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Comparative Study of Behaviour of Soil and Soil-Bentonite Mixtures for The Construction of Impermeable Barriers

Varsik Martirosyan*1, Mihran Yamukyan2
"C-Lab" Testing Laboratory LLC, Artashisyan 105, Yerevan, Armenia

ABSTRACT

The aim of the present work is to investigate the effect of admixture such as bentonite on the soil stabilization processes to determine its various characteristics and to develop a mix composition which can be economical for use as engineered impermeable barriers. Three types of the main soil materials differing grain size distribution mixed with various amount of sodium-bentonite as admixture (7.5%, 10.0% and 12.5% by soil dry weight) were used to study soil's characteristics. It has been shown that the soil-bentonite mixtures' permeability, plasticity and compaction characteristics are greatly affected by the type of main materials used in the mixtures. The plasticity index increased linearly with increasing amount of bentonite content and maximum dry density in compacted samples decreased linearly with increasing amount of bentonite content in all soil-bentonite mixtures. It was estimated that hydraulic conductivity of soil-bentonite mixtures decreased about two orders of magnitude only for **Sample 2**. Our data demonstrated that mixtures were suitable materials for barriers, because they met the statutory hydraulic conductivity requirement (i.e., $k \leq 1.0 \cdot 10^{-8}$ m/s). Overall conclusion of this work is that improvements in the geotechnical properties of soil-bentonite mixtures depend on the amount of bentonite added and as well the type of main materials.

Keywords: Soil-Bentonite Mixture, Construction Materials, Impermeable Barriers, Permeability, Soil Stabilization

I. INTRODUCTION

Nowadays, there is an increasing need to produce or construct some good materials, which will meet the current geo-environmental challenges.

Waste disposal has been an ongoing societal problem since medieval times. The quantities of hazardous wastes produced by the industry are increasing along with a growing economy and improved standard of living. As the poorly-disposed wastes would contaminate the surrounding environment, the containment of hazardous waste is certainly one of the most urgent problem facing industrialized country today [1]. Presently, the landfills play a vital role in the whole wastetreatment/disposal process.

On the other hand, landfill dams have become the most widely used dams in agriculture as water storage for livestock or irrigation. Moreover, the fact that these landfill dams can be built on various types of foundations is one of the principal reasons for choice of these dams as a cost-effective method of water and hazardous wastes storage.

The most suited soil typefor landfilling to satisfy the Environmental Protection Agency (EPA) standards is fine grained soil with highclay content which has low permeability.

The EPA regulation requires that the hydraulic conductivity of the barriers should be in range 10^{-8} and 10^{-10} m/s [1-3].

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Clays are therefore being considered increasingly as barrier materials in the design of disposal facilities for hazardous wastes, and some modern landfills are built using compacted clay liner. However, it is not always possible to find the clay material that provides the sufficient impermeability.

Currently, many different synthetic barrier materials exist [4]. However the long-term stability of the synthetic materials is questionable. Although the synthetic liner material is virtually impermeable during early period, there is no long-term field experience as to the performance of synthetic material [5]. The synthetic liner material would be degraded and eventually failed with the passage of time after installation of liner in the landfill facilities. It is the reason that is why, presently landfill dams constructed with natural materials: such as clays, and they have become the most widely used dams since they are constructed with materials found in nature with minimum processing. Clays are natural materials and lead to excellent long-term stability in nature. The efficiency of these insulated barriers depends largely on their hydraulic and mechanical behaviour along with their abilities of contaminant retention.

The studies constructing such barriers focused on mechanical stabilization of the main materials: by mixing other soil materials with the target soil to change the gradation, and chemical stabilization: by adding stabilizing additives to improve the soil properties [6-9]. In the construction work the main known stabilizing additives are cement, bentonite, bitumen, lime and chemicals, etc.

The low value of the hydraulic conductivity of the soil-bentonite mixture can be attributed primarily to the high swelling potential of bentonite in the presence of water resulting in the formation of a relatively "tight" matrix [10].

Different percentages of bentonite additions are reported by many authors [9, 11-14]. Gillham [15] and Chapuis [16] have found this percentage ranges between 5% to 8% for sodium bentonite and from 9% to 15% for calcium bentonite.

The effects of grain size distribution, percent bentonite, consolidation pressure, field stress conditions, permeameter type, water table position, gradient, and permeant on the hydraulic conductivity of soil-bentonite have been reported [6-9, 17-19].

In is worthy to mention that resently riealized the study about modeling soil-bentonite mixture [20] Mishra el al. [20] found that the permeability predictions obtained from developed model agree well with experimental observations.

The objectives of the work are to design mixtures with low permeability properties that can be used as impermeable barriers instead of natural clays. The mail focus of the study on mechanical (changing gradation) and chemical (adding admixtures) stabilization of the main materials to improve the soil properties. Bentonite was chosen as admixture for improved permeability of the different type of soil materials. Economical consideration was also taken into accounting creation of a mixture that satisfies the hydraulic and mechanical properties specified by regulation rules.

The major aims of this study are given below:

- Evaluating the effects of the variation in particle-size distribution of compacted soil-bentonite mixtures on their permeability characteristics.
- Comparing different characteristics of soil-bentonite mixtures containing different particle-size distribution.
- Recommending a specific soil-bentonite mixture composition which can produce permeability to

meet the hydraulic barrier/liner design requirements.

In searching for an adequate mixture, the investigation was carried out on several types of main soil materials and sodium bentonite mixtures with different percentages of bentonite additions, which varies 7.5% to 12.5%.

II. METHODS AND MATERIAL

A. Materials

1. Soil

Three types of soil were sampled near Aragatsotn province (40°19'N, 44°27' E), Armenia through backhoe-assisted excavation works. The samples were collected in large polyethylene bags sampled and transported to the laboratory. In the laboratory the samples were combined to create 3 different samples (**Sample 1**, **Sample 2** and **Sample 3**) differing grain proportion. The percentages of the grain proportion are shown in the results (Table 2).

2. Bentonite

The laboratory tests for soil-bentonite mixture were carried out using sodium-bentonite ("Ijevan Bentonite Kombinte" OJSC, Armenia). The basis of the company raw-material is the Sarigyukh deposit which is located in the Tavush area of the Republic of Armenia. The company possesses its own raw-material base and produces bentonitic powders and bentonitic granules of the high-quality natural sodium bentonite. According to its properties it verges towards the clays of Wyoming (USA) which are considered to be the best in the world. The content of montmorillonite, a mineral which the quality of the end-product basically depends on, is almost 90 % in the Sarigyukh clay.

B. Methods and standards

All the experiments were carried out in accordance with ASTM, and BS standards.

1. **Moisture content determination** - moisture content determination conformed to ASTM D2216 – "Standard test method for laboratory determination of water (moisture) content of soil".
2. **Specific gravity test** - specific gravity testing conformed to ASTM D854 – "Standard test method for determining the specific gravity of soil solids by water pycnometer".
3. **Atterberg limits** - Atterberg limit testing conformed to ASTM D4318 – "Standard test method for liquid limit, plastic limit, and plasticity index of soils".
4. **Grain size/sieve and hydrometer test** – dry and wet sieve analysis conformed to ASTM D422 – "Standard test method for particle-size analysis of soil".
5. **Standard compaction test** – compaction testing conformed to ASTM D698 – "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3))".

The testing procedure was done in the following steps: several samples of the soil were prepared with different water content ranging from 6.0 to 17.0%. Tap water was added to the soil to obtain the desired water contents. The soil was allowed to hydrate for at least 24 hours prior to compaction. An ELE automatic compactor with a 5.5-lb hammer was used in compacting the soil into the 4-in mold (inside diameter) with 4.5-in in height in order to ensure the uniform compaction for each layer. Total of 3 layers of the soil were compacted for each mold. Number of blows/layer is 25. After compaction, the weight of the compacted soil was determined along with their water contents.

6. **Permeability (measurement of Hydraulic Conductivity by falling head method)** – permeability testing conformed to BS 1377 part 5 -Methods of test for soils for civil engineering purposes. "Compressibility, permeability and durability tests".

The hydraulic conductivity tests were performed on compacted soil in falling head permeameters. A falling head permeameter is consisting of compaction-mold used in compaction test, made of stainless steel tube, and mounted on top and bottom with stainless steel plates. It should be mentioned that the falling head permeability tests were carried out with compacted specimen (maximum dry density). The specimens has been kept in the mold for three days and then sunk into the water tank for saturation. The vacuum desiccators were also used for saturation process.

The all tests were performed using high quality testing equipment from ELE International (www.ele.com) and from MATEST (http://www.matest.com).

7. Statistical analysis: Statistical analyses were conducted by SPSS software (version17, Armonk, NY). Data are representative of three independent experiments and values are expressed in mean ($p < 0.05$).

III. RESULTS AND DISCUSSION

The effects of soil stabilization by bentonite were estimated through the analysis of different characteristics of the main materials, e.g. specific gravity, particle size distribution, Atterberg limits, compaction and permeability.

The results of physical characteristic of soil samples are presented in Table 1.

Determination of the particle size distribution of samples by wet and dry sieving test. The results of sieve analysis of the 3 type of soils are shown in Figure 1, and the percentages of the fractions are presented in Table 2.

The lowest gravel fraction had **Sample 1** (1.61%) and highest **Sample 3** (52.74%). The sand fraction was highest in **Sample 2** (63.57%) and lowest in **Sample 3** (42.39%). Silt and clay portion was high only in **Sample 1**.

Atterberg limits determination. It was established that **Sample 2** and **Sample 3** had not plasticity (Non-plastic) and the test results of Atterberg limits of **Sample 1** are presented in Table 1.

Table 1. Physical characteristics of the soil samples.

№	Sample name	Specific gravity	Atterberg limits			Proctor test		Permeability, m/sec.
			Liquid limit, %	Plastic limit, %	Plastic index, %	Max. dry density, g/cm^3	Optimum water content, %	
1.	Sample 1	2.66	21.0	17.4	3.6	1.73	16.5	$3.3 \cdot 10^{-7}$
2.	Sample 2	2.59	Non-Plastic			1.65	14.5	$5.30 \cdot 10^{-6}$
3.	Sample 3	2.59	Non-Plastic			1.76	16.5	$3.40 \cdot 10^{-7}$

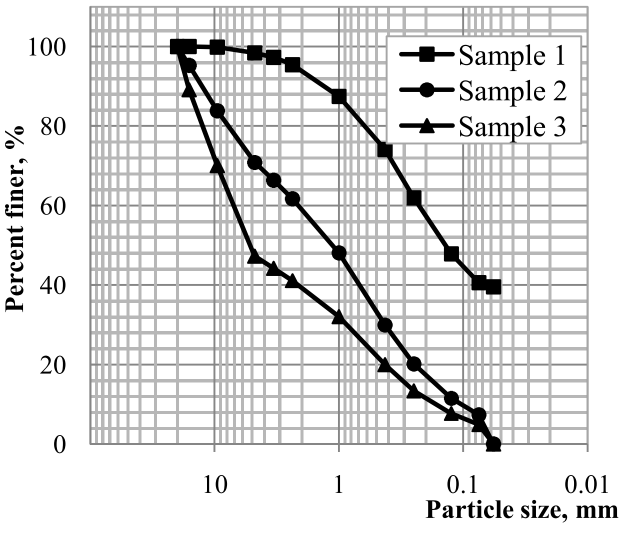

Figure 1. Particle size distribution of the soil samples.

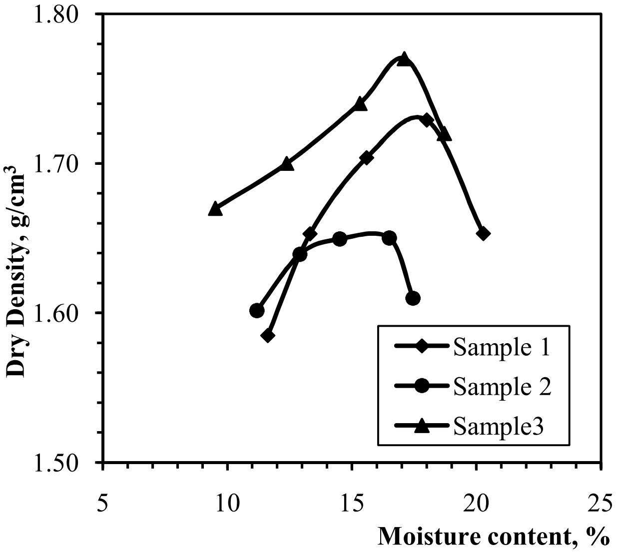

Figure 2. Standard compaction curve of the soil samples.

Standard compaction test: determination of maximum dry density and optimum water content. Compaction test was carried out to assess the optimum water content and maximum dry density of soil samples. As for the standard compaction test, the compaction curve was drawn based on the few points obtained from the specimen's water content and the dry density. Correspondingly, the maximum dry density and optimum water content of compacted soil were determined from a compaction curve (Figure 2).

Table 2. Percentages of the particle's fractions in the soil samples.

Material	Gravel, %		Sand, %			Silt & Clay, %	Overall, %		
	Coarse	Fine	Coarse	Medium	Fine		Gravel	Sand	Silt & Clay
	75-19 mm	19-4.75 mm	4.75-2 mm	2-0.425 mm	0.425-0.075 mm	< 0.075 mm			
Sample 1	0.00	1.61	2.97	21.33	33.50	40.59	1.61	57.80	40.59
Sample 2	0.00	29.10	9.24	31.68	22.65	7.33	29.10	63.57	7.33
Sample 3	0.00	52.74	6.16	21.12	15.11	4.87	52.74	42.39	4.87

The results (maximumdry density and optimum water content) of standard compaction test are presented in Table 1. The results shows that maximum dry density was higher for **Sample 3** (1.76 g/cm³, with optimum water content-16.5%), and lower values for maximum dry density was observed for **Sample 2** (1.65 g/cm³, with optimum water content-14.5%) (Table 1, Figure 2).

Falling head permeability test (measurement of hydraulic conductivity). The results of the hydraulic conductivity (K_{20}°C, m/sec.) are shown in Table 1. It was determined that lowest permeability values had **Sample 2** (10^{-6} m/sec), and **Sample 1**, **Sample 3** had same permeability properties (10^{-7} m/sec).

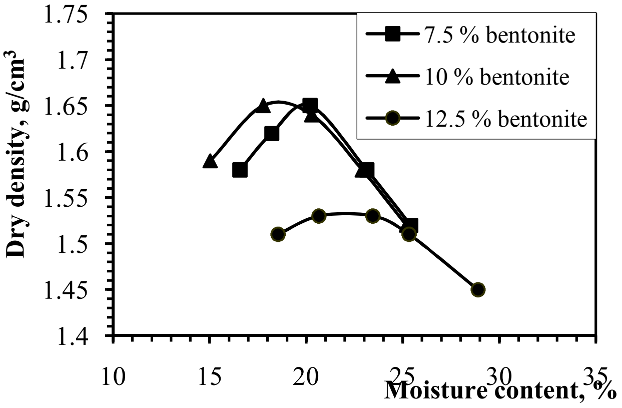

Figure 3. Compaction curves of the "sample 1 + 7.5, 10, 12.5% bentonite" mixtures.

Soil-bentonite mixture

Studies on soil-bentonite mixtures are mostly focused on rate determination and variations in physical-mechanical properties [6, 9, 17-19, 21].

After testing all main materials there have been chosen 3 percentages of bentonite content for each soil samples – 7.5%, 10% and 12.5% to investigate soil stabilization processes. The results of physical characteristic of soil-bentonite mixtures are presented in Table 3.

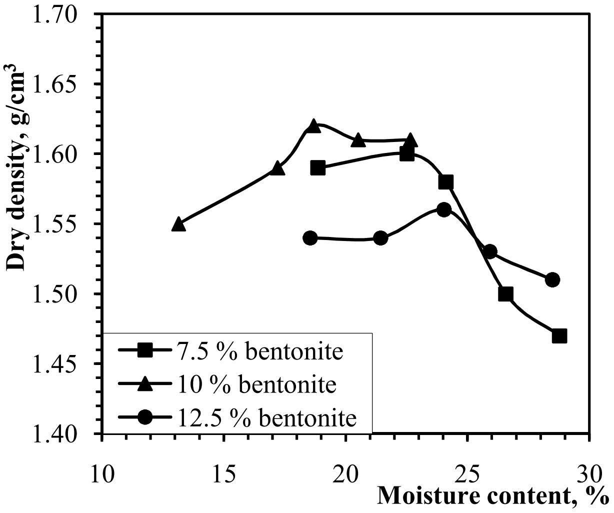

Figure 4. Compaction curves of the "sample 2 + 7.5, 10, 12.5 % bentonite"mixtures.

Atterberg limit determination. The Atterberg limit test for **Sample 1**, **Sample 2** and **Sample 3** (mixing ratio: 7.5%, 10% and 12.5% bentonite) were carried out. Atterberg limits obtained for different soil-bentonite mixtures are presented in Table 3. It was observed that bentonite increased the liquid limit values for all samples. Bentonite content led to changes also in plastic limits values, but it is not significant.

The increase of bentonite displays a linear increase on liquid limit, but it has a limited effect on plastic limit [22].We have demonstrated that addition of bentonite to the soil samples resulted in significant changes on Atterberg limits. In **Sample 1** increasing bentonite content lead to linear increase on liquid limit, but there are no significant changes on plastic limit, and there are significant differences between PL and LL values for this sample. Addition of bentonite on **Sample 2** increased plasticity and LL and PL values increased depending on bentonite content. However, differences between LL and PL values were not significant and these differences are constant for all bentonite concentrations. **Sample 3** also became plastic when bentonite was added. As in Sample 2 here also we detected linear increase on LL, but PL was detected with shows no significant changes, being almost the same for all of bentonite contents.

Thus, the addition of bentonite to the samples showed significant effect only on **Sample 2,** probably due to particle size distribution. **Sample 2** in general had higher sand content.

Standard compaction test. The standard compaction test results of the **Sample 1**, **Sample 2** and **Sample 3** with 7.5, 10 and 12.5% bentonite are shown in Figure 3-5:

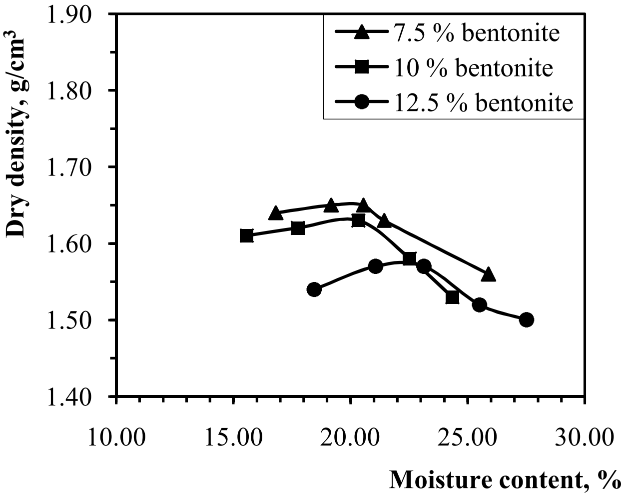

Figure 5. Compaction curves of the "sample 3 + 7.5, 10, 12.5 % bentonite" mixtures.

Preparatory compaction test: The density of the compacted specimen was changed due to the bentonite condition changing through absorption of water together with the time passage.

Table 3. Physical characteristics of soil-bentonite mixtures.

Sample name	Bentonite content (%)	Liquid limit, (%)	Plastic limit, (%)	Plasticity index, (%)	Maximum dry density, g/cm^3	Optimum water content, (%)	Permeability, m/sec.
Sample 1	7.5	34.5	17.0	17.5	1.65	20.2	$1.80 \cdot 10^{-8}$
	10.0	38.2	17.4	20.8	1.65	20.3	$1.72 \cdot 10^{-8}$
	12.5	43.5	18.4	25.1	1.53	23.0	$2.88 \cdot 10^{-8}$
Sample 2	7.5	39.5	39.2	0,3	1.61	21.0	$2.24 \cdot 10^{-8}$
	10.0	43.5	42.2	1.3	1.62	21.2	$6.98 \cdot 10^{-8}$
	12.5	46.5	45.0	1.5	1.56	24.0	$2.48 \cdot 10^{-8}$
Sample 3	7.5	41.0	39.0	2.0	1.65	19.2	$3.06 \cdot 10^{-8}$
	10.0	46.0	39.3	6.7	1.63	20.3	$1.36 \cdot 10^{-8}$
	12.5	49.0	40.6	8.4	1.57	23.0	$1.88 \cdot 10^{-8}$

The preparatory compaction tests were carried out to decide the rule how to make the specimen after the preparation of the mixed sample. The mixtures testing were carried out immediately and within 1, 2, 5 and 12 hours after preparation. Our data suggested the best results were obtained during compaction process within 2 hour after preparation as it is more compacted one (the results of the rest hours were not presented in the manuscript).

The summarized results of the standard compaction tests of the soil-bentonite mixtures are presented in Table 3.

Typical compaction curves were observed for soil-bentonite mixtures. Depending for the bentonite content on the soil samples the maximum dry density of the soil-bentonite mixture were linearly decreased within increasing water content. Thus, as expected, when more bentonite was added, optimum water content increased and maximum dry density decreased. It was observed that **Sample 3** had highest maximum dry density. The explanation is when water is added to the soil samples, the water acts like lubricant that allows soil particles to move closer to eachother, air void is minimized, and higher maximum dry density can be achieved within optimum water content. When additional water was added after optimum water content, the maximum dry density of the compacted soil-bentonite mixtures drastically decreased. The bentonite swelled further when more additional water was added. At this stage, the additional water and swelled bentonite which was lighter than soils, occupied more space in the compaction mold resulting in decreasing of the maximum dry density of the mixtures.

Falling head permeability test. The permeability tests of soil-bentonite mixtures were carried out with compacted specimens, which were compacted as standard compaction test procedures. After compaction the specimen has been kept in the mold for three days and then sunk into the water tank forsaturation. The test results of the soil-bentonite mixtures for the permability tests are presented in Table 3.

The most important effect of adding bentonite to soil is the decrease in soil permeability. This is mostly caused by the fact that as bentonite enlarges approximately ten times when it is mixed with water, it fills the cavities of coarse material [22]. Wang [23] presented correlations about the properties used in the classification of soils showing variation of permeability according to maximum dry density and optimum water content.

According to Kenney et al. [24], obtaining bentonite-sand mixtures with low permeability is dependent on the existence of adequate bentonite in the mixture and the uniform distribution of this bentonite in the mixture. Cracks caused by drying are dependent on the water content and the amount of bentonite used in the mixture. In the mixtures with a high level of bentonite rate, the decrease of water content causes cracks in the surface [25].

Regarding to the permeability properties of the soil-bentonite mixtures only in **Sample 2** two orders decrease of permeability values for all bentonite content were observed. Bentonite addition to **Sample 1** and **3** led only to an order of decrase of permabilty.

Comparative data of soils and soil-bentonite mixtures

To analyze and to make final conclusion of the bentonite stabilization effects we were compared of the data of soil samples and soil-bentonite mixtures. Figure 6 presented the data of the Atterberg limits of the soil samples and soil-bentonite mixtures.

Figure 7 shows standard compaction tests results of the soil samples and soil-bentonite mixtures and Table 3 presented hydraulic conductivity of the soil samples and soil-bentonite mixtures.

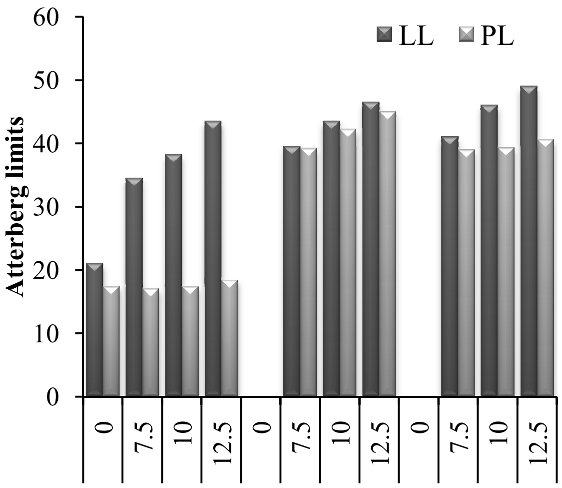

Figure 6. Atterberg limits of the soil samples and soil-bentonite mixtures. (**LL**-liquid limit,**PL**-plastic limit)

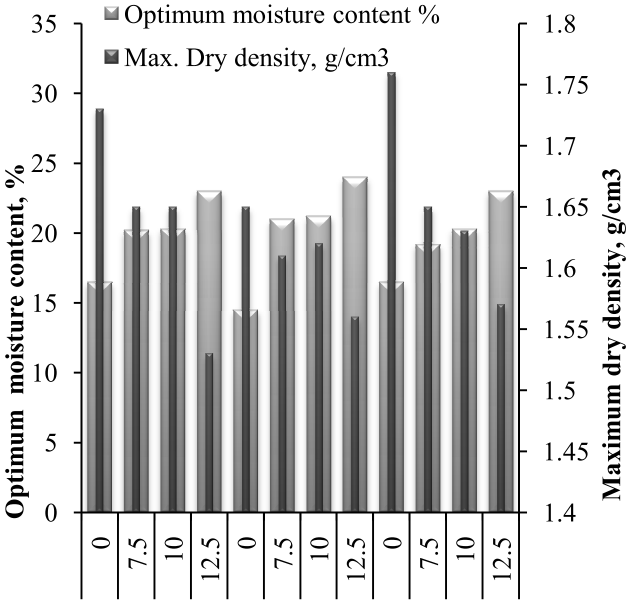

Figure 7. Standard compaction tests resuls of the soil samples and soil-bentonite mixtures.

IV. CONCLUSION

Afterwards, the following conclusions can be drawn.

1. Maximum dry density decreased and optimum water content increased with increasing bentonite content of the compacted soil-bentonite mixtures.
2. Hydraulic conductivity of the soil-bentonite mixtures decreased with increasing bentonite content. The hydraulic conductivity decreased

approximately two orders of magnitude when 7.5% bentonite content or more are used.

3. Hydraulic conductivity of the soil-bentonite mixtures is related to the swell of themixtures. As swell increased, the hydraulic conductivity decreased. Use of bentonite content of more than 7.5% did not significantly decrease hydraulic conductivity of the mixtures.

4. The common requirement on hydraulic conductivity (should be less than 10^{-8} to 10^{-10} m/sec.) was met for compacted soil with a minimum of 7.5% of bentonite addition, suggesting that bentonite in this soil samples gave high plasticity and high permeability properties.

Our investigation demonstrated that the design and investigation of the behaviour of compacted soil-bentonite mixture in some geo-environmental applications need to examine the at least the effect of two factors, namely particle-size distribution and bentonite content, which plays key factors for soil stabilization and which are important for decrease permeability of the soil-bentonite mixtures.

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VI. REFERENCES

[1]. McBean EA, Rovers F, Farquhar G. 1995. Solid Waste Landfill Engineering and Design. Prentice Hall. Prentice Hall PTR, Englewood Cliffs, New Jersey.

[2]. Gray D. 1989. Geotechnical Engineering of Land Disposal Systems. The Landfill, P. Baccini, Ed., Springer, Berlin/ Heidelberg, pp. 145-173.

[3]. Goldman LJ, Greenfield L, Damle A, Kingsbury G, Northeim C. 1987. Environmental Protection Agency, Design, construction, and evaluation of clay liners for waste management facilities, U. S. Environmental protection Agency, Cincinnati, Ohio, EPA/530-SW-86-007F.

[4]. Sallfors G, Öberg-Högsta A. 2002. Determination of hydraulic conductivity of sand-bentonite mixtures for engineering purposes. Geotech and Geol Eng 20(1): 65-80.

[5]. Brown KW. 1982. Testimony before the House Site Committee on the Natural Resources. Agricultural Research and Environmental of the Committee on the Science and Technology, 30 November 1982.

[6]. Evans JC. 1994. Hydraulic conductivity of vertical cutoff walls. Hydraulic Conductivity and Waste Contaminant Transport in Soil, ASTM STP 1142, D. E. Daniel and S. J. Trautwein, eds., ASTM, Philadelphia, Pa, 79-94.

[7]. Evans JC and Fang HY. 1988. Triaxial permeability and strength testing of contaminated soils. Advanced Triaxial Testing of Soil and Rock, ASTM STP 977, R. T. Donaghe, R. C. Chaney, and M. L. Silver, eds., ASTM, Philadelphia, Pa, 387-404.

[8]. Barvenik MJ and Ayers JE. 1987. Construction quality control and post-construction performance verification for the Gilson Road hazardous waste site cutoff wall. EPA/600/2-87-065.

[9]. D'Appolonia DJ. 1980. Soil-bentonite slurry trench cutoffs. J Geotech Eng Division ASCE. 106(4):399-418.

[10]. Howell JL and Sheckelford C. 1997. Hydraulic conductivity of sand admixed with processed clay mixtures. 14th Int Conf on Soil Mech And Found Engrg, A.A. Balkema, Rotterdam, The Netherlands, 1, 307-310.

[11]. Nishigaki M, Sun Y, Kono I. 1994. A study of deformation and failure of compacted sand/bentonite mixture soil foundation by model test and numerical analysis. In Proceedings of the International Symposium on Pre-failure Deformation of Geomaterials. IS-Hokkaido, Japan, 1994. vol. 1, p. 523-529.

[12]. Lopez RS, Cheung CH, Dixon DA. 1984. The Canadian program for sealing underground nuclear fuel waste vaults. Canad Geotech J 21:593-596.

[13]. Schnitter G, and Zeller J. 1961. Geotechnical investigations of mixtures of bitumen, clay or bentonite with sandy gravel. In Proceedings of the 7th International Conference on Large Dams, Rome, 1961.vol. 4, Q27 R38.

[14]. Lauffer H, Schober W. 1961. Investigation for the earth core of the Gapatsch rockfill dam with a height of 150 m. In Proceedings of the 7th International Conference on Large Dams, Rome, 1961.vol. 4, Q27 R92.

[15]. Gillham RW, Robin M, Dytynyshyn D, Johnston H. 1984. Diffusion of non reactive and reactive solutes trough fine-grained barrier materials. Canad Geotech J 21:541 550.

[16]. Chapuis RP. 1990. Sand - Bentonite liners: predicting permeability from laboratory tests. Canad Geotech J 27:47-57.

[17]. Evans JC. 1991. Geotechnics of hazardous waste control systems, Chapter 20, Foundation Engineering Handbook, 2nd Edition, H. Y. Fang, ed., Van Nostrand Reinhold, New York, NY, 765-777.

[18]. Millet RA, Perez J, Davidson R. 1992. USA practice slurry wall specifications 10 years later. Slurry Walls: Design, Construction and Quality Control, ASTM STP 1129, D. B. Paul, R. R Davidson, and N. J. Cavalli, eds., American Society for Testing and Materials, Philadelphia, Pa.

[19]. Kallur VG, Haug MD, Barbour SL. 1995. Effects of hydraulic gradients on pore fluid chemistry. Geoenvironment 2000, ASCE GSP 46, Y. B. Acar and D. E. Daniel, eds., 732-745.

[20]. Mishra A, Kumar B, Vadlamudi V. 2017. Prediction of hydraulic conductivity for soil-bentonite mixture. I J Environ Sci Technol 14(8):1625-1634

[21]. Heslin GM, Filz GM, Baxter DY. 1997. An improved method for interpreting API filter press hydraulic conductivity test results. Proc., Int. Containment Technology, 71-77.

[22]. Bowles JE. 1998. Engineering Properties of Soil and Their Measurement, Mcgraw-Hill Book Company, Singapore.

[23]. Wang MC. 1984. Soil compaction and Permeability Prediction Models, ASCE J Environ Eng:1063-1083.

[24]. Kenney TC, van Veen WA, Swallow MA, Sungaila MA. 1992. Hydraulic Conductivity of Compacted Sand-Bentonite Mixtures, Canad Geotech J 29(3):364-374.

[25]. Esener AB. 2005. Geotechnical Studies to Design Soil Fill Structures, thesis of MSc., Pamukkale University, Institute of Scienes, Denizli.