Geotechnical characteristics of processed drilling wastes stored in drilling waste disposal factory in Wronów, Poland

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Abstract: In this publication, there are results of laboratory testing of drilling wastes' (so called filter cakes) physical and mechanical features presented. Filter cakes that are taken into consideration, are under disposal in Drilling Waste Disposal Factory, part of Exalo Drilling S.A., located in Wronów, Lower Silesia. These wastes are products of liquid phase filtration from the used drilling fluids, which is lead in the cellular hydraulic press.
As a result of lead tests, it was possible to specify the granulometric composition of tested samples, some of its basic and secondary physical features (water content, bulk density, liquid limit, plasticity limit, plasticity index, liquidity index, consistency index), swelling sensitivity (swelling curve, swelling index, swelling level, swelling moisture) and compressibility (consolidation curve, compressibility curve, oedometer compressibility modules, settlement curve). Tests also lead to stating filtration features (filtration coefficient, filtration curve) and ground's shearing resistance (shearing resistance diagram, angle of shearing resistance, cohesion). Results were presented as diagrams and tables. Based on the results, the characteristics of filtered drilling fluid wastes/filter cakes was described.

Keywords: cohesive ground, drilling waste, drilling waste features/characteristics, disposal of operational waste, laboratory testing of drilling wastes

CHARAKTERYSTYKA GEOTECHNICZNA ODPADÓW WIERTNICZYCH DEPONOWANYCH W OBIEKCIE UNIESZKODLIWIANIA ODPADÓW WYDOBYWCZYCH WE WRONOWIE W POLSCE

Streszczenie: W publikacji przedstawiono wyniki laboratoryjnych badań właściwości fizycznych i mechanicznych odpadów wiertniczych, tzw. placków filtracyjnych, składowanych w Obiekcie Unieszkodliwiania Odpadów Wydobywczych należącym do spółki Exalo Drilling S.A., który znajduje się w miejscowości Wronów, w województwie dolnośląskim. Odpady te powstają po odsączeniu fazy ciekłej, ze zużytych płuczek wiertniczych, w komorowej prasie filtracyjnej.
W wyniku przeprowadzonych badań określono skład granulometryczny badanego gruntu, niektóre podstawowe i pochodne właściwości fizyczne (wilgotność, gęstość objętościowa, granica płynności, granica plastyczności, wskaźnik plastyczności, stopień plastyczności, wskaźnik konsystencji), podatność gruntu na pęcznienie (krzywa pęcznienia, wskaźnik pęcznienia, stopień pęcznienia, wilgotność pęcznienia) i ściśliwość (krzywe konsolidacji, krzywa ściśliwości, edometryczne moduły ściśliwości, krzywa osiadania). Określono właściwości filtracyjne (współczynniki filtracji, krzywa filtracji) oraz wytrzymałość gruntu na ścinanie (wykres wytrzymałości gruntu na ścinanie, kąt tarcia wewnętrznego, kohezja). Wyniki badań przedstawiono w formie wykresów i tabel. Na podstawie uzyskanych wyników badań podano charakterystykę odsączonych odpadów płuczek wiertniczych/placków filtracyjnych.

Słowa kluczowe: grunt spoisty, odpady wiertnicze, cechy/charakterystyka odpadów wiertniczych, unieszkodliwianie odpadów eksploatacyjnych, badania laboratoryjne odpadów wiertniczych

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1. Introduction

Processed drilling fluids from south-western Poland are neutralized by disposal at Drilling Waste Disposal Factory, part of Exalo Drilling S.A., located in Wronów, Lower Silesia. This method is the easiest and the cheapest one out of all so far known methods (Stryczek et al. 2000, Kaliski and Zięba 2002, Rzyczniak et al. 2002, 2016, Gonet 2006).

Wastes/used drilling fluids are stored in special forms. These wastes are mostly given codes 01.05.07 – drilling fluids containing barite and others not mentioned in 01.05.05, and 01.05.06 as well as codes 01.05.08 – drilling fluids containing chlorides and others not mentioned in 01.05.05. and 01.05.06 (*Rozporządzenie*… 2014).

Tests covered mixtures of used drilling fluids stored in various time periods in working frame III. Gel structures which create this waste are instable in terms of sedimentation. It leads to automatic phase decomposition, although liquid phase contains suspended particular matter.

Test was run on the so called "filter cakes" which came from the treatment following the standard method (coagulation, flocculation and pressurized filtration in a chamber filter press) on liquid wastes from drilling fluids used in the disposal factory in Wronów.

A result of liquid phase filtration, was a waste/filter – white and beige colored mineral ground what results from zinc oxide addition to neutralize hydrogen sulfide created in a decay processes.

Filtered and solidified drilling fluids wastes (filter cakes) were treated with a laboratory testing which was to describe their physical and mechanical characteristics.

All tests were part of a research study in terms of increasing safety of drilling fluids disposal, throughout modification of its chemical, mechanical and physical characteristics (Gonet 2015, Gonet et al. 2016, Malata et al. 2016).

Mining wastes are wastes generated in exploration, extraction, physical and chemical processing of ores and other minerals. They constitute about 55% of all waste generated in Poland. Management of this type of waste poses great problems due to its properties and mass occurrence. Improper handling poses a great risk to the environment. This can have long-term environmental and socio-economic consequences that are difficult to address (Jamrozik et al. 2010, *Sprawozdanie*… 2015, Uliasz-Bocheńczyk et al. 2015, 2016a, 2016b, Hydzik-Wiśniewska et al. 2018).

According to industry data, in case of drilling in conventional reservoirs, it should be assumed that for a drilled section of 1 m, the amount of drilling waste generated is about 0.6 m^3. The average amount of waste generated in the form of spent mud and drill cuttings per borehole, up to a depth of 3,000 m, is about 2,400 Mg (Drilling Fluids Department (Dział Płynów Wiertniczych) of Exalo Drilling S.A.). Wastes classified under 01 05 08 may be in the form of rock borings or in liquid form with a water content of up to 85%. In the waste catalogue, used drilling mud containing chlorides is indicated under the code 01 05 08 and named: Drilling muds containing chlorides and wastes other than those mentioned in 01 05 05 and 01 05 06. Drilling mud used in the drilling process contains, in addition to the components used in its production, substances that permeate from the well itself. Whenever selecting materials for scrubber preparation, care should be taken to prevent direct contact of the materials with the environment (Gonet 2006, Bielewicz et al. 2015).

Chemical properties of waste depend on: properties of drilled rock, type of drilling fluid, type of drilling equipment, drilling technology, method of processing (e.g. dewatering). The substances penetrating from the environment during drilling, contained in drilling waste are mainly salt particles (sodium and chloride ions). The content of petroleum substances in waste is low and metals are present in the form of hardly soluble compounds and do not pass into aqueous extracts. In the case of non-saline wastes, the environmental hazards are small, whereas in the case of saline wastes (occurring where Zechstein salt deposits are drilled), they are considerable and should be taken into account during final management. The physical characteristics of the waste are as follows: waste of liquid, semi-liquid or solid consistency; usually fine-grained often thixotropic properties. The physical properties of the waste depend on: the properties of the rock being drilled, the type of mud, the drilling technology and other factors related to the well being drilled, the method of processing (*Sprawozdanie*… 2015, Żurek et al. 2017).

The drilling waste includes:

- chemicals used for the preparation and regulation of technical parameters of drilling fluids;
- reservoir fluids, e.g., salts from drilled intervals;
- heavy metals (Pb, Cr, Cd, Cu, Zn, Mn, Fe) derived from minerals or chemical additives used to prepare mud, from materials used to cement boreholes, from casing components in boreholes or from drilled rock;
- biocides (agents which prevent the fermentation processes to which certain scrubber components are easily subjected at high temperature);
- petroleum-based substances (fats, oils and greases) used in the drilling process to ensure proper operation of the equipment;
- corrosion inhibitors;
- alkaline compounds – to adjust the pH of the drilling mud;
- organic compounds with high reduction potential;
- surfactants;
- breakdown products of chemical components of scrubbers (difficult to identify).

Nuisance pollutants that pose a threat to the ground and water environment are soluble salts of alkali metals in the form of chlorides, sulphates, bicarbonates and carbonates in excessive quantities. The most serious problem is salinization of drilling wastes resulting from the use of salt as components of drilling muds and additional sources of salt entering them from drilled saline geological formations (Raczkowski et al. 1979, Raczkowski and Półchłopek 1998).

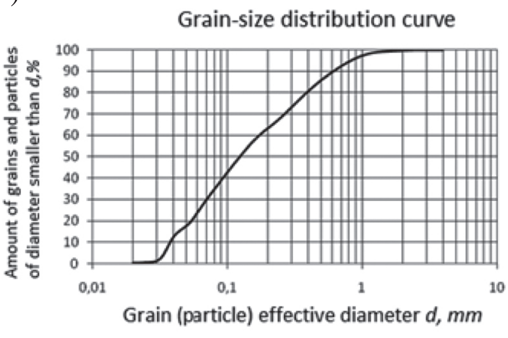
The concentration of salt results in very limited possibilities of managing drilling waste by introducing it into the ground and water environment as excess salt significantly affects the metabolism of plant cells disrupting their activity (*Sprawozdanie*… 2015).

2. Physical features and soil condition

2.1. Granulometric analysis

Granulometric composition of tested waste/filter cakes has been determined with grain sieve analysis (Pisarczyk 1999, PN-EN 933-1:2000, Wiłun 2001, Myślińska 2016). Grain-size distribution curve is presented in Figure 1, while Figure 2 is showing a graph of granulometry location.

a)



b)

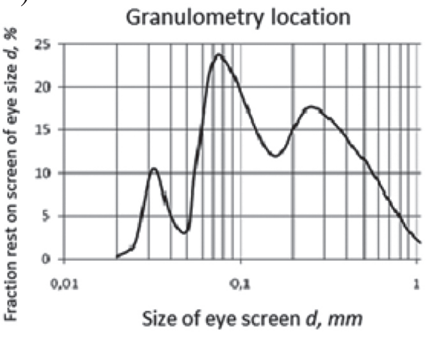


Fig. 1. Waste/filter cake's grain-size distribution curve (a) and waste/filter cake's granulometry location (b)

Analysis of both graphs (see Fig. 1) shows that tested waste is a semi-fractional ground (C_u < 6, C_c < 1) (PN-EN ISO 14688-2:2006) in terms of content and size of particular grain fractions and it is classified as a dusty sand siSa (PN-EN ISO 14688-1:2006).

2.2. Physical features

Laboratory testing enabled determination of following physical features of waste/filter cake: bulk density of soil ρ, water (moisture) content W, consistency boundaries (liquid limit W_L, plastic limit W_P), plasticity index I_P, liquidity index I_L, consistency index I_c (Pisarczyk 1999, Wiłun 2001, Mazurek 2002, 2005, Jamrozik et al. 2014, Myślińska 2016, Krzaklewski et al. 2017). Tests results are collected in Table 1.

Low content of bulk density (Tab. 1) in the filter cake is caused by a significant amount of water remaining in the pore space after the liquid phase filtration in the hydraulic press.

2.3. Swelling

Ground swelling test was lead in a laboratory with use of M4600 HPHT Linear Swell Meter device, produced by Grace Instrument Prior. Ground sample was dried out to the solid part in a temperature of 110°C ±5°C.

Graph showing waste/filter cake swelling is presented in Figure 2. Values of parameters characterizing filter cake's swelling process is shown in Table 1.

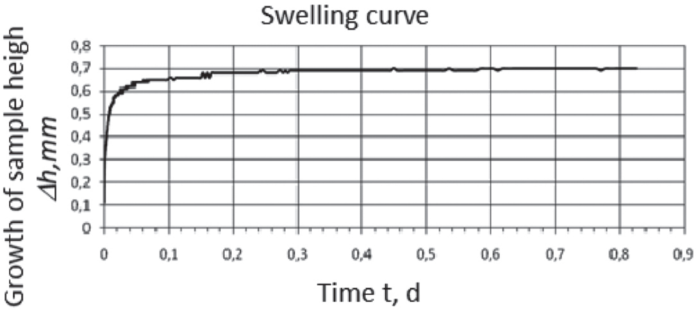


Fig. 2. Waste/filter cake swelling chart

Table 1
Physical features and values of parameters characterizing waste/filter cake swelling

Quantity name	Unit	Value
Bulk density of soil ρ	kg/m^3	1390
Water (moisture) W	%	52.82
Liquid limit W_L	%	65.58
Plastic limit W_P	%	47.74
Plastic index I_P	%	17.84
Liquidity index I_L	–	0.54
Consistency index I_C	–	0.46
Swelling index E_p	%	7
Swelling level	–	high
Swelling moisture W_{Ep}	%	45.81

As a result, it was stated that the waste/filter cake is characterized with a high value of swelling moisture (Tab. 2), which leads to its big water absorption abilities. Swelling index value indicates a high swelling degree (Tab. 2) (Pisarczyk 1999, Wiłun 2001, Myślińska 2016) and big expansiveness in a condition of a significant humidity modifications.

3. Mechanical features and filtration

There were tests lead in order to define mechanical features of waste/filter cake samples, compressibility and ultimate stress, which are described below.

3.1. Compressibility

Compressibility of waste/filter cake samples was tested with the use of oedometers. Samples were loaded with a normal stress, following the standard oedometric method with values of subsequently (12.5; 25; 50; 100; 200) kPa I_C (Pisarczyk 1999, Wiłun 2001, Myślińska 2016). Consolidation process of waste/filter cake is shown in the consolidation curve on Figure 3a. It was stated that after stabilized consolidation of waste/filter cake, under the stress of σ = 12.5 kPa, with the increase of a load on the sample within a range of 25–100 kPa, the hight of the sample decreased insignificantly (Fig. 3).

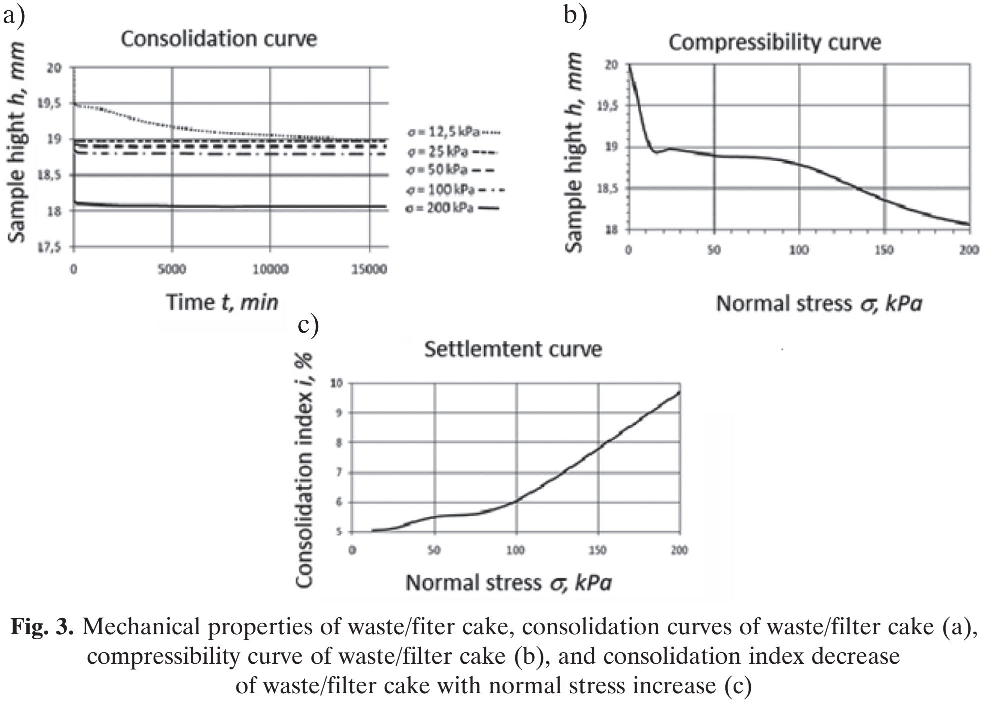


Fig. 3. Mechanical properties of waste/fiter cake, consolidation curves of waste/filter cake (a), compressibility curve of waste/filter cake (b), and consolidation index decrease of waste/filter cake with normal stress increase (c)

The reason of this was that the strength of the ground's frame, which reduced the ability of ground's pore area to decrease under the small value of vertical load. Rising intensity of ground's subsidence was noticed after increasing a normal stress on the sample to value of σ = 200 kPa. Maximum value of the initial sample height decreases under the stress of σ = 200 kPa was around 9.7% (Fig. 3c). Figure 4 shows the relation between values of oedometric compressibility modules of tested grounds and increase of a normal stress value.

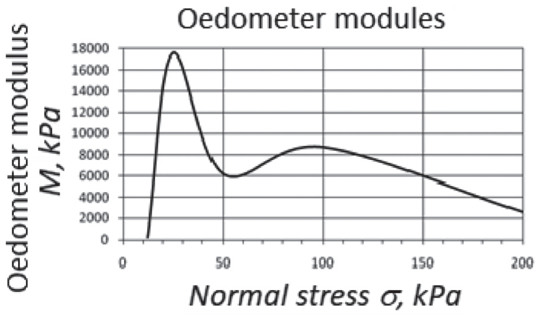


Fig. 4. Oedometric consolidation ground modules curve of waste/filter cake with normal stress increase

3.2. Filtration

Filtration waste/filter cake's features were defined by pointing filtration index values in a compressibility testing, after reaching stabilization of settlement under the constant stress (PKN-CEN ISO/TS 17892-11:2009). Dependency between filter cake's filtration coefficient changes and increase of normal stress was presented in Figure 5, as a filtration curve.

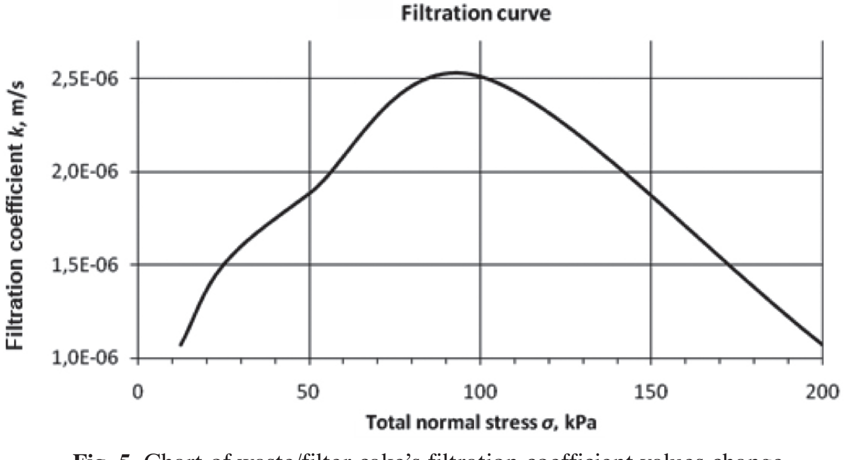


Fig. 5. Chart of waste/filter cake's filtration coefficient values change permeability with normal stress increase

Filtration coefficient was stated to raise with an increase of normal stress in a range of $\sigma \in$ 12.5–100 kPa. Reason for this is to be found in the results of compressibility test, in which a small intensity of ground settlement in this range of stress was noticed (Fig. 3). After this test, brown sediment was noticed on the filtration drains, what indicates that solid matter was rinsed out of the ground. As a result, patency of water migration in pore area increased, despite of a normal stress increasing.

Decrease of filtration coefficient value was noticed after increasing normal stress to σ = 200 kPa (Fig. 5). As a result, intensity of ground sample consolidation increased significantly (Fig. 3), pore area capacity decreased and resistance of water flowing through the ground sample increased, which lead to decreasing of waste/filter cake's filtration coefficient value.

The level of filtration coefficient values (Fig. 5) indicates, that tested matter does not fulfill the criteria of grounds which can be used for proofing screens construction (Pisarczyk 2000).

3.3. Shearing resistance

Shearing resistance of the waste/filter cake was tested with the use of a direct shearing method. As a result, shearing resistance curve $\tau_f = f(\sigma)$ was delivered (Fig. 6). Based on the mathematical model of a linear regression (shaped to the test's results) with a high value of determination coefficient R^2, it was possible to determine the value of shearing resistance angle Φ as well as cohesion c values of tested samples (Fig. 6). It was stated that tested ground is characterized with low values of resistance parameters.

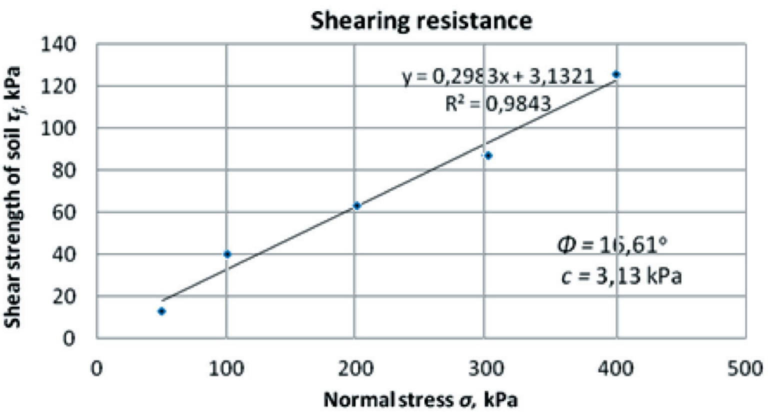


Fig. 6. Chart of waste/filter cake's shearing resistance: Φ – angle of shearing resistance, c – apparent cohesion intercept

Due to relatively big content of Zn and Cl compounds (Fijał 2015) samples should be wasted on the waste land. In order to enable save storage of drilling waste, there was an attempt taken to increase their mechanical parameters (Fijał 2015). Also, abilities of processed drilling waste were tested towards their usefulness in recultivation after landfill exploitation is completed (Krzaklewski 2015).

4. Conclusion

Solid waste/filter cake, which was received after filtration of liquid phase in the hydraulic press, is a white and gray ground of a medium density, fine grayed and of a soft-plastic consistency. Filtered drilling waste/filter cake is characterized with a high swelling level, which makes it expansive waste in condition of variable humidity. As for its positive filtering features, tested drilling waste does not meet the requirements which apply to materials used for example to build proofing screens under the waste fields and land fields. High value of swelling moisture of the waste/filter cake indicates to its significant water absorption possibilities. Waste/filter cake is featured with unsteady consolidation intensity under the normal stress. Characteristic feature of tested ground is the increase of filtering properties with an increase of normal stress in the range of low stress level. Waste/filter cake shows a high settlement index, especially in the range of high level of normal stress. Waste/filter cake is characterized with low cohesion and angle of shearing resistance values. Waste/filter cake is characterized with high amount of moisture, which results from its soft-plastic consistency. For its potential future usage or safe disposal, it is crucial to increase waste/filter cake's mechanical parameters.

Designation list

C_c – coefficient of curvature [–]
C_u – uniformity coefficient [–]
c – apparent cohesion intercept [kPa]
D – diameter of sample of soil [mm]
d – grain (particle) effective diameter, size of eye screen [mm]
E_p – swelling index [%]
h – height of sample of soil [mm]
Δh – increase height of sample of soil [mm]
I_C – consistency index [–]
I_L – liquidity index [–]
I_P – plasticity index [%]
i – consolidation index [%]
k – filtration coefficient [m/s]

M – oedometer modulus [kPa]
R^2 – coefficient of determination [–]
t – time [min] [day]
W – water (moisture) content [%]
W_{Ep} – swelling moisture [%]
W_L – liquid limit [%]
W_P – plastic limit [%]
x – independent variable [–]
y – dependent variable [–]
ρ – bulk density of soil [kg/m^3]
σ – total normal stress [kPa]
τ_f – shear strength of soil [kPa]
Φ – angle of shearing resistance [°]

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