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Evaluation of cohesive soils of the Mazowsze region as natural geological barriers

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The safety system for waste storage consists of at least two – synthetic and natural – mineral layers. Clay soils are among the materials, that can be used as a mineral layer. In this paper, mineral layer standards from different countries are described. Some investigations of the important properties of clay soils such as hydraulic conductivity, mineral composition, void ratio are presented. Clay soils as a geological barrier are examined.

Key words: barriers, clay soils, hydraulic conductivity

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INTRODUCTION

Different aspects of environmental protection are among the main objectives of research in many developed countries. First of all they focus on searching for the possibilities to preserve the natural environment against pollution produced by the developing industry and growing population. One of the most negative effects of industrial pollution on the natural environment is shortage of good quality drinking water resources. The preservation and protection of such resources may be achieved through a reliable isolation of waste disposal sites. Cohesive soils of specific physicochemical properties may serve as isolating geological barriers which limit the migration of harmful pollutants to the hydrosphere (Lang, 1989; Kühnel, 1990).

Besides the specific physicochemical properties, the geological barrier must have a proper thickness (Table 1). To provide the maximum protection of the aquifer, it must be composed at least of two independent layers complementing one another (Fig. 1), namely a synthetic and a mineral (clay) layer (Burkhard et al. 1997; Garbulewski, 2000).

The use of clay layers for isolation has many advantages:

– sites of clay occurrence are economically the best solutions for locating waste dumps;

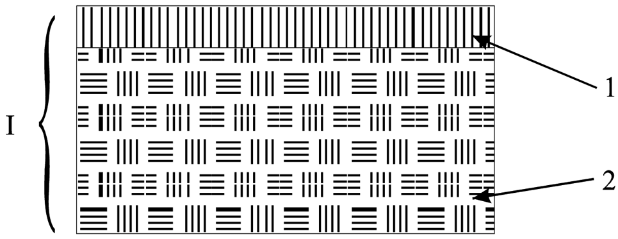
– a high content of clay fraction is responsible for the low coefficient of infiltration and scanty underground runoff of fluids formed in the waste disposal;

– the clay barriers are less subjected to breakdown or perforation than the synthetic ones because of their much larger thickness.

Table 1. **Parameters characterizing clay soils as natural barriers**

Parameters	ITB, 1995	US EPA/ 625/4-89/022, 1989	LAGA M3, 1990	Rowe et al., 1997	Gawriuczenkow, 2001
Thickness of layer	0.3–0.9 m	1.0 m	0.75–1.5 m	0.9–1.0 m	0.3–1.0 m
Liquid limit LL	>30%	< 90%	–	–	–
Plasticity index I_p	20%	>10 %	–	> 7%	–
Grain size f_i	≥ 20%	> 10%	≥ 20%	min.15–20%	–
Grain size $f_i + f_\pi$	> 60%	> 30%	–	–	–
Grain size f_p	≤ 40%	–	–	–	–
Grain size $f_ż$	–	< 10%	–	–	–
Swell pressure σ_{sp}	–	–	–	–	>50 kPa
Clay minerals	–	–	≥ 10%	–	>10%[1]
Max ∅ of grain	40 mm	75 mm	20 mm	–	–
Porosity index *e*			≤ 5%		–
Per cent of $CaCO_3$	≤ 10%	–	≤ 15%	–	–
Hydraulic conductivity *k*	≤ 10^{-9} m/s	≤ 10^{-9} m/s	≤ 5 × 10^{-10} m/s	≤ 10^{-9} m/s	≤ 10^{-9} m/s
Per cent of organic matter I_{om}	≤ 2%	–	≤ 5%	–	–

[1] Smectite.



I – composite liner: *1* – geomembrane, *2* – clay liner.

Fig. 1. Sample of clay liner system

EVALUATION CRITERIA OF COHESIVE SOILS AS NATURAL GEOLOGICAL BARRIERS

The protection of natural environment against pollutants formed during waste disposal forces the necessity of evaluation of geological materials utilized in the construction of sealing barriers.

There are a variety of criteria, regulations and recommendations in different countries concerning the requirements for soils or soil mixtures. The most often used criteria to evaluate the geological material as an isolation barrier have been gathered from the literature and analysis of archival as well as new data (Pusch, 1994; Benson, Daniel, 1994; Drągowski, Łuczak-Wilamowska, 2005).

According to the requirements and regulations that are obligatory nowadays, the value of only one parameter, hydraulic conductivity, is unequivocally defined in the same range of 10^{-9}–$5 \cdot 10^{-10}$ m/s. The recommended values of other parameters differ in a considerable range (table 1). Sometimes the differences are small, but, on the other hand, quite a great difference occurs in recommendations of their calculation.

METHODS

Altogether, 14 naturally undisturbed structure samples (NNS) of different cohesive soils were taken for analysis from three sites of the Mazowsze region: six samples of "Poznań Clays" were taken from the transition zone of the Pliocene basin described by Grabowska-Olszewska and Kaczyński (1994) as Region C; four samples of ice-dammed clays were taken from the vicinity of Radzymin, and four samples of glacial tills of the Warta Glaciation period were taken from the vicinity of Warsaw. The sites of sampling and selected physical properties of samples are presented in Table 2.

The cone penetrometer method (BS 1377: Part 2:1990:4.3) was applied to determine the values of liquid limit.

The empirical method based on the specific and volumetric density values was applied to calculate the porosity of soils.

The content of organic matter was determined by the combustion method (ASTM D 2974-87).

Areometric analysis was applied to determine the content of particular size distribution.

The mineral composition of soils and the content of particular minerals were determined by thermogravimetric analysis (Kościówko, Wyrwicki, 1996) with the aid of the Labsys™ TG-DTA12 apparatus (SETARAM Co.).

A compression permeameter (GEONOR) was applied to determine the hydraulic conductivity coefficient with a constant hydraulic gradient of 30. Experiments made by Kaczyński et al. (2000) have shown that this method is the most reliable from the technical and economical points of view and gives the most reliable results of hydraulic conductivity assessment.

POSSIBILITIES OF UTILIZING THE MAZOWSZE COHESIVE SOILS AS GEOLOGICAL BARRIERS

Cohesive soils, depending on the depth of their occurrence and formation, can be utilized in two general ways: (1) in the construction of waste disposal sites in places where they occur as the sealing bottom layers, and / or (2) in the construction of isolating barriers in general, in which they are the main component. Both options have advantages and disadvantages form the geological, economical and technical points of view. Cohesive soils with a naturally undisturbed structure (NNS) are usually preconsolidated (Kaczyński et al., 2000) due to geological processes and reveal

Table 2. **Some properties of examined clays: water content w_0, grain-size distribution f_i, f_π, f_p, liquid limit LL, plasticity index I_p, porosity n, percentage of organic matter I_{om}, percentage of $CaCO_3$, hydraulic conductivity k**

Sample number		w_0, %	f_p, %	f_π, %	f_i, %	LL, %	I_p, %	n, %	I_{om}, %	$CaCO_3$, %	%, clay minerals	Mineral composition	k, m/s
"Poznań Clays"	1.1	23.3	12.0	31.0	57.0	69.3	48.1	41	3.9	0	59.1	B > K >> I*	$8.4 \cdot 10^{-11}$
	1.2	33.7	2.0	34.0	64.0	89.0	65.5	50	3.1	0.3	71.2	B > K	$1.6 \cdot 10^{-10}$
	1.3	33.9	1.0	41.0	58.0	84.1	61.7	49	1.3	0.1	72.2	B > K	$9.6 \cdot 10^{-11}$
	1.4	30.7	6.0	30.0	64.0	86.5	65.1	47	2.3	0.1	63.7	B > K	$4.7 \cdot 10^{-11}$
	1.5	24.0	5.0	39.0	56.0	80.8	60.1	40	2.5	0	63.2	B > K	$2.1 \cdot 10^{-11}$
	1.6	34.0	3.0	29.0	68.0	87.1	66.2	50	2.0	4.8	61.2	B > K >> I	$3.7 \cdot 10^{-11}$
Ice-dammed clays	2.1	23.1	0.0	44	56	55.2	33.1	43	2.1	2.8	51.4	I > B > K	$7.5 \cdot 10^{-10}$
	2.2	24.6	1.0	43	56	56.3	35.4	44	1.4	2.9	52.7	I > B > K	$8.1 \cdot 10^{-10}$
	2.3	24.2	0.0	30	70	58.4	39.1	51	1.2	3.3	60.2	I > B > K	$2.1 \cdot 10^{-10}$
	2.4	19.8	4.0	36	60	57.9	37.2	47	1.5	4.1	57.3	I > B > K	$4.2 \cdot 10^{-10}$
Tills	3.1	9.1	47	33	18	26.4	14.9	22	0.0	2.2	23.3	B > K	$5.5 \cdot 10^{-7}$
	3.2	10.3	45	34	21	18.9	6.7	23	0.0	5.7	13.2	B > I >> K	$1.2 \cdot 10^{-6}$
	3.3	15.4	32	41	27	35.1	21.6	29	0.0	6.3	26.4	I > B > K	$9.9 \cdot 10^{-10}$
	3.4	16.4	43	38	19	33.8	20.9	30	0.1	8.2	38.2	I = B > K	$2.1 \cdot 10^{-9}$

* B – beidellite; I – illite; K – kaolinite.

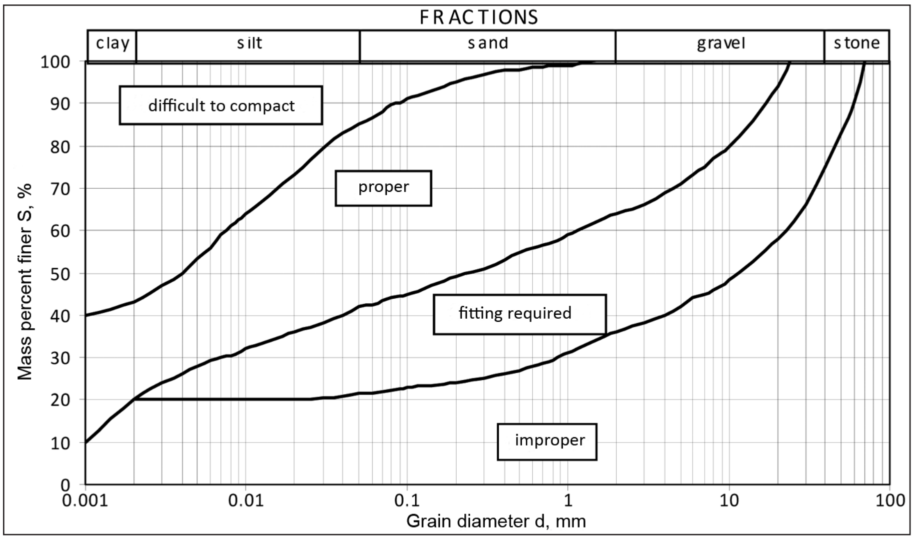


Fig. 2. Usefulness evaluation of soils for mineral layers building (Garbulewski, 2000)

a breccia-like structure (Meissner, 1970; Kumor, Andrzejewski, 2000) which may lead to formation of privileged internal paths of fluid migration. On the other hand, cohesive soils of disturbed structure, as the main component of isolating geological barrier, are usually difficult to compact (Fig. 2). This paper focuses on cohesive soils used as a component of isolating barriers.

The soils studied may be divided into two groups:

1. Miocene-Pliocene clays and ice-dammed clays – soils which fit all standards required for isolating (sealing) barriers, namely: hydraulic conductivity lower than 10^{-9} m/s, content of clay minerals higher than 10%, clay fraction content higher than 20%, $CaCO_3$ concentration lower than 10%, plasticity index higher than 10%.

2. Glacial tills – soils with variable physicochemical features and variable values of parameters required for isolating barriers and usually do not meet the standards.

The first group of soils is characterized by a high content of clay fraction (55–89%), which is a considerable obstacle in the compaction of such soils (Fig. 2) and requires their enrichment in coarser fractions (Rowe et al., 1997). The content of clay minerals is usually between 51% and 72% (Gawriuczenkow, 2005). Ca-beidellite is a dominant clay mineral in Miocene-Pliocene clays, whereas illite prevails in ice-dammed clays (Table 2). Such mineral composition determines the properties of particular soils and affects directly the values of other important parameters, for example, liquid limit which is much higher for Miocene-Pliocene clays with beidellite prevailing, despite a similar grain size distribution in both types of soils.

Because of the low content of clay fraction (18–27%), glacial tills do not meet the requirements of some regulations (Table 1). Moreover, they show high values of hydraulic conductivity (>10^{-9} m/s) which disqualify them as potential natural sealing layers. The other parameters important for natural isolating barriers do not attain the proper values, either.

CONCLUSIONS

1. Miocene-Pliocene clays and ice-dammed clays of the Mazowsze region meet all the basic requirements for soils utilized as sealing barriers.

2. Due to the very high content of clay fraction Miocene-Pliocene clays and ice-dammed clays are extremely difficult to compact and require enrichment with coarser fractions.

3. Glacial tills only partially meet the requirements for natural geological barriers due to variations of their physicochemical properties; therefore, they can be used only to a limited degree.

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MAZOVIJOS RIŠLIŲJŲ GRUNTŲ, KAIP NATŪRALIŲ GEOLOGINIŲ BARJERŲ, ĮVERTINIMAS

Santrauka
Atliekų kaupimo sistemos izoliacinį pagrindą dažniausiai sudaro du sluoksniai: sintetinis ir mineralinis. Mineralinį sluoksnį galima formuoti iš rišliųjų gruntų. Straipsnyje pateikiami įvairiose šalyse taikomi kriterijai, kuriais remiantis siekiama užtikrinti sąvartynų sandarumą panaudojant rišliuosius gruntus. Aptariamos svarbiausios Mazovijos rišliųjų gruntų savybės: hidraulinis laidumas, mineralinė sudėtis, poringumo koeficientas. Patikrinta šių gruntų panaudojimo sandariems sąvartynams galimybė. Išskirtos dvi gruntų grupės: mioceno–plioceno limnoglacialinis molis ir moreninis priemolis. Pirmos grupės gruntai turi didesnį molio dalelių kiekį (55–89%). Nors juos sunkiau sutankinti, jie užtikrina gerą sandarumą (maža filtracijos koeficiento vertė). Moreninio priemolio fizinių savybių rodiklis kinta plačiame intervale. Šie gruntai dažnai neatitinka sąvartynų sandarumui užtikrinti keliamų reikalavimų.

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OCENA GRUNTÓW SPOISTYCH MAZOWSZA JAKO NATURALNYCH BARIER GEOLOGICZNYCH

Streszczenie
Systemy bezpiecznego składowania odpadów składają się co najmniej z dwóch warstw – syntetycznej i mineralnej (rys. 1). Materiałem mogącym stanowić warstwę mineralną są grunty spoiste. W artykule zaprezentowano proponowane w różnych krajach kryteria stawiane warstwom mineralnym stosowanym jako uszczelnienia (tab. 1). Przedstawiono również najważniejsze właściwości gruntów spoistych rejonu Mazowsza, takie jak przewodniość hydrauliczna, skład mineralny, wskaźnik porowatości (tab. 2). Sprawdzono możliwość wykorzystania tych gruntów jako barier.

Zbadane grunty spoiste podzielono na dwie grupy – iły mio-plioceńskie i iły zastoiskowe, oraz gliny lodowcowe. Pierwsza grupa gruntów charakteryzuje się znaczną zawartością frakcji iłowej (55–89%). Z jednej strony, powoduje to trudności w zagęszczaniu (rys. 2), ale, z drugiej strony, znacznie zmniejsza jest przepuszczalność tych utworów. Gliny lodowcowe ze względu na duże zróżnicowanie parametrów fizyko-chemicznych (tab. 2) często nie spełniają kryteriów (tab. 1) stawianych mineralnym warstwom uszczelniającym.

Иренеуш Гаврюченков

ОЦЕНКА МАЗОВСКИХ СВЯЗАННЫХ ГРУНТОВ КАК ГЕОЛОГИЧЕСКИХ БАРЬЕРОВ

Резюме
Изоляционное основание систем накопления отходов обычно состоит из двух слоев – синтетического и минерального. Минеральный слой можно формировать из связанных грунтов. В статье представлены критерии разных стран, определяющие возможность использовать естественные связанные грунты для изоляции отходов от геологической среды. Приводится характеристика мазовских связанных глинистых грунтов – гидравлическая проводимость, минеральный состав, коэффициент пористости. Оценена возможность использовать грунты для формирования изоляционного слоя. Выделены две группы связанных грунтов: 1) миоценовые, плиоценовые и лимногляциальные глины; 2) моренные суглинки. Грунты первой группы содержат повышенное количество глинистых частиц (55–89%). Их затруднительно уплотнить, но они обеспечивают малые значения коэффициента фильтрации. Физические свойства моренных суглинков изменяются в широком диапазоне и часто не соответствуют предъявляемым требованиям.