INVESTIGATIONS OF SPOIL DUMP SOILS IN SELECTED AREAS OF THE INTERNAL SPOIL HEAPS OF THE „PAK KONIN LIGNITE MINE S.A".

BADANIA GRUNTÓW ZWAŁOWYCH W WYBRANYCH REJONACH ZWAŁOWISKA WEWNĘTRZNEGO KOPALNI „PAK KOPALNIA WĘGLA BRUNATNEGO KONIN S.A."

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The article presents the scope and methodology of investigations carried out in selected two locations of the internal spoil heaps of Jóźwin IIA and Jóźwin IIB open pits, PAK Konin S.A. Lignite Opencast Mine. The results obtained are also discussed. The studies carried out included geological drilling with undisturbed specimen sampling and borehole core sampling, SCPTu static soundings, and laboratory tests.

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Keywords: *spoil dump soils, geotechnical laboratory testing of soil, SCPTu soundings*

W artykule przedstawiono zakres oraz metodykę badań wykonanych w wybranych dwóch lokalizacjach zwałowiska wewnętrznego PAK Kopalni Węgla Brunatnego Konin S.A.: odkrywek Jóźwin IIA oraz Jóźwin IIB. Omówiono również uzyskane wyniki. W ramach przeprowadzonych badań wykonano m.in wiercenia geologiczne z poborem próbek NNS oraz rdzeni wiertniczych, sondowania statyczne SCPTu oraz badania laboratoryjne.

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Słowa kluczowe: *grunty zwałowe, badania laboratoryjne, sondowania SCPTu*

Introduction

The usage of spoil heaps in lignite opencast mines for the placement of photovoltaic panels and wind turbines has recently become a very attractive form of its reclamation. This makes it possible to simultaneously maintain the industrial and energy function of these areas with virtually zero emissions of harmful substances into the environment. Despite the high attractiveness of the use of these areas for this type of investment, it should be noted that the soils building up spoil heaps are often characterized by high lithological variability and reduced strength parameters. Therefore, in the aspect of the foundation of the aforementioned objects, it is important to carry out geological-engineering studies to determine basic physical-mechanical parameters of spoil dump soils.

The studies in the area of Jóźwin IIA and Jóźwin IIB pits of internal spoil heaps at PAK Lignite Opencast Mine Konin S.A were carried out for geological-engineering reconnaissance and the purpose of further analysis of technical solutions for the foundation of a photovoltaic farm or wind turbines in this place based on obtained results.

Location and land development of the study area

Administratively, the study area is located in the Kleczew Commune, in the Konin District of the Wielkopolskie Voivodeship, in the areas of spoil dumps of the Jóźwin IIA and Jóźwin IIB pits of the „PAK Konin S.A Opencast Mine." (Fig.1).

The study area has been restored to its original elevation as a result of the end of lignite mining and the reclamation works carried out. At present, the area is leveled, with numerous drainage drains, partly covered with turf (Jóźwin IIB pit), and used for agriculture (Jóźwin IIA pit).

Fig. 1 Location of the study area
Rys.1 Lokalizacja terenu wykonanych badań

Tab. 1 Scope and quantity of laboratory samples taken from the area of Jóźwin IIA and Jóźwin IIB spoil heaps
Tab. 1 Zakres i ilość badań laboratoryjnych próbek pobranych z obszaru zwałowisk Jóźwin IIA oraz Jóźwin IIB

Test type	Number of the performed laboratory tests
Soil macroscopic description	23
Water content	25
Bulk density	22
Particle density	22
Aerometric (hydrometric) analysis	23
Liquidity index	13
Consistency	13
Oedometric modulus of primary compression and secondary compression	8
Total angle of internal friction	6

Fig. 2 Part of the Jóźwin IIA spoil dump - study area
Rys.2 Fragment zwałowiska Jóźwin IIA - obszar badań

Scope of conducted studies

Within the framework of the studies described in this paper, 49 boreholes, 3 to 10 m deep were drilled in the area of the Jóźwin IIA and Jóźwin IIB spoil heaps using the „dry" mechanical rotary drilling system. One borehole 40 m deep was drilled using the "drilling mud" method. The boreholes took 69 undisturbed soil samples from which, after verification, the material was selected for laboratory tests (Tab.1).

Static SCPTu soundings were also carried out in the vicinity of the boreholes drilled, for a total of 49 tests (46 tests to a depth of 3 m and 3 tests to a depth of 10 m) [12-15].

Geological structure

The investigated soils are a composite of sediments originating from the overburden of the Pątnów lignite deposit, which were redeposited during the mining process, i.e. they were excavated to the ground surface and then, after the end of mining, during the reclamation of the excavation, the soils were reused to fill the mining pit to the pre-excavation level.

These were originally cohesive and non-cohesive Quaternary and Palaeogene-Neogene formations. The Quaternary formations were represented mainly by glacial till and sandy clays of the Mid-Polish Glaciation (about 50%) and less abundantly by clays, organic soils, sands, and gravels.

Paleogene-Neogene sediments were mainly represented by Pliocene clays, the so-called Poznan clays. In general, cohesive soils originally accounted for 2/3 of the total volume of the overburden [16].

Based on the performed boreholes, SCPTu soundings, and laboratory tests, it was recognized that the investigated soils occur mostly as sandy loams and clayey sands with an admixture of gravel and stony fractions and the so-called Poznan clays. Cohesive soils account for more than 90% of the tested samples. Non-cohesive soils are represented mainly by silty sands, occasionally fine and medium sands. The results of the study of the granulometric composition are generally similar to the results of the archival studies of these soils, where cohesive soils in the form of clays and loams accounted for 2/3 of the volume of the overburden among the samples studied from various depths [12-14].

Methodologies used in laboratory tests

For all the undisturbed samples (Fig.3) delivered to the laboratory, macroscopic analysis was carried out according to the standard [1,2], where the primary and secondary fractions of the soil were separated, its color, consistency, compactness, and carbonate content class were determined using 10% hydrochloric acid. During macroscopic testing, the natural moisture content of the soil was determined according to [3] and the bulk density according to [4]. Due to the presence of gravel and stones in the soil, the ring method was used to determine the bulk density ρ. This involves forcing a ring of known mass and volume into a soil sample with an intact structure and natural moisture content in such a way that the structure is not disturbed. The density of the soil particles ρ_s was determined according to the method described in the standard [5] using calibrated pycnometers with a 50 ml capillary.

An areometric (sedimentation) analysis was carried out to determine the percentage compactness of the fraction for fine-grained soils where the fraction below 0.063 mm is at least 10 % [6]. The test was performed using a dispersant in the form of a 4% sodium hexametaphosphate solution. A set of sieves with square mesh side sizes of 0.063 mm; 0.100 mm; 0.200 mm; 0.63 mm; 1.0 mm; 2.0 mm; 6.3 mm; 10.0 mm were used for sieving. The density of the solution was measured 30 s, 1, 2, 4, 8,30 minutes, 1, 2, 6, and 24 hours after mixing with a Casagrande areometer. The temperature of the suspension was monitored during the readings. From the data obtained, a grain size curve was drawn up and the percentage of each fraction (gravel, sand, dust, and clay) was separated.

Testing of the liquid limit w_L was carried out with a cone penetrometer using an 80 g stainless steel cone at an apex angle of 30° according to standard [7]. From the prepared ground paste, the depth of immersion of the cone was read after each addition of water and a sample was taken for moisture determination. For one sample, the operation was repeated until a minimum of 4 points of different moisture content were obtained.

From the data obtained, a liquid limit diagram was drawn up from which the moisture content of the soil at a cone penetration of 20 mm was read. This represents the result of the liquid limit. The plactic limit was determined by rolling a 6 mm diameter ball into a 3 mm diameter roller according to [7]. The test was terminated when the first cracks appeared on the roller. After obtaining parameters such as natural water content, plastic limit and liquid limit, liquidity I_L, plasticity index I_p and consistency index I_C were determined.

The primary compressibility modulus M_0 and secondary compressibility modulus M of the soil were performed on soil samples with intact structure placed in a non-deformable ring without the possibility of lateral expansion according to [8]. Rings with a diameter equal to 65 mm and a height equal to 20 mm were used. A cylindrical specimen placed in the oedometer apparatus was subjected to gradual increments of loading and unloading. The load steps were successively 12.5 kPa; 25 kPa, 50 kPa; 100 kPa; 200 kPa; and 400 kPa after each load and unload change, sensor readings were recorded at 5; 10; 15; 30 seconds 1; 2; 5; 15; 30 minutes 1; 2; 4; 8; 19; 24 hours. At the end of the test, a plot of soil compressibility and consolidation curves was prepared for each load.

A triaxial test without consolidation and drainage according to the method given in [9] was performed in a GDS 76TC3 apparatus on 3 cylindrical specimens of φ = 50 mm and H = 100 mm under loads of 50 kPa, 100 kPa, and 150 kPa. Shearing was carried out at an average rate of 0.20 mm/min while maintaining constant pressure in the chamber until the vertical strain of the specimen reached 15%.

Fig. 3 The undisturbed soil samples from the internal dump of the KWB Konin mine
Rys.3 Próba gruntu o nienaruszonej strukturze pochodząca ze zwałowiska wewnętrznego KWB Konin

Methodologies used during drilling

The boreholes were drilled using the mechanical-rotary method with ‚dry' spiral augers and full cored using a ‚drilling mud' drill crown. Boreholes up to a depth of 3 m were drilled in a regular 100/100 m grid. On the other hand, 3 boreholes to a depth of 10 m were drilled in a grid forming a triangle with a central 4 borehole of 40 m depth. In this case, the distance between boreholes was several metres. During the drilling, observations of the lithological formation were also carried out and the following parameters were determined: soil type, consistency, moisture content and color in accordance with the applicable standards [1,2].

Soil samples of intact undisturbed-type specimens were taken in accordance with the standard [11], from a depth of 2 m below ground level, using a Shelby-type piston sampler.

Methodologies used in the SCPTu tests

In-situ measurements with the method of static penetration tests were carried out with piezocone, the structure of which meets the requirements of the CPTu test standard and is characterized by the following geometry: area of the cone base - 10 cm^2 or 15 cm^2; area of the friction sleeve - 150 cm^2 or 225 cm^2 respectively; cone angle 60^o; and a filter built-in directly behind the tip of the cone (according to the standard, the u2 location of the measurement). The cone penetration tests were carried out with a constant penetration velocity equal to 2 cm/s. The geotechnical equipment was compliant with [10] and Eurokod 7 [15].

During the SCPTu tests, the following parameters were registered with a depth resolution of 1 cm:

- Channel 1: Cone resistance q_c [MPa] in the range of 0-100 MPa with a resolution of 0.01 [MPa];
- Channel 2: Sleeve friction f_s [kPa] in the range of 0-3000 kPa with a resolution of 0.71 [kPa];
- Channel 3: Pore pressure at the u2 position [kPa] (directly behind the cone, below friction sleeve) in the range of 0-3000 kPa with a resolution of 0.27 [kPa];
- Channels 4-5: The inclination of the cone in two mutually perpendicular directions ix and iy [°] in the range of ± 30 ° with a resolution of 0.1 °;
- Depth encoder channel: cone penetration velocity v [cm/s] with a resolution of 0.08 cm / s.

In the performed SCPTu tests, the courses of time accelerations were additionally recorded in the ground in a horizontal plane in two mutually perpendicular directions ax(t) and ay(t), and additionally the acceleration in a vertical direction az(t). The registration took place every 1 m of the tested depth [15].

Discussion of the findings

The sample subjected to the laboratory analysis was characterized by high variability of compaction. After cutting the cores, a significant loosening of the soil and a lot of free spaces (pores) were observed (Fig.4). In some places within the core, the soil showed greater compaction. During macroscopic tests, variable soil moisture and soil conditions (consistency) were observed within one sample. For the moisture testing, samples were taken from several places within the tested core material. An arithmetic mean of the obtained results was assumed as a final result. The water content in the tested boreholes varies between 9,6% and 22,5%.

The tested plastic limit w_p ranges from 9.4% to 11.8% while the results of the liquid limit w_L range from 16.5% to 62.0%.

On the basis of laboratory tests, geological-engineering parameters such as plasticity index I_p ranging from 6.0% to 41.2% and consistency index I_c ranging from 0.37 to 1.10 were derived.

The values of the consistency index I_c determined from SCPTu static soundings also show great variability, especially to a depth of about 10 m and range from 0.26 to >1. The relative density index compaction I_D determined from SCPTu static soundings for non-cohesive soils ranges from 0.13 to 0.77 [15].

The conducted grain size distribution analysis shows a high content of sand f_p=46-67% and silt fπ=22-34% while clay constitutes fi=4-46%. It should therefore be stated that these are cohesive soils and their cohesion is mainly determined by the silt content. Only in one case, it is clay. The density results of the analysed material are from dry density of solid particles ρ_s 2,66-2,72 Mg/m^3, from bulk density of soil ρ 1,80 Mg/m^3 to 2,20 Mg/ m^3. These values are lower than those typical for this type of soil occurring naturally. The occurrence of pore voids is evidenced by a void ratio *e* ranging from 0,42 to 0,74 (Fig. 5).

Laboratory-determined primary compressibility moduli in the range 0-400 kPa, range from 8.6 MPa to 21.5 MPa, and secondary compressibility moduli in the range 12.5-400 kPa range from 17.1 MPa to 125.8 MPa.

The oedometric modulus of primary compressibility estimated from SCPTu static soundings is in the broad range M_o=6-113 MPa, while the oedometric modulus of primary soil strain is in the range E_o=5-94 MPa [15].

The obtained oedometer modulus results indicate high compressibility of the material which proves a significant loosening of the soils and the presence of voids. During primary loading, the height of the sample was significantly reduced, which indicates its high compaction. With the secondary loading, the changes in height were not as large as for the primary loads.

The results determined by the laboratory of the angle of internal friction φ range from 1.43 deg to19.95 deg and the cohesion *c* varies from 22.52 kPa to 63.33 kPa. Low values testify to the reduction of the geotechnical parameters in the dump process.

Determined from SCPTu static soundings, the undrained shear strength of the soils is in the range S_u=12-605 kPa and the effective angle of internal friction of the non-cohesive soils is φ'=28.6-40.9 deg [15].

Summary

The aim of the studies carried out in selected areas of the Jóźwin IIA and Jóźwin IIB open-pit mine dump was to establish, based on the obtained results, the basic geological-engineering parameters for further analysis of technical solutions for the foundation of a photovoltaic farm or a wind turbine in this place.

The results showed a wide spatial and depth range of variation in the physical-mechanical parameters of the investigated soils and a clear deterioration of their parameters as a result of the spoil dumping process.

Archival laboratory strength tests of the original till and sandy clays building up the spoil heap before lignite mining showed semi-solid and hard-plastic consistency with an internal friction angle averaging 28 deg [16]. Currently, these soils do not reach half of this value based on tests carried out. The soils during laboratory testing often showed high porosity, reduced density compared to the original density, and heterogeneous moisture content, often within a single test sample.

Fig.4 Part of the core from borehole S-5
Rys.4 Część rdzenia z otworu S-5

Fig.5 Soil from borehole S-2 collected with a bulk density ring
Rys.5 Grunt z otworu S-2 pobrany za pomocą pierścienia do badania gęstości objętościowej

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Applicable standards

[1] PN-EN ISO 14688-1:2018-05 Geotechnical investigation and testing- Identification and classification of soil- Part 1: Identification and description
[2] PN EN ISO 14688-2:2018-05 Geotechnical investigation and testing- Identification and classification of soil- Part 2: Principles for a classification
[3] PN-EN ISO 17892-1:2015-02 Geotechnical investigation and testing- Laboratory testing of soil- Part 1: Determination of water content
[4] PN-EN ISO 17892-2:2015-02 Geotechnical investigation and testing- Laboratory testing of soil- Part 3: Determination of bulk density
[5] PN-EN ISO 17892-2:2016-03 Geotechnical investigation and testing- Laboratory testing of soil- Part 3: Determination of particle density
[6] PN-EN ISO 17892-4:2017-01 Geotechnical investigation and testing- Laboratory testing of soil- Part 6: Fall cone test
[7] PKN CEN ISO/TS 17982-12:2009 Geotechnical investigation and testing — Laboratory testing of soil — Part 12: Determination of Atterberg limits.
[8] PKN-CEN ISO/TS 17892-5:2009 Geotechnical investigation and testing — Laboratory testing of soil — Part 12 oedometer test;

[9] PN-EN ISO/TS 17892-9:2018 Geotechnical investigation and testing-Laboratory testing of soil-Part 9: Consolidated triaxial compression test on water saturated soil.

[10] PN-EN ISO 22476-1:2013-03 Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test.

[11] PN-EN 1997-2:2007. Eurokod 7 – Geotechnical design. Part 2: Ground investigation and testing;

Archival materials

[12] Szymanowicz S. and others; 2022 Geological and engineering report for the purpose of investigating geological and engineering conditions of the ground under the planned fotovoltaic panels at the Jóźwin IIA overburden disposal area; Poltegor Instytut „Instytut Górnictwa Odkrywkowego"

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Urdari pit lake, Romania