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Oedometer tests of soft soil and attempt of their numerical simulation

Badania edometryczne gruntów słabych i próba ich numerycznego odwzorowania

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Abstract: For the purpose of this article, oedometer tests were performed on organic silt samples derived from the bottom of an excavation made near the Dead Vistula River. Three independent oedometer tests, with required basic tests for them, were carried out on specimens made from the same sample. Based on the test results, compressibility characteristic, physical and strength parameters of organic silt were determined. Using finite element method, attempts of simulation oedometer tests and calibration of compression parameters were made.

Keywords: edometer, soft soil, Plaxis, finite element method, test, compressibility, calibration, organic soil, silt, adjustment..

Streszczenie: Dla potrzeb niniejszego artykułu przeprowadzono badania edometryczne na próbkach gruntu pyłu organicznego pochodzących z dna wykopu wykonanego niedaleko Martwej Wisły. Wykonano trzy niezależne badania edometryczne na próbkach z tego samego bloku gruntowego wraz z badaniami towarzyszącymi. Na podstawie wyników badań wyznaczono cechy fizyczne, charakterystykę ściśliwości oraz parametry wytrzymałościowe pyłu organicznego. Dokonano próby symulacji badań edometrycznych z wykorzystaniem Metody Elementów Skończonych oraz przeprowadzono kalibrację parametrów ściśliwości badanego gruntu.

Słowa kluczowe: edometr, grunty słabe, Plaxis, Metoda Elementów Skończonych, ściśliwość, kalibracja, grunt organiczny, pył, dopasowanie.

Introduction

A wide range of constitutive models exist to describe the soil behaviour under loading, unloading or another external solicitation. Depending on the soil strength, compressibility and soil – water conditions an appropriate model should be adopted. One, commonly used for soft soils, is called the Soft Soil model. The purpose of this paper was to check the convergence of the mentioned model with real data from oedometer test performed on soft soil such as organic silt. Using the finite element method (FEM) software with the implemented soil models, "soil test" option was used for simulation of the oedometer test.

Sampling and laboratory tests

The soil was sampled in Gdansk, near Dead Vistula River, directly from the bottom of the excavation, at a depth of 2.40 – 2.60 m. All needed classification tests were made in accordance with current standards and best engineering practice. Effective friction angle and cohesion of soil were determined with triaxial apparatus using the consolidated undrained test by British Standard [5]. An oedometer test and its procedure are described in the following parts of this paper where obtained results are compared with FEM test.

Oedometer tests

To determine the soil compressibility, the oedometer tests were performed on three specimens subjected to incremental loading steps. In case of this publication, the following loading sequence was adopted:

6.25; 12.5; 25.0; 37.5; 50.0; 62.5; 75.0; 100; 200; 100; 50.0; 25.0; 50.0; 100; 200; 400; 800 [kPa]

During the test, for each loading step, the settlements of the specimen were recorded. Each step lasted 24 hours, which was enough time to ensure that primary consolidation was achieved. Basing on that and in accordance with the Technical Specification [9], the appropriate charts were plotted to determine the required soil compressibility parameters.

Tests results

Geotechnical parameters for each specimen, obtained in laboratory tests, are summarized in table no. 1 whereas a stress-strain relationship is presented in Fig. 2.

Determined physical parameters of organic silt such as moisture content, wet bulk density, and particle density are comparable for these three specimens. Slight differences may result from different organic matter content or inhomogeneity of the sample. Each curve presented in Fig. 2 was compared to results from the appropriate simulation of oedometer test, which is described, in detail, in the next chapters.

Required by the Soft Soil model compression and swelling indexes, shown in table no. 2, were obtained from the chart of void ratio – stress in semi-logarithmic scale.

Obtained values of compression indexes confirms that the tested organic silt is a soft soil and may lead to significant settlements during loading. Relying on modified compression and swelling indexes and their ratio approximately equal to 4.7 [-] indicates the Soft Soil model, according to the [3], is suitable for this organic silt. The mentioned modified indexes were calculated using initial void ratio, compression and swelling indexes. Besides basic physical properties and compressibility characteristics, the values of preconsolidation stress and strength parameters were needed for simulation. To determine the values, the authors of this paper used Casagrande's [9], Silva's [13] method and triaxial tests, respectively.

Numerical simulation and comparison to laboratory data

Numerical test of compressibility was made using the finite element method. Soil test in the Plaxis software was adopted to simulate oedometer test to compare results from the constitutive model with laboratory results. The same loading se-

Tab. I. Basic physical parameters of soil

PARAMETER	SPECIMEN NO 1	SPECIMEN NO 2	SPECIMEN NO 3
Soil		Organic Silt (orSi)	
Moisture content [%]	57.8	54.0	63.8
Wet bulk density ρ [g/cm³]	1.63	1.65	1.65
Particle density ρ_s [g/cm³]	2.64	2.66	2.64
Initial void ratio e_0 [-]	1.56	1.48	1.62
Degree of saturation S_r [%]	97.82	97.05	100.0
Soil organic matter [%]		~ 5.30	

Fig. 1. Dead weight oedometers

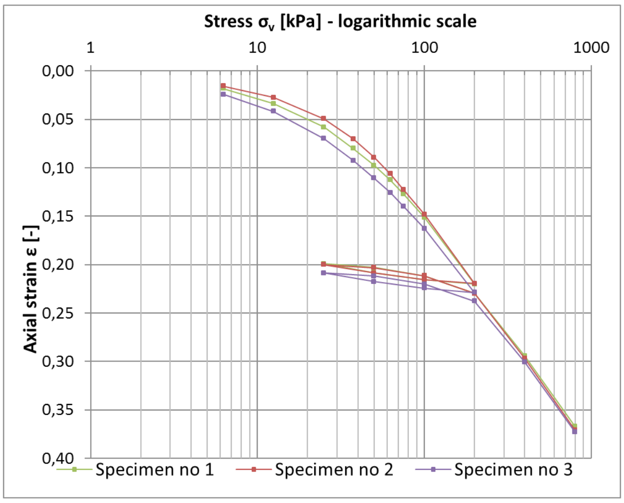

Fig. 2. Stress – strain relationship

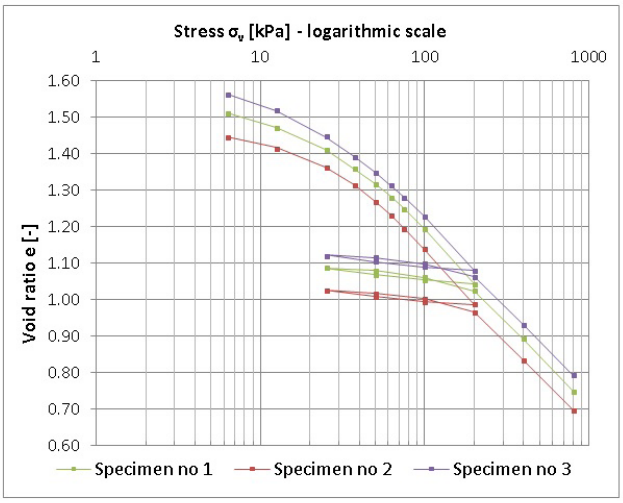

Fig. 3. Stress – void ratio relationship

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quence as for laboratory test was used for simulation.

The charts from laboratory tests and numerical analysis are presented in Fig. 4 and Fig. 5. To obtain better convergence of laboratory results with the Soft Soil model, a smooth adjustment of the soil parameters was made. For every change of parameters, another test was calculated and then compared with laboratory data.

The comparison between laboratory results and data from the numerical analysis for estimated soil parameters is given in Fig. 4. Lack of convergence at the beginning of the test i.e. up to 30 kPa may be caused by the disturbance of the soil structure. Better convergence is observed above 30 kPa, and according to the authors, it may be because of the smaller effect of soil disturbance soil under higher stress. Authors of this article had made an adjustment of compressibility parameters, leaving strength parameters unchanged. The slopes of normal consolidation (NC) and unloading - reloading (OC) lines obtained from laboratory testing differ from those from the simulation. Compression and swelling indexes were increased to make those lines parallel. To achieve the best possible convergence, the preconsolidation pressure has been changed.

The comparison, including final adjusted soil parameters, is given in Fig. 5. The convergence, according to the authors, is good up to 800 kPa, except for the beginning of the test i.e. below 30 kPa. An adjustment made a big difference and allowed much better convergence of the results. The Soft Soil model is sensitive to preconsolidation pressure and does not allow a smooth transition from overconsolidated to normal consolidation line. Strains are calculated in a different way, and their increments are higher when stress exceeds preconsolidation pressure. In the Soft Soil model, a clear point of maximum curvature is always more visible compared to laboratory data, where the same point was very difficult to determine. According to the authors, the disturbance of soil structure [10] or Soft Soil model sensitivity to preconsolidation stress are probably the main reasons for the lack of convergence at the beginning of the test. The same procedure and adjustment were made for other specimens, and the list of calibrated parameters is presented in table no. 3.

Recapitulation and conclusions

Authors of this paper conducted laboratory tests, which indicated that organic silt may be classified as a soft soil. The determined compression and swelling indexes in the range of 0.44 – 0.46 and 0.048 – 0.053, respectively, are typical for such soils. These parameters were the basis for choosing an appropriate constitutive model for attempt simulation of oedometer test. Authors of this article chose the Soft Soil from many available soil models. Tested organic silt probably would show some rheological properties e.g. creep and the Soft Soil Creep model would be better. The first attempt of simulation using the measured geotechnical parameters showed a good convergence with laboratory data except for the beginning

Tab. II. Geotechnical parameters of soil

PARAMETER	SPECIMEN NO 1	SPECIMEN NO 2	SPECIMEN NO 3
Compression index C_c [-]	0.4622	0.4457	0.4526
Swelling index C_s [-]	0.0529	0.0485	0.0504
Preconsolidation stress σ_p [kPa] Casagrande's method		27	
Preconsolidation stress σ_p [kPa] Silva's method		30	
Effective friction angle φ' [°]		18.79	
Effective cohesion c' [kPa]		4.17	

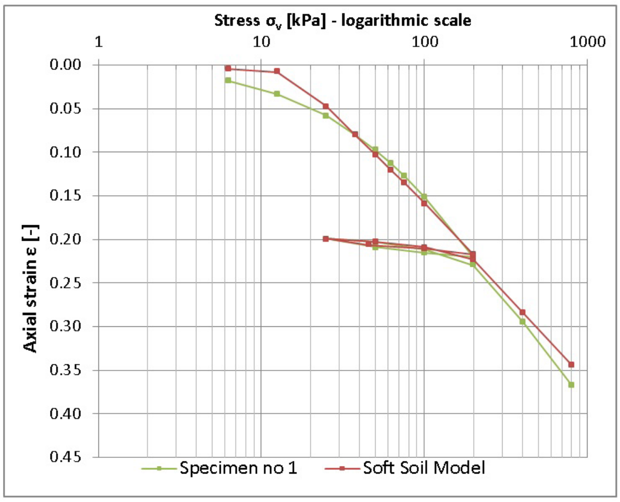

Fig. 4. Comparison laboratory data to simulation (determined parameters)

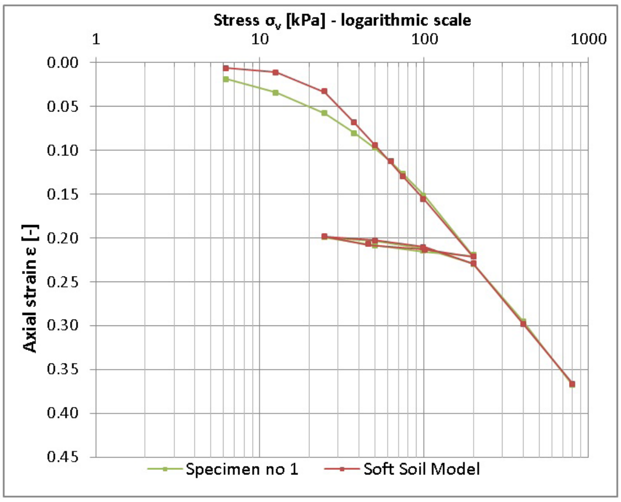

Fig. 5. Comparison laboratory data to simulation (calibrated parameters)

Tab. III. Adjusted parameters

PARAMETER	SPECIMEN NO 1	SPECIMEN NO 2	SPECIMEN NO 3
Compression index C_c [-]	0.5123	0.5077	0.5273
Swelling index C_s [-]	0.0707	0.0685	0.0723
Preconsolidation pressure σ_p [kPa]	22.70	24.00	20.00

of the test. A common procedure, used by many geotechnical designers, when using constitutive modelling, is calibration of soil parameters. Besides oedometers tests, usually, triaxial or other advanced tests are simulated and then compared with laboratory data to calibrate geotechnical parameters. Authors of this article made the adjustment by changing only compressibility characteristic i.e. C_c, C_s, and preconsolidation pressure. Compression and swelling indexes were increased by 10 – 17% and 33 – 43%, respectively. Strength parameters also have an influence on compressibility results in the Soft Soil model, although the authors left them unchanged. Adjustment of compression, swelling indexes and preconsolidation pressure made a difference in convergence. Strains from the oedometer and simulation data were comparable, except for the beginning of the test. The reason for that, according to the authors, may be the disturbance of the soil structure (no clear point of maximum curvature) [10] or the Soft Soil model sensitivity to preconsolidation stress.

Laboratory tests, conducted with best engineering practice provides reasonable soil parameters. According to the authors, it is recommended to adjust them for chosen constitutive model of soil, when using finite element method modelling of geotechnical structures. Without the appropriate procedure, using data directly from tests without critical estimation and calibration the numerical modelling may lead to unreliable results.

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