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LABORATORY TESTS OF BENTONITE STABILIZATION OF BOTTOM SEDIMENTS FROM A DAM RESERVOIR IN RELATION TO THEIR USAGE IN MUNICIPAL SOLID WASTE LANDFILL LINERS

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Abstract. Geotechnical parameters of bottom sediments from a dam reservoir (Rzeszowski Reservoir, Poland) with bentonite addition are presented in the paper. Tests were carried out in the aspect of the possible usage of sediments as a material for soil liners in Municipal Solid Waste Landfill. Mentioned sediments did not fulfilled the permeability and plasticity criteria defined for soils that can be used in liners. The bentonite addition caused, among other things, a decrease in permeability coefficient and increase in plasticity index. Based on the carried out tests it was stated that sediments with 6% addition of bentonite fulfil all requirements and can be used for liners in MSWL.

Key words: siltation, soil improvement, sealing

INTRODUCTION

Bentonite is a clay (fine-grained rock) composed mainly of montmorillonite minerals formed by the alteration of volcanic ash. Water absorption and low hydraulic conductivity of the activated bentonite makes it perfect for sealing in big water reservoirs, ponds, small fish ponds, swimming pools as well as hydrotechnical constructions (flood protection levees), slurry wall and landfills [Sieczka 2015]. Bentonite is built from lamellar platelets which consists of three sandwich-arranged layers: a central octahedral alumina (Al_2O_3) layer, and two tetrahedral silica (SiO_2) layers (fig. 1). Based on the exchangeable cations that are between platelets there are sodium, calcium, hydrogen and other types of bentonite. Research showed that using sodium bentonite is the most advantageous.

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It has a significantly high swelling capacity because of high hydration of sodium ions. When wet it has a high specific surface area (up to 800 $m^2 \cdot g^{-1}$) and is a self-sealing, low permeability barrier for water filtration, it is also plastic and resistant to low temperatures and moisture changes (there is no danger of cracks and punctures).

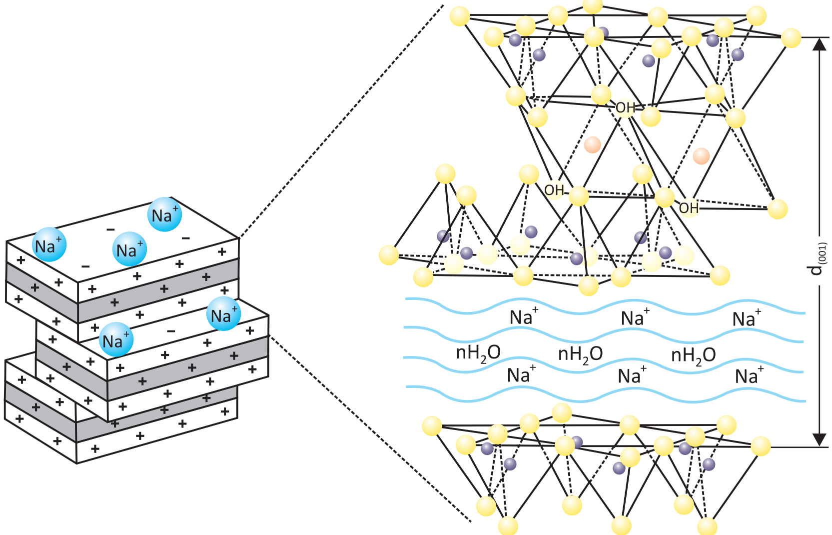

Fig. 1. Sodium bentonite structure [www.technologie-budowlane.com]

After mixing bentonite with soil it fills spaces between grains and in presence of water it hydrates and swells, thanks to that permeability of the soil significantly decreases. Ameta and Wayal [2008] carried out research on the influence of bentonite addition to dune sand (it had the granulation of sandy silt). Permeability coefficient reduced from 10^{-6} to 10^{-10} $m \cdot s^{-1}$ after addition of 10% bentonite with compaction at maximum dry density at optimum moisture content. According to the authors a mix of dune sand and bentonite is a great alternative for clay liners, because there are no problems with compaction and cracking during period of desiccation. A mixture of sand, silt and bentonite is cheaper, easy to form, it has better strength parameters and there is no danger of cracks (fig. 2).

For bentonite stabilization non-cohesive soils are the most suitable. In general it is recommended that the plasticity index should be lower than 10% [Cichy and Bryk 2006]. Designing of a liner from bentonite enriched soils takes the following steps:

- soil laboratory tests,
- choosing of the bentonite type – as it was mentioned sodium bentonite should be used, while choosing the product montmorillonite content (minimum 75%) and specific surface are (above 800 $m^2 \cdot kg^{-1}$) should be taken into account,
- mixtures laboratory tests (permeability coefficient, liquid and plasticity limits, specific surface area, compaction parameters),
- designing the composition of the soil-bentonite mixture,
- field tests on a trial liner.

Primary properties	Secondary properties
• Very low hydraulic conductivity and low gas permittivity. • Moderate to high shear strength (sufficient to ensure minimum deformation under the design loading with a factor of safety). • Density > 95% of maximum dry density with a 4.5 kg hammer. • Homogeneity • The BES shall be physically and chemically suitable for its proposed end use.	• Good plasticity and workability. • Low shrinkage. • Low frost susceptibility. • Chemical resistance and compatibility with many site-specific leachates. • Low dispersivity and erosion susceptibility. • Appropriate actuation capacity. • Some resistance to settlement damage. • The minimum bentonite dosage rate applied to the mixture is 1.5% by weight. • An additional bentonite dosage of 0.5% for batch mixed BES (1.5% for the rotavation mixed BES) by weight is added to the results of the laboratory testing to provide a factor of safety for all mixture designs.

Fig. 2. Bentonite enriched soils properties required for landfill liners [www.environment-agency.gov.uk]

PURPOSE

The purpose of this research was to determine the influence of bentonite addition on properties of fine-grained, organic soils by the example of bottom sediments from Rzeszowski Reservoir (southern Poland). Geotechnical parameters of sediments with 3, 6 and 12% addition of bentonite were determined. The tests were carried out on the sediments because of planned desiltation of mentioned reservoir, where it is estimated that over 1.5 million m^3 of sediments can be removed from the basin. In most cases sediments are treated like waste and put on a heap, however it can be a valuable material, useful in earthworks. Thus, determining the possibilities of sediments usage is very important from the ecological point of view. Research presented in the paper was carried out in relation to the possible usage of sediments in Municipal Solid Waste Landfill liners.

BOTTOM SEDIMENTS FROM RZESZOWSKI RESERVOIR

Geotechnical parameters of bottom sediments are presented in table 1. This material was classified as silt, with increased organic matter content. At optimal moisture content and high compaction level (I_s = 1.00) it has relatively high values of shear strength parameters (determined in a shear box apparatus) and high compressibility. Sediments usability evaluation for liners [Koś and Zawisza 2014b] showed that sediments do not fulfil the plasticity criterion (relatively low clay fraction content) and the value of permeability coefficient close to the required one ($k = 1.12 \cdot 10^{-9}$ m · s^{-1}) is obtained only at a very high compaction index (I_s = 1.00). Nevertheless, tested sediments had good geotechnical parameters and fulfilled most of the required criteria, so an attempt to improve their parameters was made. For this purpose an addition of bentonite was used.

Table 1. Geotechnical parameters of bottom sediments [Koś and Zawisza 2014a]

Parameter	Bottom sediments
Fraction content, %: – sand 2–0.063 mm – silt 0.063–0.002 mm – clay < 0.002 mm	 8.5 83.0 8.5
Name acc. to PN-EN-ISO 14688: 2004	Si (silt)
Uniformity coefficient, C_u	13.3
Specific density, $g \cdot cm^{-3}$	2.53
Loss on ignition, LOI, %	4.67
Organic matter content, OM, %	3.33
Optimal moisture content, o.M.c., %	24.8
Maximum dry density, $g \cdot cm^{-3}$	1.445
Permeability coefficient, k_{10} at $m \cdot s^{-1}$: – $I_s = 0.90$ – $I_s = 1.00$	 $1.05 \cdot 10^{-8}$ $1.12 \cdot 10^{-9}$
Passive capillary, PC, cm	`137.1
Specific surface area, SSA, $m^2 \cdot g^{-1}$	52.44
Reaction, pH	7.30
Calcium carbonate, %	4.68
Liquid limit, LL, %	40.6
Plastic limit, PL, %	26.8
Plasticity index, IP, %	13.8
Swelling index, SI, %	26
Angle of internal friction, φ, °, at: – $I_s = 0.90$ – $I_s = 1.00$	 23.1 33.5
Cohesion, c [kPa] at: – $I_s = 0.90$ – $I_s = 1.00$	 33.1 35.8
Oedometric modulus of, MPa: – primary compression – secondary compression	 $M_o = 3.9$ $M = 18.6$

MATERIALS AND METHODS

Determining of the basic parameters was carried out using standard methods [PN-EN-ISO TS 17892: 2009]. Liquid limit was determined in cone penetrometer and plastic limit by rolling threads. Optimal moisture content and maximum dry density were determined using Standard Proctor Tests (compaction energy of 0.59 $J \cdot cm^{-3}$). Falling-head permeability tests with consolidometer were carried out under the load of 12.5 kPa. The specimens were 7.5 cm in diameter and 1.9 cm high, they were compacted at the optimal moisture content and the compaction index of $I_s \approx 1{,}00$ (two samples were tested for each silt-bentonite mixture). Specific surface area was determined using methylene blue absorption method.

Hekobent sodium bentonite in the form of powder, produced by Hekbentonity, was used in the tests [www.benotnit.pl]. Montmorillonite content was above 65%, moisture content from 6–11% and the addition of bentonite was 3, 6 and 12% in relation to dry matter of the sediments. Each silt-bentonite mixture was prepared the same way: dry sediments were mixed with powdered bentonite and then water was added so th at the mixture was at the optimal moisture content.

RESULTS AND DISCUSSION

Optimal moisture content of sediments was almost 25%, 3% addition of bentonite caused a decrease of this value, down to about 23% (table 2, fig. 3). Optimal moisture content of the mixtures increased along with the bentonite addition up to almost 28%.

Maximum dry density of the sediments was over 1.44 $g \cdot cm^{-3}$, along with the bentonite addition this value increased up to 1.49 $g \cdot cm^{-3}$ (for the mixture with 6% bentonite addition). However, for the mixture with 12% addition the value was much lower – about 1.43 $g \cdot cm^{-3}$.

As expected, plasticity index increased along with the bentonite addition, from about 14% (pure sediments) up to over 20% (sediments with 12% bentonite addition).

Table 2. Parameters of sediments and bentonite mixtures

Parameter	Bentonite addition, %			
	0	3	6	12
Maximum dry density, ρ_{ds}, $g \cdot cm^{-3}$	1.445	1.483	1.487	1.431
Optimal moisture content, o.M.c., %	24.8	22.6	24.5	27.7
Plastic limit, PL, %	26.8	25.9	22.9	24.8
Liquid limit, LL, %	40.6	43.4	40.6	45.0
Plasticity index, IP, %	13.8	17.5	17.7	20.2
Specific surface area, SSA, $m^2 \cdot g^{-1}$	52.44	53.74	67.71	70.86
Permeability coefficient, k_{10} at $I_s = 1{,}00$, $m \cdot s^{-1}$	$1.12 \cdot 10^{-9}$	$6.78 \cdot 10^{-9}$	$3.80 \cdot 10^{-10}$	$3.49 \cdot 10^{-11}$

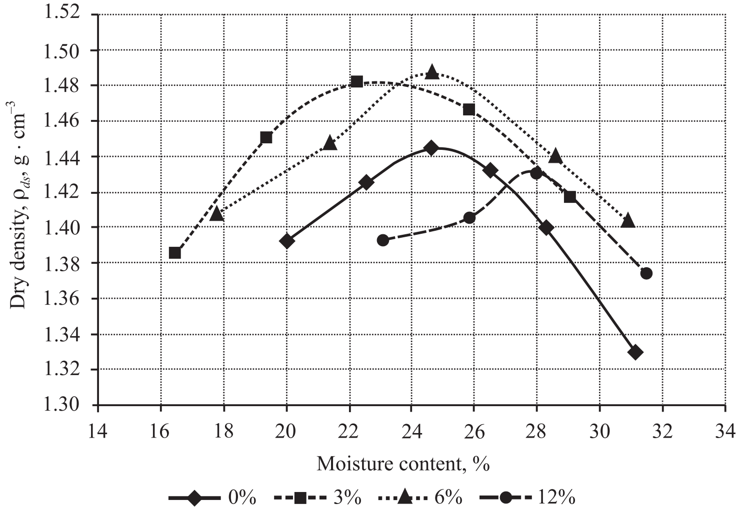

Fig. 3. Proctor curves for bottom sediments and their mixtures with bentonite

Specific surface area also increased – from about 53 m$^2 \cdot$ g^{-1} for pure sediments up to over 70 m$^2 \cdot$ g^{-1} for sediments with 12% bentonite addition. Sodium bentonite has a very high specific surface area (700–800 m$^2 \cdot$ g^{-1}) because not only outside surfaces of the particles are accessible for water and exchangeable cations, but also surfaces between the platelets. A 12% addition caused an increase in specific surface area of the sediments by 26%.

A 3% bentonite addition did not change the value of permeability coefficient – for pure sediments and mixture with 3% addition comparable values were obtained. 6 and 12% addition of bentonite caused a significant decrease in this value – up to 3.5 · 10^{-11} m · s^{-1} (fig. 4).

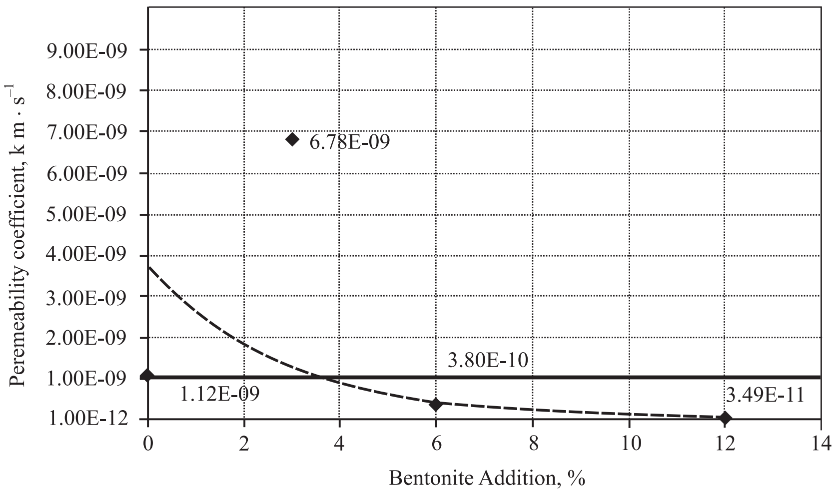

Fig. 4. The influence of bentonite addition on the permeability of sediments in relation to Polish Regulation requirements [Rozporządzenie… 2003]

CONCLUSIONS

Adding bentonite to the bottom sediments from Rzeszowski Reservoir (classified as silt) significantly improved their geotechnical parameters:

- permeability coefficient decreased,
- plasticity index increased, so the mixture will be easier to form during compaction of the liner. Recommended value of plasticity index for soils that are to be used in liners is over 15% [Majer et al. 2007]. Sediments without bentonite addition did not fulfil this criterion, whereas with bentonite every mixture fulfils it,
- specific surface increased, in relation to pure sediments by 2–35%. Thanks to that, a potential liner will have a better capacity to stop leachate.

To sum up, it can be stated that the bentonite addition improved properties of bottom sediments from Rzeszowski Reservoir in relation to their usage in liners. Recommended bentonite addition is 6% – the value of permeability coefficient was lower than the allowable one and in the usability evaluation for liners the number of points was higher than the recommended (fig. 5). Thus it can be stated that the permeability and plasticity criteria are fulfilled and bottom sediments with 6% addition of bentonite can be used for liners.

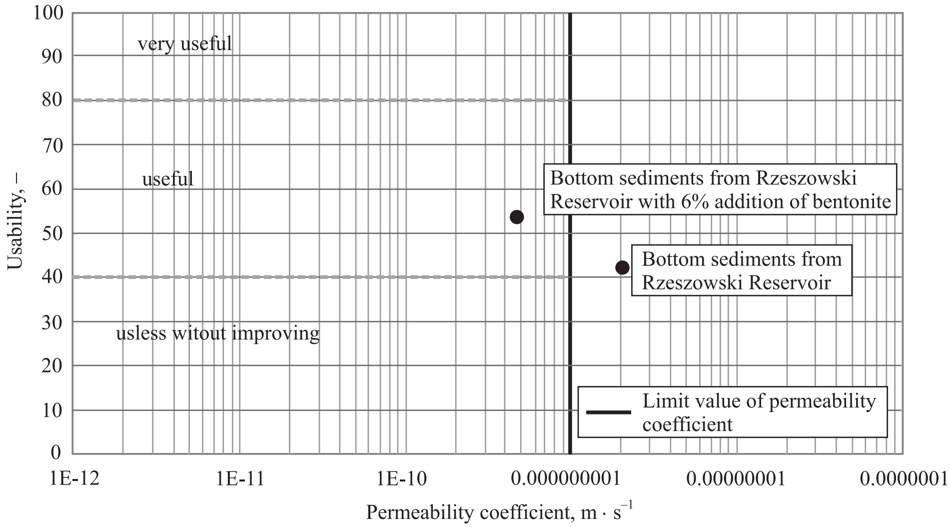

Fig. 5. Nomogram for soils usability evaluation for liners in MSWL [Majer et al. 2007]

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STABILIZACJA BENTONITEM OSADÓW DENNYCH ZBIORNIKA ZAPOROWEGO W ASPEKCIE ICH WYKORZYSTANIA DO USZCZELNIEŃ SKŁADOWISK ODPADÓW KOMUNALNYCH

Streszczenie. W pracy przedstawiono wyniki badań parametrów geotechnicznych mieszanek osadów dennych Zbiornika Rzeszowskiego z dodatkiem bentonitu. Badania przeprowadzono pod kątem wykorzystania osadów jako materiału na uszczelnienia w składowiskach odpadów komunalnych. Przedmiotowe osady denne nie spełniały kryterium przepuszczalności i plastyczności, dodatek bentonitu spowodował zmniejszenie współczynnika filtracji oraz wzrost wskaźnika plastyczności. Na podstawie uzyskanych wyników badań dla mieszanek z różnym dodatkiem procentowym bentonitu stwierdzono, że osady z 6% dodatkiem stabilizatora można dopuścić do stosowania na uszczelnienia w składowiskach odpadów.

Słowa kluczowe: zamulanie, ulepszanie gruntów, uszczelnienie

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