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Original Research Article

ANALYSIS OF GEOTECHNICAL PROPERTIES OF MIOCENE DEPOSITS OF THE CARPATHIAN FOREDEEP

Wanda KOKOSZKA[1], Izabela SKRZYPCZAK, Krzysztof WILK
Faculty of Civil and Environmental Engineering and Architecture,
Rzeszow University of Technology

Abstract

The Miocene deposits of the Carpathian Foredeep are relatively poorly recognized in geotechnical terms. The article analyzes the properties of the Krakowiec clays of the Przemyśl region, in particular physical and deformation parameters. In this part of the Carpathian Foredeep, clay usually occurs at considerable depth under younger Quaternary deposits. Particular attention was paid to the structural characterization of the tested samples. Structural heterogeneity of the studied clay, noticeable already at the stage of macroscopic studies, causes difficulties in conducting laboratory tests of strength parameters, especially the angle of internal friction and cohesion. The specific, layered, clay-silt structure may cause difficulties in assessing load-bearing capacity and stability of the ground made of this type of soil. The unusual structure should draw attention of the contractors of geological-engineering and geotechnical documentation and encourage them to check mechanical properties by testing material with direct methods. An important issue is also forecasting changes in strain parameters in relation to the estimation of the effects of settlements of engineering structures.

Keywords: Krakowiec clays, oedometer testing, soil structure

[1] Corresponding author: MSc, Eng., Rzeszow University of Technology, Al Powstańców Warszawy 12, 35-959 Rzeszów, +48 178651013, e-mail: wandak@prz.edu.pl

1. INTRODUCTION

Very cohesive soils occurring in Poland, irrespective of factors affecting their origin, nature and intensity of subsequent consolidating loads, are often considered similar to each other in terms of geotechnical strength parameters. This belief is the aftermath of current building standards in use [8,9], where the only factor that is considered to be important to determine value of mechanical parameters of clays is the liquidity index [7,16], regardless previously mentioned factors, as well as possible differences in the grain size or mineral composition.
Very cohesive soils occurring in the area of southern Poland [1,2] are much less recognized in geotechnical terms than clays in central and northern parts of the country. This does not mean, however, that they have not been the subject of both scientific and cognitive interest in the past, as well as in practical applications in industry and construction [3-5,6,13,17]. For geotechnics, the most important are the possibilities of using clays in the construction industry: as a foundation of buildings or as an unprocessed material used in earthworks.
Conducted studies of the Krakowiec clays from the Miocene Machów Formation in the area of the Carpathian Foredeep indicate that the heterogeneity of the structure of the analyzed soil may be the main reason for the dissimilarity of its mechanical properties in comparison to homogeneous clay material. Studies on clay soil, described in other publications [3-5,6,13,17], do not take into account possible influence of the said factor on results of the analysis. The problem of the macroscopic complexity of soils of similar origin should be developed, but it requires the development of certain research and inference standards about the possible impact of heterogeneity on characteristics of the substrate. This article should be treated as a contribution to the exploration of the described issues, important in certain conditions and situations.

2. LABORATORY INVESTIGATIONS

2.1. Physical parameters

The tested cohesive soil originated from the construction area of a bypass road of the city of Przemyśl, from a significant depth of 9.5 - 20 m. All soil samples had similar macroscopic properties, although the humidity of the samples taken from shallower depths was slightly higher (Table 1). Nevertheless, each of them was in a semi-solid state (it had a solid consistency).

Table 1. Physical parameters

depth [m]	w_n [%]	ρ [g/cm^3]	w_P [%]	w_L [%]	I_P [%]	I_C [-]	e [-]	n [-]
9.5-10	19.9	2.09	23.8	64.5	40.7	1.09	0.578	0.366
13.5-14	16.3	2.02	23.2	65	41.8	1.06	0.583	0.368
15.5-16	18.9	2.08	24.4	76	51.6	1.02	0.572	0.364
17-17.5	17.2	2.06	24.8	85.5	60.7	1.09	0.565	0.361
19.5-20	15.4	2.2	22.9	74	51.1	1.11	0.443	0.307

w_n – natural water content; I_P – plasticity index
ρ – density; I_C – consistency index
w_P – plastic limit; e – void ratio
w_L – liquid limit; n – porosity

The natural soil had a very distinct layered structure. Clay layers, usually a few millimeters (0-5 mm) in thickness, dark-green-brown in color were alternated with silty-gray sand layers with a thickness of up to 0.5 mm. It was possible to distinguish single grains to the naked eye. The thickness of the layers was randomly alternating and their layout close to the level.

The consistency of the sand layers was very little, depending on their thickness. It probably resulted not only from the presence of the clay fraction, but it was also partly the apparent cohesion resulting from the remnants of stress consolidating the substrate in the past.

The soil contained 3-5% of calcium carbonate, which could be the reason for increased aggregation (combining of particles), especially in clay soil layers.

Limited cohesion of sand-clay layers in the soil was the cause of difficulties associated with the excision (formation) of samples of natural structure for strain and strength tests. It was not possible to take samples for testing in the triaxial compression apparatus (Figure 1).

Having conducted anometric analysis, it was found that the content of clay fraction was found to be less than 30%, which means, according to PN-88/B-04481 [10], that the tested soil is in fact a cohesive silty clay. However, the actual, lower content of particles with a diameter less than 0.002 mm was only in 40% of the samples taken from shallower depths. During the tests of both physical and mechanical properties the behavior of these samples was similar to the other ones, hence, despite the described inaccuracies, it seems reasonable to assume that the differences in the clay fraction have no decisive influence on the results of the analysis. However, classifications according to PN-EN ISO 14688-2 [11] clearly indicate that the tested soil is a silty clay (Table 2, f_{Cl} = 20 ÷ 40%).

Fig. 1. A soil sample with a visible altered structure

Table 2. Granulation of the soil

Depth [m]	Content of fraction [%]		
	Clay fraction f_{Cl}	Silt fraction f_{Si}	Sand fraction f_{Sa}
9.5-10	23	72	5
13.5-14	23	72	5
15.5-16	30	65	5
17-17.5	30	66	4
19.5-20	31	64	5

2.1. Deformation parameters

Samples with a natural structure were subjected to standard tests in oedometers in the 0 - 400 kPa load range.

Changes in height of the samples depending on the value of a load applied for the first time are presented in Fig. 2. The bold line shows mean values of height changes.

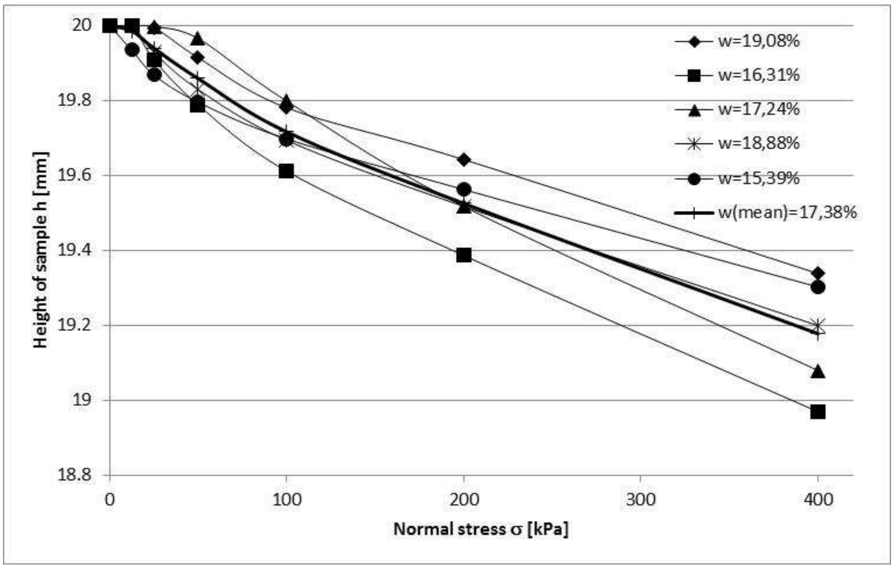

Fig. 2. Diagram of original compressibility of the natural undisturbed samples

Due to transparency of the results, the graph depicting the entirety of compressibility test, based on the values of average deformations, is shown in Fig. 3.

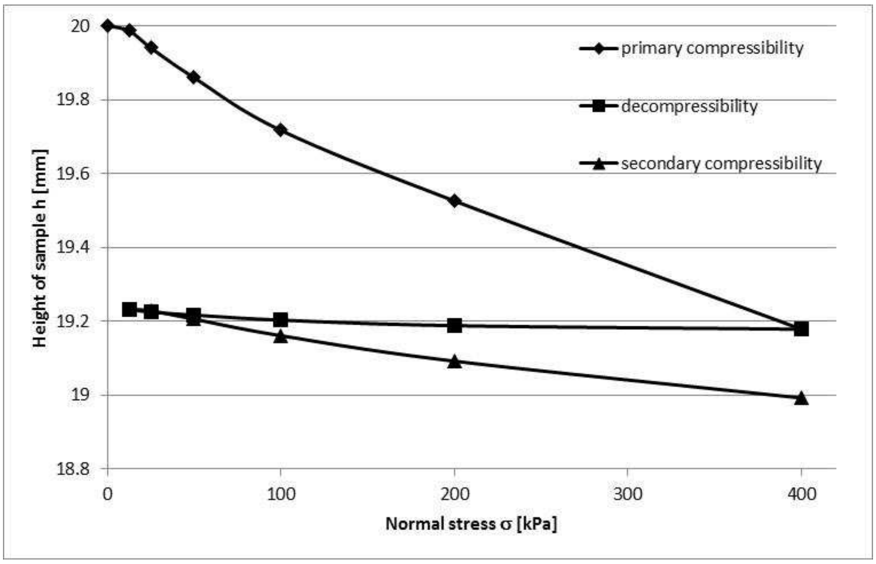

Fig. 3. Diagram of primary compressibility, decompressibility and secondary compressibility of the natural undisturbed samples (mean values)

Important information on deformation capacity of soil is provided by its consolidation index (Table 3), which is the ratio of oedometric modulus of primary and secondary compressibility of soil. This parameter has changed with the increase of normal stress.

Table 3. Coefficients of soil consolidation

Range of stress changes [kPa]	Coefficient of soil consolidation [-]
12.5 - 25	0.09
25 - 50	0.29
50 - 100	0.33
100 - 200	0.37
200 - 400	0.29

For clays, according to PN-81/B-3020) [8], this parameter should be about 0.8. In the case of samples with a natural structure, the analyzed index turned out to be more than twice lower than the norm values. This means there is a significant porosity of soil in the native state, and also confirms that deformation properties result from a macroscopic soil structure (clay-silt alterations present in soil).

3. OTHER INVESTIGATIONS OF KRAKOWIEC CLAYS

Krakowiec clays have already been the subject of research due to their use as a building foundation and as a material of ceramic products. The most advanced studies of this medium were conducted by Kaczyński and concerned grounds located in the south-eastern part of Poland [3-5]. The subject of this research was soil taken from 54 locations, including Przemyśl-Buszkowice. The author points to the diverse structure of Krakowiec clays and the lack of repeatability of physical features. The oedometric values of the compressibility modulus determined within the aforementioned tests were within the limits of 5900-148000 kPa (23400 kPa for the soil from Przemyśl-Buszowice classified as clay), with Kaczyński stating that higher values concern semi-solid clays [3,5].
In Kaczyński's work [5], based on the results of extensive research, correlation relationships between various parameters of the Upper-Moravian Krakowiec clay were derived, including the parameters describing the pre-consolidation of such substrate. The following relations have been determined, among others:

(1) modulus of compressibility of soil and preconsolidation stress,
(2) content of clay fraction and preconsolidation stress,
(3) liquidity index and preconsolidation stress.

For a particular soil material, the preconsolidation stress determined on the basis of each of previously mentioned relations ((1), (2) and (3)) should be the same. Knowing, therefore, the content of clay fraction or liquidity index of soil and comparing the relations in pairs ((1) with (2) and (1) with (3) - for a constant value of preconsolidation stress), the value of oedometric compressibility modulus can be determined in relation to the mentioned parameters. The compressibility modulus values calculated using this method were the following: 24600 kPa - based on the content of clay fraction and 43350 kPa - based on liquidity index of soil.
In other study, concerning very cohesive soils from all over Poland (34 places) [17] for liquidity index of -0.34-0.35, the value of oedometric compressibility modulus was within the range of 5000-39000 kPa. In analysis limited only to samples of Krakowiec clays (from 5 locations), the oedometric values of compressibility modulus ranged from 14000 kPa to 20000 kPa, respectively for liquidity index between -0.12 and 0.14.

4. CONCLUSION

The soil described in the article is a material with a specific structure, but it certainly should not be treated as a unique case. The oedometric modulus of compressibility of the substrate made of Krakowian clays proved to be much lower than suggested in the standard (PN-81/B-03020) [8], but also lower than those described by other researchers [5,17]. It seems reasonable to assume that the reason for differences in the behavior of the studied ground was its layered structure. The above mentioned structure of the material fostered the acceleration of consolidation deformations (accelerating the outflow of water) during ground load in the past. On the other hand, when such a load ceased, it facilitated the physical recompression of soil (increase in volume) due to small cohesion of the sand altering layers.
Low thickness of clay and sand layers makes it impossible to isolate them, let alone treat them as two ground bases with different properties. The tested soil should be considered as a kind of natural composite whose features will certainly not be “the resultant” of properties of soils that form it.
At the stage of ground recognition, the described abnormal soil structure should draw attention of the contractors of geological-engineering or geotechnical documentation and at least encourage them to check mechanical properties by direct material testing.
Regarding the soil analyzed and described in this paper, the attention should be paid to the lack of scientific studies that would take into account the specificity (layered structure) of a cohesive soil in the zone of the glaciation border of the South-Pomeranian region of Przemyśl [15]. In any case, the necessity to extend

geological and geotechnical analysis to the impact of heterogeneous structure on the characteristics of soil material concerns all the locations, not only the mentioned one. It should be emphasized that a reliable identification of a ground foundation for construction purposes cannot be based only on determination of basic physical parameters, and then, based on that, on mechanical properties of soil and stress-strain relations [12,14]. Dependencies given in the standards, although certainly needed, should not be the only determinant and point of reference in matters relating to the assessment of the soil.

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ANALIZA WŁAŚCIWOŚCI GEOTECHNICZNYCH UTWORÓW MICEŃSKICH ZAPADLISKA PRZEDKARPACKIEGO

Streszczenie

Iły mioceńskie Zapadliska Przedkarpackiego są dość słabo rozpoznane pod względem geotechnicznym. W artykule przeanalizowano właściwości iłów krakowieckich rejonu Przemyśla, w szczególności parametry fizyczne i odkształceniowe. W tej części Zapadliska Przedkarpackiego iły występują przeważnie na znacznych głębokościach pod nakładem młodszych osadów czwartorzędowych. Zwrócono szczególną uwagę na charakterystykę strukturalną badanych próbek. Niejednorodność strukturalna badanych iłów, zauważalna już na etapie badań makroskopowych, powoduje trudności w przeprowadzaniu badań laboratoryjnych parametrów wytrzymałościowych, głównie kąta tarcia wewnętrznego i spójności. Specyficzna warstwowana iłowo-pyłowa budowa może powodować trudności w ocenie nośności i stateczności podłoża zbudowanego z tego typu gruntów. Nietypowa struktura powinna zwrócić uwagę wykonawców dokumentacji geologiczno-inżynierskich i geotechnicznych i skłonić ich do sprawdzenia właściwości mechanicznych poprzez badania materiału metodami bezpośrednimi. Ważną kwestią jest również prognozowanie zmian parametrów odkształceniowych w nawiązaniu do szacowania skutków osiadań obiektów inżynierskich.

Słowa kluczowe: iły krakowieckie, badania edometryczne, struktura gruntu

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