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THE MEASUREMENT OF SELECTED SOIL PARAMETERS OF FORMER OPEN PIT MINE WITH THE USE OF TRIAXIAL STRESS APPARATUS

Identification of geotechnical soil conditions often requires execution of laboratory tests, especially if you want to measure dynamic parameters of the soil. At present, the triaxial shear apparatus is widely applied in determination of the parameters of the soil. On the basis of the soil samples analysis, the examination results provide a wide range of data from basic performance parameters, e.g. internal friction angle and cohesion, to most complex ones like Young's modulus permanent side effective stress of water samples. Furthermore, the Soil Structure Interaction Laboratory of Cracow University of Technology, has carried out the measurements of propagation of shear waves velocity with the use of bender elements tests.
This work presents geotechnical conditions and the analysis of the results, which might be found useful to determine the transportation load parameters of designed S-7 and S-52 routes, as well as overall impact on soil/structure and surrounding areas located over the former clay open-pit mine. The landslides existing in the vicinity of the mine have prompted the authors to take that action.

Keywords: bender, triaxial stress apparatus, wave propagation

1. Introduction

Zesławice Clay Mine (Kraków, District XVII – Wzgórza Krzesławickie) is located on the area of 45,12 ha [1]. Currently, no minerals or clay raw materials are extracted there for the industrial purposes. However, the mine and its surrounding area have been classified as industrial wasteland and intended for land rehabilitation. The purpose of the land rehabilitation is to return the soil and the mine site to an acceptable degree of its former state. The prospective of development there is also taken into account. Furthermore, the western side of the mine may be a part of a transport hub for Kraków – Mistrzejowice. It means that

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the link of S-7 expressway and S-52 route, a northern bypass of Kraków, will be located there. Although the area is abundant in clay from the Miocene period, it has been valuable for its Tertiary deposits. When the land rehabilitation process is completed as well as other investments made, this transport hub will definitely be the next operated route nearby Kraków.

2. Geotechnical conditions

Soil classification and description is based on analyses and laboratory tests, all according to principles of European and ISO standards. The triaxial shear apparatus has also been used in the laboratory research to determine and verify soil parameters for geotechnical strata. Archival footage [2] and contemporary publications [3-4,5], with a reference to the mentioned above area, have also been analyzed. Currently, the area around the mine is situated on vast but rough terrain, which contributed to mining industry and has negative impact on the landscape. Nowadays, no works are carried out. In the past, the open pit mine has been utilized for its Tertiary clay deposits from the Miocene period, that are covered by the Quaternary layers with the thickness from 2 m up to 10 m. The deposits, layered on a local hill, extend from west-side to the east-side of the mine. The Baranówka river was the starting point for the mining works, and then they were moving southwards and eastwards. The mine stretches within Miechowski Plateau and partially Krakowski Plateau, close to two reservoirs of drinking water located nearby. The borehole (for undisturbed samples) is located by the southern part of the mine, at about 220-230 m above the sea level. The Tertiary clay deposits do not contain water bearing layers, while the Quaternary deposits are poorly watered. But the water leakage is clearly noticeable there, especially on the border between the Tertiary and Quaternary layers.

3. Soil parameters

Soil samples for three consecutive geotechnical layers have been investigated [6]. The first layer consists of plastic silts (Si) to clayey silts (clSi). The following layers constitutes of medium dense sands (Sa) to silty sands (siSa) and stiff and very stiff clays (Cl) from the Miocene period. The undisturbed soil samples have been collected in the mine at the depth of 1 m below the surface, from different parts of the site, where they are exposed. Afterwards, the samples have been kept stored at +5 °C degrees to prevent the loss in humidity. Furthermore, the base material is for the comparative study and analyses, the results of which are presented below (Table 1).

Tabela 1. Wybrane wyniki analiz laboratoryjnych gruntów z kopalni iłów Zesławice przeprowadzonych zgodnie z PN EN ISO 14688 [6] and PN EN ISO 17892 [6]

Table 1. Selected laboratory results from Zesławice mine, according to PN EN ISO 14688 [7] and PN EN ISO 17892 [6]

Soil layer		I	II	III
Water content [%]		15 ÷ 18	7 ÷ 9	26 ÷ 28
Soil density ρ [g/cm^3]		2,30	1,65	2,10
Soil particle density ρ_S [g/cm^3]		2,67	2,65	2,70
Particles	sand f_{sa} [%]	5	88	1
	silt f_{si} [%]	79	10	20
	clay f_{cl} [%]	16	2	79
Plastic limit w_p [%]		20÷23	-	30÷32
Liquid limit w_L [%]		30÷32	-	87÷90
Liquidity index I_L [-] or density index I_D [-]		0,12	0,55	0
Soil consistency/Soil density		Firm	Medium dense	Stiff

4. Triaxial shear apparatus tests

As to describe basic soil properties and determine the stress-strain curve for considerable range of deformations, the triaxial shear apparatus has been utilized. The Soil-Structure Laboratory has got installed two types triaxial shear apparatuses, VJ-Tech (Fig.1), manufactured by VJTech Ltd (UK), one of which

Rys. 1. Widok ogólny aparatu trójosiowego ściskania

Fig. 1. Triaxial stress apparatus

is equipped with piezoelectric *bender* elements. The use of piezoelements, which mounted in a stand and soil sample cap, enable to determine the dynamic properties for small soil deformations range. The piezoelements are able to generate transverse and longitudinal waves. Shear modulus parameters, $G_{s,}$ is determined by measuring time history of a transverse wave propagation in soil sample and the soil density with the following formula:

$$G_s = \rho V_s^2 \tag{1}$$

The test results may be confirmed by the in-situ investigations with the use of SASW method [8]. The triaxial shear apparatus analyses soil samples with a diameter range *38÷150 mm*. Undisturbed soil sample, as well as disturbed ones (remoulded) are also a subject of analyses, but the latter entails a preparatory test to determine and calculate overconsolidation ratio (OCR) before the next tests are carried out. Only undisturbed soil samples, cut out from a block of soil collected on the spot are examined.

5. Static tests results

As far as stress-strain interdependence is determined, the triaxial shear apparatus has been used. The procedure of consolidated drained (CD) test is conducted according to PN EN ISO 17892 (a British BS 1377 is also applicable). The sample, of a cylindrical cross-section with 50 mm diameter and height of 100 mm, secured in rubber membrane, has been positioned in a loading frame. Water saturated soil (Skempton’s formula’s parameter was 0.95 which stood for 95% of pores saturated with water) is the starting point for conducting the tests, while the saturation is performed using the back pressure method in which the vented water is pumped into the soil sample. As a result, back pressure increases proportionally if effective stress is on a fixed level. All samples are subject to isotropic consolidation, with effective stress at several levels (e.g. *100, 150, 200 kPa*). During the tests, the effective stress and stress in the chamber is maintained at fixed levels, changes in volume are recorded until the whole water has drained in order to allow the water pore pressure to dissipate.

Tabela 2. Rezultaty badań przeprowadzonych na próbach gruntu z kopalni Zesławice

Table 2. Test results based on samples from Zesławice open-pit mine

Layer	I	II	III
Effective internal friction angle ϕ' [°] (CD method)	30	32	16
Effective soil cohesion c' [kPa] (CD method)	25	4	40
Dynamic shear modulus G_s [MPa]	78,8	117,3	75,8

The timing is dependent on the soil being investigated. It takes 36 hours for clayey silt to consolidate, and about 1 hour for sand, while nearly 336 hours as far as clay is concerned. This constituted the most complex and the longest process during the investigation. After preparing the soil samples, they are subject to shear tests in order to determine the maximum deviator stress value as the considerable range of deformations is expected. As a result, the triaxial stress apparatus enables all necessary measurements to be conducted in order to obtain parameters for different geotechnical layer of soil investigated. Table 2 exhibits the results of the investigations.

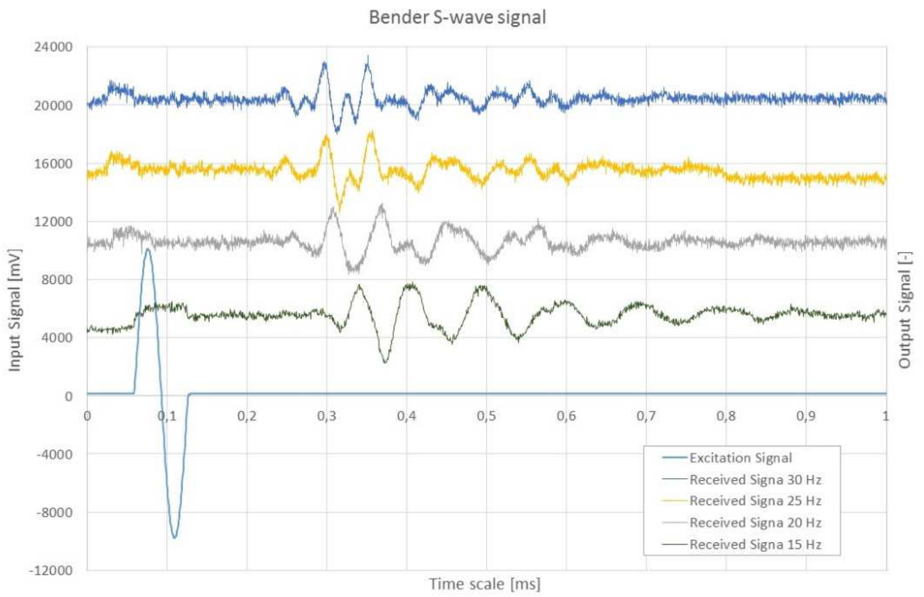
6. Determining the velocity of a transverse wave

The triaxial shear apparatus has been adjusted to specify the velocity of transverse waves in soil specimens. The use of piezoelements, which enhance the quality of testing, enable the acoustic waves to travel throughout the soil specimen. Fig. 2 presents typical cylinders with visible piezoelectric elements.

Rys. 2. Cylindry z widocznymi elementami piezoelektrycznymi używane w badaniu propagacji fal w warunkach laboratoryjnych w aparacie trójosiowego ściskania (http://geotechpedia.com/Equipment/Show/211/Bender-elements).

Fig. 2. Cylinders with visible piezoelectric elements used to study wave propagation in laboratory conditions in the triaxial stress apparatus (http://geotechpedia.com/Equipment/Show/211/Bender-elements).

As for the calculation of the velocity of a transverse wave, the time of the signal propagation from the first particle of a medium to the last particle needs to be calculated, provided the values are known. The condition of soil influences the excitation signal as well as the frequency range. The amplitude of a signal depends on soil response. Fig. 3 presents the exemplary output values for different excitation signals. The response signal for the excitation of the frequency equal to $f = 15\ kHz$ is the one, which seems to be the most reliable as it represents the perfect sinusoid. The *peak to peak* method is the simplest and may be useful to calculate the timing of a signal from acquired data.

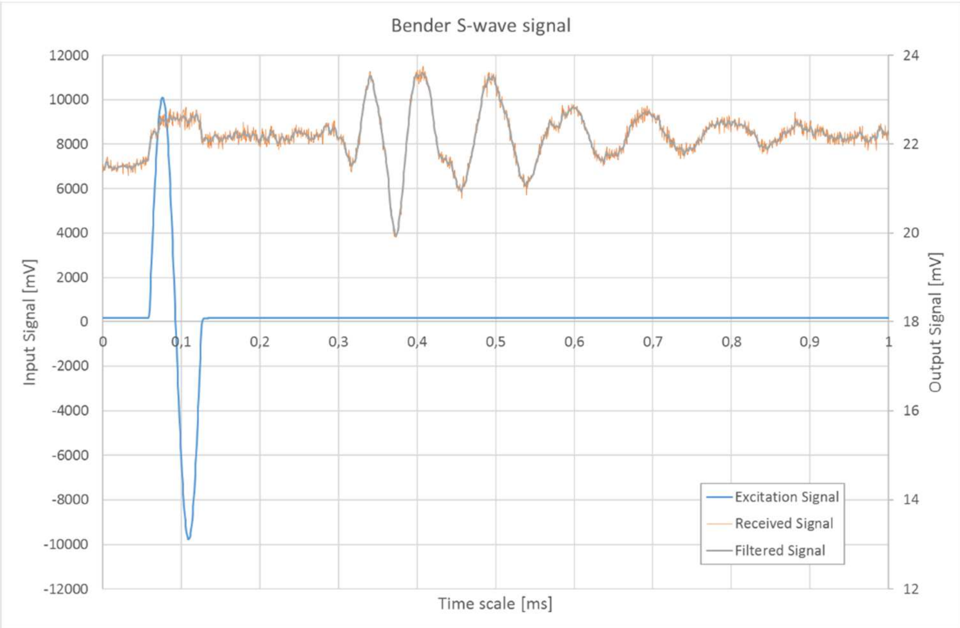


Rys. 3. Przykładowe przebiegi czasowe drgań dla różnych częstotliwości wymuszeń

Fig. 3. Exemplary output values of bender elements for various excitation frequencies

The recorded shear wave (S-wave) signals may also be analysed using typical methods of signal processing. Example of which is the standard filtering with the use of Kalman filter in order to receive filtered time history of vibrations, which gives more accurate data on wave propagation. Fig 4 presents the exemplary output value of time history for excitations input and received output signals. The output signals represent the original signal recorded by sensor and processed with Butterworth low-pass filter. In table 2 the Kirchhoff dynamic shear modula (G_s), for each layer of soil that is investigated, are shown. The values correspond to consolidated isotropic stresses equal to $\sigma = 150\ kPa$.

As far as the shear modulus G_s is concerned, two methods of tests are applied namely unconsolidated undrained (UU) and consolidated isotropic drained (CID or CD). The first method – unconsolidated undrained (UU) in which the shear process does not include the consolidation part. In this case only the first and the third layer of soil are subject to tests. The other method – the consolidated isotropic drained (CID) method in which the specimen, in the discussed case sand, being partially consolidated, is investigated. During the last investigation, the water flows slowly out of the specimen, while the water pressure is adjusted to fixed pore pressure level.



Rys. 4. Przykładowy przebieg czasowy zarejestrowany przez element bender – sygnał oryginalny oraz przefiltrowany

Fig. 4. The exemplary time histories in bender elements for original and filtered signals

7. Final remarks

This work presents the research results of soil specimens that are extracted in former clay open-pit mine Zesławice. The in-situ field tests and laboratory investigation enabled us to determine the soil condition, as well as the soil physical properties. The soil parameters such as effective values of internal friction angle and cohesion are beneficial for the slope stability analysis. Such analysis helps us to identify unstable slopes, specify the triggering factors of a slope failure and find endangered areas where various mechanisms might lead to soil mass movements. The output of the analysis should be not only the risk probability but also it should include the evaluation of the slope shape, which reduces the risk of sliding or collapsing. As far as slope stability analysis is concerned, it should definitely be based on detailed geotechnical research and field work.

The authors of this paper would like to point out, that the Laboratory of Soil-Structure Interaction, a unit of Cracow University of Technology carried out the field work in Zesławice mine from 2011 to 2016 only for the scientific purposes. Presently, the reclamation scheme draft of the mine is being prepared alongside the steps taken to secure the mine site by leveling off the ground.

References

[1] Uchwała NR LXIV/820/09 Rady Miasta Krakowa z dnia 4 lutego 2009 r. w sprawie Uchwalenia miejscowego planu zagospodarowania przestrzennego obszaru "Zesławice" w Krakowie.

[2] Dokumentacja geologiczna złoża surowców ceramiki budowlanej "Zesławice" w kat. B+C1+C2, Kraków: Zakład Projektów i Dokumentacji Geologicznych w Katowicach - oddział w Krakowie. Ministerstwo Budownictwa i Przemysłu, 1979.

[3] Olesiak S, Badania wybranych właściwości mioceńskich iłów w rejonie Krakowa z wykorzystaniem sondy wkręcanej WST. Rozprawa doktorska, Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie, Wydział Górnictwa i Geoinżynierii, Katedra Geomechaniki, Budownictwa i Geotechniki.

[4] Wysokiński L (ed.), Zasady oceny przydatności gruntów spoistych Polski do budowy mineralnych barier izolacyjnych. Instytut Techniki Budowlanej. Warszawa 2007.

[5] Olesiak S, Wykorzystanie sondy wkręcanej WST w badaniach mioceńskich iłów krakowieckich. Górnictwo i Geoinżynieria, issue 1, 2009, pp. 467-473.

[6] PKN-CEN ISO TS 17892-1÷12. Geotechnical investigation and testing – Laboratory testing of soil.

[7] PN EN ISO 14688 Geotechnical investigation and testing. Identification and classification of soil. Principles for a classification.

[8] Kogut J, Oszacowanie parametrów dynamicznych podłoża gruntowego. Czasopismo Techniczne, zeszyt 2-B, 2007, pp. 55-63.

WYZNACZENIE WYBRANYCH PARAMETRÓW GRUNTU Z KOPALNI IŁÓW PRZY UŻYCIU APARATU TRÓJOSIOWEGO ŚCISKANIA

S t r e s z c z e n i e

Rozpoznanie warunków geotechnicznych podłoża gruntowego wykonywanego w celu ustalenia parametrów dynamicznych podłoża często wymaga wykonania badań laboratoryjnych. Obecnie jednym z najbardziej popularnych sposobów określania parametrów gruntów jest użycie aparatu trójosiowego ściskania. Wynikami badania próbki gruntowej w aparacie trójosiowym mogą być oprócz podstawowych parametrów wytrzymałościowych czyli kąta tarcia wewnętrznego i spójności, parametry takie jak moduł odkształcenia liniowego przy stałym bocznym naprężeniu efektywnym w próbce w warunkach z odpływem, jak i bez odpływu wody z próbki. Dodatkowo w laboratorium Katedry Współdziałania Budowli z Podłożem Politechniki Krakowskiej, przeprowadzano badania określenia prędkości fali poprzecznej przy wykorzystaniu elementów *bender*. W pracy przedstawiono warunki geotechniczne, a następnie podsumowano wyniki badań, które w przyszłości posłużą autorom do określenia wpływu obciążeń komunikacyjnych trasy S-7 i S-52 na podłoże gruntowe terenu kopalni i ich okolic. Analiza ta wynika z występowania kilku osuwisk w bezpośredniej otoczeniu kopalni.

Słowa kluczowe: bender, aparat trójosiowego ściskania, propagacja fal

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