's energy policy. At the beginning of the 21st century, large scale onshore wind power projects have been executed in Poland. Wind farms used to be located mostly in the northern, central and western parts of the country. Over the past few years, the Polish Exclusive Economic Zone of the Baltic Sea has become of great interest to investors seeking profits from offshore wind energy.

The optimum environmental, wind and bathymetric conditions in the area of the Baltic Sea can be found in the region of the Słupsk Bank. This area, located approx. 25 nautical miles from the shore, to the north of Ustka, is covered with gravel and sand sediments deposited on glacial silts, clays, and tills.

Due to the high costs connected with realisation of offshore wind farms, all factors that may have possible impact on an investment location should be taken into account. Apart from the meteorological conditions (wind strength and direction), the soil conditions, which determine the type of support structures foundations and methods of electric connection cables installation, are of importance to the choice of investment location. Geotechnical properties of soils are extremely important when designing foundations, hence it is crucial to provide a robust ground investigation in the area of investment. This is associated with the necessity to perform laboratory tests, often specialised ones, which supplement field works and in situ surveys.

The literature provides limited information on geotechnical properties of clays in the area of the Słupsk Bank, therefore it was decided to collect seabed surface samples using a vibrocorer and subject them to laboratory tests. The aim of this paper was also to present an example of a laboratory testing procedure which could be used for a preliminary investigation of soil conditions for the purpose of wind farm realisation.

SOIL SAMPLING

Depending on the soil type, the required penetration depth and the sample quality, the following seabed surface sediment sampling techniques and devices are used:

- grab sampler,
- box corer,
- vibrocorer,
- piston corer.

One of the most commonly used sampling devices is a vibrocorer (Fig. 1), which can retrieve seabed sediment core samples of a length up to 6 m, depending on the geological conditions. This technique is highly efficient (in terms of core recovery).

In the case of the VKG-6 device, used by the Maritime Institute in Gdańsk, cores are collected using a set of pipes (core barrels) with the internal diameter of 102 mm. In order to secure the cores from damage and drying, a PCV liner is installed inside the core barrel. After sampling, the PCV liner is cut into 1.0 m long sections, labelled and transported to the laboratory. In the Geotechnical Laboratory of the MIG, PCV liners are cut and cores are subjected to macroscopic description. Photographic documentation is also prepared and soil samples are secured for the purposes of further analyses.

The core selected for the tests, conducted within the framework of this article, was retrieved in the south-western part of the Słupsk Bank, with the use of a vibrocorer, from the board of the MIG's research vessel IMOR. The core recovery in the sampling point reached the length of 3.65 m.

It should be added that, despite numerous preventive actions (e.g. minimizing the vibration time), sampling with a vibrocorer may disturb the natural soil structure. During sampling, the developed vibration, enabling the core barrel to penetrate into the soil, causes, to a greater or lesser extent, damages to the soil structure and, in the case of sand, it often leads to its liquefaction and decompaction. Sometimes, such structure disturbance may be clearly observed while conducting macroscopic description of a core.

The entire process of cores transportation and storage may also have an impact on soil structure. Inside PVC liners, soils may be subjected to, e.g. decompression, when the pipe is not entirely filled up with the material (there is an air gap above the core).

LABORATORY TESTS

The selected core with the length of 3.65 m (Fig. 2) was subjected to the macroscopic description in accordance with the applica-

Fig. 1. VKG-6 vibrocorer in a 3-meter configuration

Fig. 2. The selected core

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Tab. I. Methods and results of the laboratory tests

TEST	METHOD	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4
Depth	[m]	2.75	2.80	2.85	2.90
w_n [%]	CEN ISO/TS 17892-1	16.6	17.5	19.0	21.6
ρ [g/cm³]	CEN ISO/TS 17892-2	2.12	2.09	2.05	2.05
ρ_s [g/cm³]	CEN ISO/TS 17892-3	2.744	2.746	2.749	2.745
Depth	[m]	3.00–3.10			
PSD	CEN ISO/TS 17892-4	sasiCl			
k [cm/s]	CEN ISO/TS 17892-11	1.66E-08			
w_L [%]	CEN ISO/TS 17892-12	25.60			
w_P [%]	CEN ISO/TS 17892-12	12.63			

Tab. II. The loading sequence

Time [h]	24	24	24	24	24	72	24	24	24	24	24	48	24	72
Stress [kPa]	6.25	12.49	25	50	100	200	100	50	25	50	100	200	400	800

ble standard [10]. In order to carry out the laboratory tests, soil samples were selected from the depth of 2.65–3.65 m.

Four samples were selected for oedometer tests. The samples were also subjected to the basic classification tests, e.g. determination of physical characteristics. From a geotechnical point of view, as far as soil suitability for construction is concerned, strength and compressibility are the most important geotechnical properties of a soil. Undrained shear strength was determined for only one sample due to the limited length of the analysed fragment of the core.

The basic tests

Basic physical characteristics were determined for the samples collected at the depths of 2.75 m, 2.80 m, 2.85 m, 2.90 m and one sample collected from the depth range of 3.00–3.10 m. The vertical effective stress σ_1' in the sampling point was equal to approx. 27–32 kPa. Methods and results of the laboratory tests are collated in Table I.

Based on the basic tests, the following physical parameters of the soil were determined:

- natural moisture content of soil w_n,
- bulk density ρ,
- specific gravity ρ_s,
- particle size distribution PSD,
- coefficient of permeability k,
- Atterberg limits w_L, w_P.

The investigated samples were classified as clay with silt (56%) and sand (24%), soft (I_c = 0.54) in accordance with [11].

Strength tests

Shear strength is one of the most important geotechnical parameters of a soil. It can be described as the internal resistance that soil mass can obtain to resist a shear stress along any plane inside it. This parameter allows the determination of the bearing capacity of a soil, necessary for any foundation design. In practice, various methods for determining shear strength are applied:

- pocket shear vane test and laboratory shear vane test,
- cone penetrometer test,
- triaxial compression test.

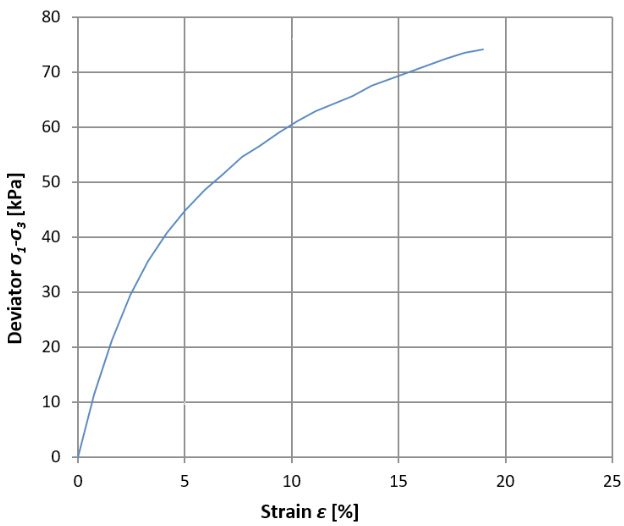

Fig. 3. Deviator stress versus axial strain curve

It was decided to perform the UU test (unconsolidated undrained) in a triaxial apparatus, as it is the most reliable procedure. The test was conducted on a cylindrical specimen of the dimension of H = 100.32 mm, D = 51.08 mm (H/D = 1.96) and the weight of 443.94 g, collected from the depth of 3.20 m. The specimen was sheared under a 100 kPa confining pressure. The obtained result of the test is shown in Fig.3.

Deviator stress increased with axial strain continuously, hence the failure type was considered as plastic. This kind of failure is typical for clays and can also indicate soil structure disturbance as a result of sampling, transportation or the applied storage methods.

None of the specimen failure criteria applied in practice occurred during the test, wherefore the undrained shear strength c_u was determined for the following strain value:

10% $c_u = 30.37$ kPa

OEDOMETER TESTS

The compressibility characteristics of soils are usually determined by means of the constant rate of strain or incremental loading oedometer tests. For the purpose of this paper, the incremental loading oedometer tests were carried out on the specimens in the Geotechnical Laboratory of Maritime Institute in Gdańsk. Four representative samples were taken from the collected core (from the depth of 2.75–2.90 m) for the purpose of the laboratory tests. The values of oedometric modulus E_{oed} and secondary compression index C_α were determined in accordance with [6]. The applied loading sequence is set out in Table II. To ensure correct determination of creep parameters, loading time was extended for the load steps of 200 and 800 kPa. Other load steps were kept constant for 24 hours.

The final vertical strain for each load step and the related values of the oedometric modulus are presented in Fig. 4 and Fig. 5.

Based on the plots, it can be concluded that, despite short distances (~5 cm) separating the sampling points, the tested samples show similar values of the oedometric modulus of primary compression.

The secondary compression index was determined for the rectilinear part of the sample height versus time plot, based on the following formula:

$$C_\alpha = \frac{\delta H}{H_i} \cdot \frac{1}{\delta logt} \qquad (3.1.)$$

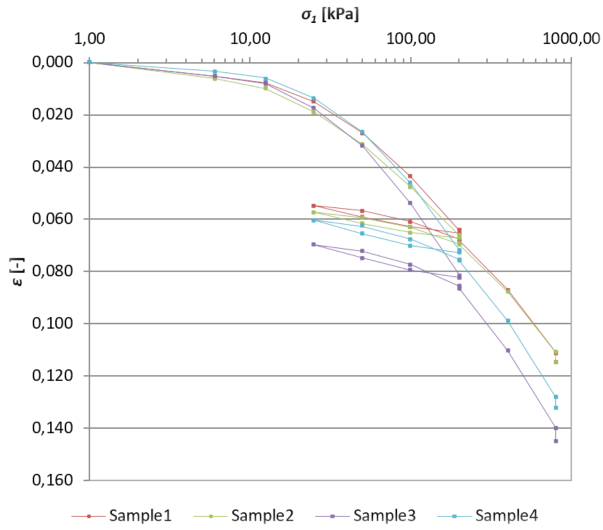

Fig. 4. Compressibility curve

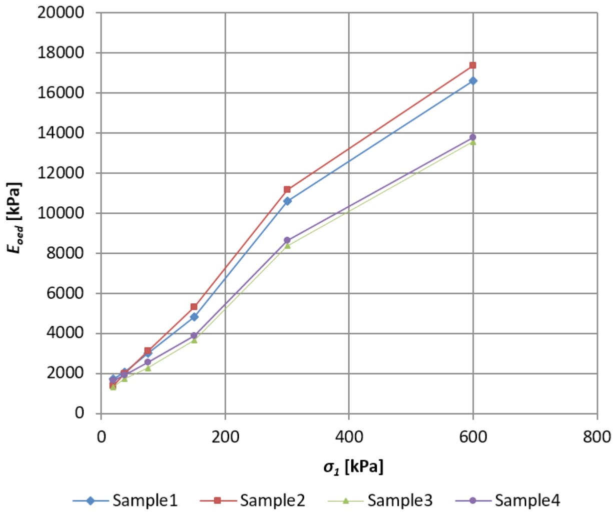

Fig. 5. Oedometric modulus – stress relationship

Tab. III. The oedometric moduli of primary compression [kPa]

Stress σ_1	12.5–25	25–50	50–100	100–200	200–400	400–800
Sample 1	1712	2083	3003	4831	10610	16598
Sample 2	1397	1992	3115	5333	11173	17354
Sample 3	1330	1736	2257	3670	8368	13559
Sample 4	1645	1916	2564	3899	8658	13793
Standard deviation	161	128	344	678	1210	1673
Average	1521	1932	2735	4433	9702	15326
Coefficient of variation [-]	0.11	0.07	0.13	0.15	0.12	0.11

Low values of the C_α index indicates that the collected clay samples do not exhibit rheological behaviour (creep). Comparing values of the C_α index, it can be noticed that they grow with the increasing load.

Tab. IV. Values of secondary compression index C_α

	200 kPa	800 kPa
Sample 1	0.0014	0.0024
Sample 2	0.0013	0.0025
Sample 3	0.0017	0.0030
Sample 4	0.0018	0.0028
Standard deviation	0.0002	0.0002
Average	0.0016	0.0027
Coefficient of variation [-]	0.1330	0.0892

Conclusions

For the purpose of this paper, four determinations of compressibility characteristics of the soil by oedometer test, determination of undrained shear strength in triaxial compression, and four determinations of physical characteristics of the soil were made, which allowed to determine physical properties of the soil. The samples intended for the tests were taken at small intervals of 2.70–3.20 m. The tested soil was classified as clay with silt and sand.

On the basis of the surveys it was concluded that, despite the small distance between individual samples, they exhibit various values of physical and geotechnical parameters.

Natural moisture content, which is the basic property of a soil, increased from 16.6 to 21.6% with the sampling depth, contrary to this, the bulk density decreased from 2.12 to 2.05 g/cm^3 with the sampling depth. The specific density of the soil was very similar for all samples, and it ranged from 2.744 to 2.749 g/cm^3.

The results of the test, conducted on the sample in a triaxial compression apparatus, indicated the plastic type of failure. The reason behind that could be soil structure disturbance during the sampling, transportation or storage processes. None of the specimen failure criteria applied in practice occurred during the test. The undrained shear strength c_u was determined for the strain value of 10 % and is equal to 30.37 kPa.

After exceeding approx. 30 kPa, soil stiffness started to increase with the load. The value of the secondary compression index varies depending on depth and the applied loads. Its average value of 0.0016, with the load of 200 kPa, and 0.0027 with the load of 800 kPa. Low values of C_α indicate that the collected clay samples do not show rheological behaviour (creep).

The preconsolidation pressure of the soil was not determined. Based on the already conducted tests and analyses of compressibility curves plotted on a half-logarithmic scale, determinations of the inflexion points of the compressibility curves were inconclusive. Probably, it is associated with soil structure disturbance, which might have occurred during core sampling with a vibrocorer, their transporting or processing. Soil compressibility and preconsolidation pressure depend to a large extent on the quality of the sample and the degree of the disturbance of soil structure. Therefore, the obtained tests results, presented in this paper, should be interpreted with caution.

The introduced laboratory testing procedure was executed for preliminary determination of the physical properties of soils to the depth of 6 m bsf. In case of the research program for the purpose of wind farm realisation, the scope of the laboratory tests and sampling depth should be extended, depending on the water depth and the selected foundation type. In each single case, an investment should be preceded by a proper soil survey programme due to changing conditions, construction type, and the magnitude of the construction load.

References:

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

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

[3] PKN-CEN ISO/TS 17892-1; Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content.

[4] PKN-CEN ISO/TS 17892-2; Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density.

[5] PKN-CEN ISO/TS 17892-3; Geotechnical investigation and testing – Laboratory testing of soil – Part 3: Determination of particle density.

[6] PKN-CEN ISO/TS 17892-5; Geotechnical investigation and testing – Laboratory testing of soil – Part 5: Incremental loading oedometer test.

[7] PKN-CEN ISO/TS 17892-8; Geotechnical investigation and testing – Laboratory testing of soil – Part 8: Unconsolidated undrained triaxial test.

[8] PKN-CEN ISO/TS 17892-11; Determination of permeability by constant and falling head.

[9] PKN-CEN ISO/TS 17892-12; Determination of Atterberg limits.

[10] PN-EN ISO 14688-1; Geotechnical investigation and testing – Identification and classification of soil. Part 1: Identification and description.

[11] PN-EN ISO 14688-2; Geotechnical investigation and testing – Identification and classification of soil. Part 2: Principles for a classification.

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