Volume change behavior of sand-bentonite liner and the effect of cement enhancement

Anoosheh Iravanian
Eastern Mediterranean University, Famagusta, N. Cyprus, anooshah.iravanian@cc.emu.edu.tr

Huriye Bilsel
Eastern Mediterranean University, Famagusta, N. Cyprus, huriye.bilsel@emu.edu.tr

Özgür Eren
Eastern Mediterranean University, Famagusta, N. Cyprus, ozgur.eren@emu.edu.tr

KEYWORDS: Sand-bentonite, landfill, volume change, cement.

ABSTRACT: This paper presents the volume change behavior of compacted mixtures containing different amounts of sand and bentonite. The volume change behavior of two samples containing 15% and 10% bentonite are compared with samples containing 5% and 15% bentonite and 5% cement addition by dry weight. The effect of cement addition to optimum water content, maximum dry density, swell and compressibility behavior of sand-bentonite mixtures is studied. The test results show that addition of cement prevents the swelling of samples and significantly reduces the compressibility. The compressibility of sand-bentonite mixtures is also analyzed and the relationship between swell pressure and shape of the compression curve is discussed. The hydraulic conductivity of all samples tested are determined to be much lower than the minimum required for landfill barriers.

1 INTRODUCTION

In the past few decades due to enormous developments in industry, a huge amount of waste is produced every day by factories and cities. Quantity of leftovers and urban garbage is drastically raised and not all of them can be refined and fed back into cycle of industry. The rest are burned or simply stored in waste dumps (Kazimoglu et al., 2003; Bielinski et al., 2001). Using granular soils like sand together with clayey material in landfill liners is a well-known solution for preventing the leakage of contaminated water to the surrounding environment. However, in arid and semi-arid areas the soil is not always saturated, and hydraulic and evapo-transpirative barriers are continuously subjected to repetitive cycles of wetting and drying. Desiccation of waste containment material leads to crack formation, and hence creation of preferred paths for hydraulic leakage. Bentonite as a clay material with high amounts of montmorillonite appears to be a good option to be used together with sand due to its high water absorption capacity and very low hydraulic conductivity, while sand holds the main structure of the compacted mixture together. Montmorillonite is an alteration product of volcanic ash, a highly colloidal mineral composed of one gibbsite sheet squeezed in between two silica sheets. In between each layer of montmorillonite there are few amounts of exchangeable cations and large quantity of water molecules. The negative charge of outer layer of this mineral attracts water molecules and it makes the basal spacing of it to range from 9.6 Å to complete separation in full hydration (Das 2006; Mitchel 1993). This property of montmorillanite makes it a favorable material to be used as drilling mud, backfill slurry and as soil admixture. The granular particles of sand maintain the strength and stability of composite while the small particles of bentonite seal the voids between them and reduce the hydraulic conductivity. Using sufficient amounts of bentonite will produce a combination that can absorb water and swell in saturated condition and simultaneously be fairly resistant to desiccation cracks in dry seasons (Stewart et al 2003).

Cement may also be used as an additive in order to increase the strength of the compacted sand-bentonite, reduce the hydraulic conductivity and possibility of crack formation. Using small amounts of cement in stabilizing the soil, both as slurry or mixed with soil is studied by many researchers (Stavidakis & Hatzigogos 1999; Tchakalova & Todorov 2008; Bellezza & Fratalocchi 2006). A major factor in considering a soil-cement liner for sanitary or hazardous waste landfill sites is its compatibility with stored wastes. Adaska (1985) in testing on a full scaled hydraulic barrier indicated that after one year of exposure to leachate from municipal solid wastes such as toxic pesticide formulations, oil refinery sludge, toxic pharmaceutical wastes and rubber and plastic wastes, the soil-cement got hardened considerably and cored like portland cement concrete, in addition, it became less permeable during the exposure period. Bellezza & Fratalocchi (2006) presented the results of an experimental study on effectiveness of 5% cement in compacted soil-cement mixtures considering 28 days curing time. The Proctor standard effort was used to prepare their samples and they reported that for soils having fine fraction > 20% and plasticity index of >7 hydraulic conductivity was always less than $2x10^{-7}$ cm/s, which is a reasonable hydraulic conductivity for the waste containments. They finally concluded that adding 5% cement can be adequate to guarantee a low hydraulic conductivity provided that the insitu mixing, compaction procedure and curing conditions are kept close to the laboratory test conditions.

In this study, 10% and 15% bentonite-sand mixtures and 5% and 10% bentonite-sand with 5%cement additions are used to study the volume change as well as hydraulic conductivity to attain a feasible landfill barrier mixture in a semi-arid climate.

2 MATERIALS AND METHODS

The material used in this research was a poorly graded uniform sand from Silver Beach near Famagusta in North Cyprus with mean diameter D_{50}= 0.20 mm, effective diameter D_{10}= 0.14 mm, uniformity coefficient C_u=1.53, coefficient of curvature C_c= 0.99. This sand was taken in autumn after repetitive rains and therefore the amount of salt was very small. The other soil material used was Na-bentonite obtained from Karakaya Bentonite Inc., Turkey. The liquid limit is 486% and plastic limit is 433%. The cement used in this study was ordinary Portland cement type I.

The mixtures of 15% bentonite-85% sand, 10% bentonite-90% sand, 5% bentonite-5% cement-90% sand and 15% bentonite-5% cement-80% sand by dry weight were prepared by pre-drying sand and bentonite in oven. Sand was then passed through a 2.00 mm sieve to limit the impurities like sea weeds and shell fragments. The optimum water content and maximum dry density were calculated through standard proctor compaction test ASTM D698. In order to attain homogenous moisture content within each sample, the batches were mixed thoroughly in mechanical mixer, sealed in double nylon bags and kept 24 hours previous to each compaction. For the cement included samples, half of the water and cement were preserved and added to the mixture just before the compaction.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Compaction Test

In all of the samples, addition of more bentonite to the mixture increases the optimum water content and maximum dry density. Higher optimum water contents are due to the higher water holding capacity of bentonite in comparison to sand. On the other hand, fine particles of bentonite work as a lubricant between the sand grains and by making a decent matrix, lead to a better compaction and hence higher dry densities. Compaction curves of both 10% and 15% bentonite added mixtures are quite flat showing that the small water content variations would not affect the dry density noticeably. However, addition of cement to the mixture will increase the maximum dry density significantly due to the higher specific gravity of cement, cementing action and reduction of water absorption. Cement containing samples demonstrate high sensitivity to water content variations and small increments of moisture cause visible reductions in dry density. The Proctor compaction curves are shown in Figure 1. Since sand is not capable of adsorbing water replacement of 5% sand with cement in 15%b-5%c mixture did not have a noticeable effect on optimum water content compared to 15% b mixture with no cement, although dry densities increased with addition of cement. Reduction of bentonite in 5%b-5%c mixture causes decrease in optimum water content, although it has a appreciable increase in maximum dry density. The compaction characteristics are given in Table 1.

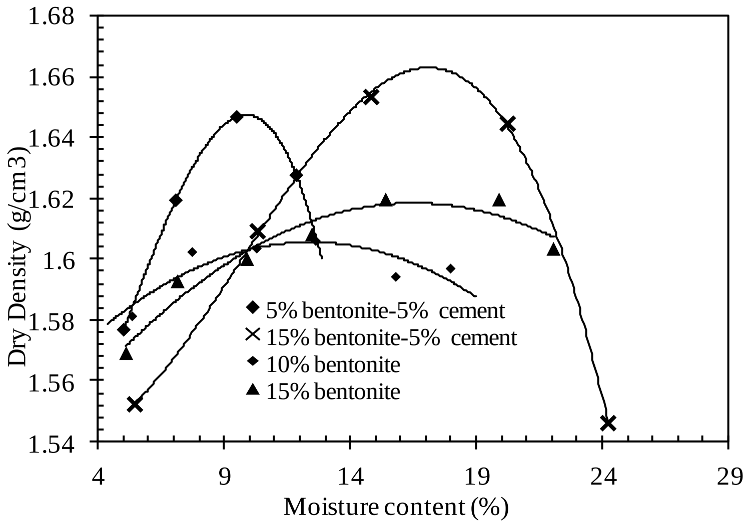


Figure 1. Compaction curves.

Table 1. Compaction characteristics of samples used.

	10%b-90%s	15%b-85%s	15%b-5%c-80%s	5%c-5%b-90%s
Maximum dry density (g/cm^3)	1.606	1.624	1.663	1.65
Optimum water content (%)	12.50	17.00	17.00	9.50

b:Bentonite, c:Cement, s: Sand

3.2 One-dimensional Swell

One dimensional swell test was carried out on two statically compacted samples from each mixture having maximum dry density and optimum water content. The average preliminary swell curves are plotted in Figure 2. While 15% bentonite containing samples swelled up to 32%, reducing the bentonite by 5% amount caused the samples to swell 20% less. However, addition of cement to the mixtures lead to strong bonding between the soil particles and prevent swelling; therefore the maximum swell of cement containing 5% bentonite and 15% bentonite mixtures were not any higher than 0.02%.

3.3 Consolidation Test

Oedometer test was performed on swelled samples and the average results are plotted on Figure 3. Consolidation curve of 15% bentonite content samples were very steep showing a high void ratio variations between 7 and 1569 kPa pressures. Reduction in the amount of bentonite makes a significant difference by lowering the void ratio and compressibility at the initial point. Comparing with 15% bentonite mixture, lower void ratio of 10% bentonite content mixtures in the starting point explain a better compaction and denser sample. The volume change of cement containing samples were very low in both swell and consolidation parts. Smooth curves with small changes of void ratio under different loads are observable characters of stable dense samples containing cement.

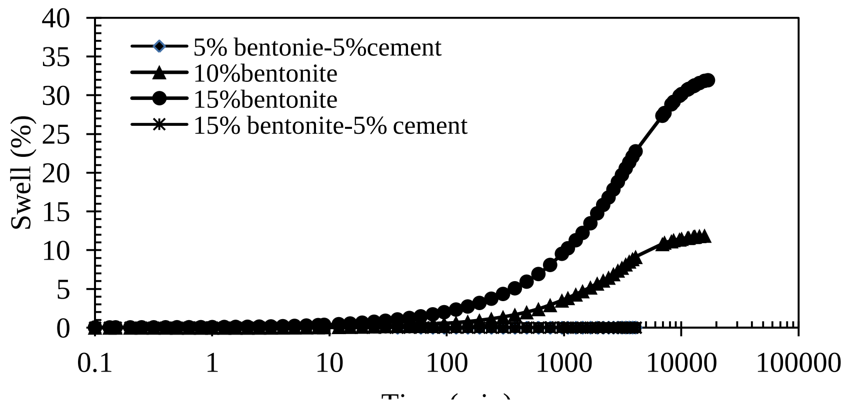


Figure 2. One dimensional free swell curves.

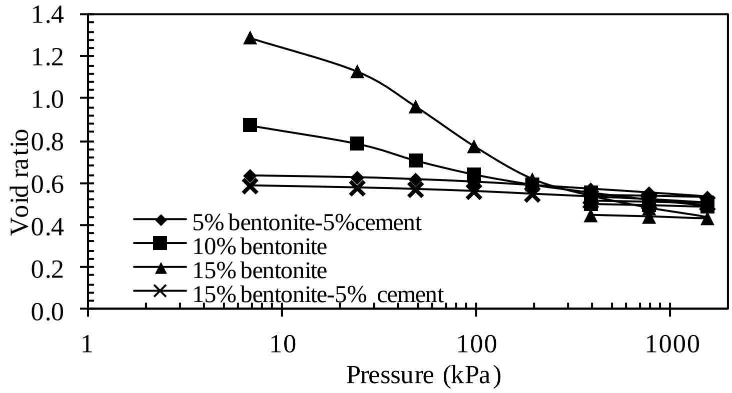
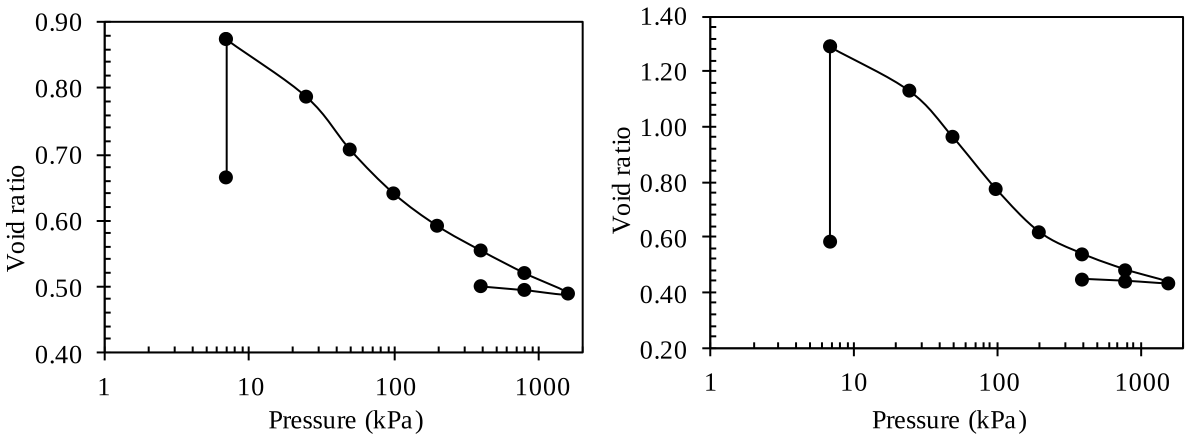


Figure 3. Consolidation test results.



(a) (b)

Figure 4. Consolidation curves of (a) 15% bentonite and, (b) 10% bentonite samples.

The samples without cement had a high tendency for swell as shown in Figure 4. The compressibility is also high but the curves surprisingly display two different slopes. It is suggested that sand-bentonite mixtures containing different amounts of bentonite can exhibit two characteristic conditions: at lower than a threshold stress the bentonite particles tend to separate sand particles and support the whole applied stress, and above the threshold stress the bentonite particles are mostly consolidated and a matrix of sand grains is formed that support most of the stress (Stewart et al., 2003). The bilinear characteristic of sand-bentonite is clearly visible in graphs of void ratio versus pressure. As it is shown in Figure 4 the slope changes at about the same values of initial void ratio, meaning that the bentonite part of soil absorb the water and swells leading to higher void ratios. Subsequently, the same part of sample gets compressed when it is exposed to stress and gradually leave out the water till it reaches the initial void ratio, the point at which sand particles appear to be the main part of mixture. From this point onward the sand particles are the dominant structure of soil tolerating the stress and since sand cannot be compressed as much as bentonite, the slope of curve and coefficient of compressibility decrease. Compression index before and after the threshold stress is shown as c_c (1) and c_c (2) in Table 2. Comparison of cement added mixtures shows that the amount of bentonite added to the mixture was not enough to break the cementitious bonds between soil particles and both of 15% and 5% bentonite mixtures with cement show low compressibility and no swell pressure.

Table 1 Consolidation parameters.

Mixtures	$C_c(1)$	$C_c(2)$	C_r	C_v (m^2/s)	m_v (7-200 kPa)	m_v (200-1570 kPa)	Swell Pressure (kPa)
15b-85s	0.468	0.141	0.0183	3.93E-06	1.63E-03	7.96E-04	250 kPa
10b-90s	0.212	0.103	0.0199	4.97E-06	6.99E-05	4.08E-05	80 kPa
5b-5c-90s	0.057		0.0179	5.64E-06	1.58E-04	2.40E-05	
15b-5c-80s	0.0529	______	0.0186	2.59E-06	8.36E-05	1.65E-05	

b:Bentonite, c:Cement, s: Sand

Since the amount of settlement in a specimen subjected to surcharge load has direct relationship with the drainage of water through the sample, therefore the saturated hydraulic conductivity of samples can be indirectly measured from consolidation test results using Equation 1.

$$k_s = \gamma_w m_v c_v \qquad (1)$$

where,

k_s is the saturated hydraulic conductivity,
γ_w is unit weight of water,
m_v is the coefficient of volume compressibility, and
c_v is the coefficient of consolidation.

All samples displayed low hydraulic conductivity as expected due to presence of bentonite. The very fine particles of bentonite reduce the permeability of the mixture by filling the voids between the sand particles. Even though sand and bentonite are completely different types of soils with respect to their grain size distribution, permeability, chemical activity and strength, when mixed together at right proportions can form an excellent material to be used as a hydraulic barrier. As Kumar and Yong (2002) indicate that low hydraulic conductivity of sand-bentonite mixtures is because of high specific surface of bentonite particles that allow them to hold a portion of water on their double layer and prevent water molecules from flowing among voids. They conclude that high swell potential and fineness of bentonite are the main reasons in reduction of hydraulic conductivity.

Addition of cement also slightly reduces the hydraulic conductivity by making bonds between the particles and reducing the connected pores which can lead the water flow. The hydraulic conductivity of samples under higher ranges of pressure is less than the hydraulic conductivity of the same sample exposed to lower pressures as it is expected. With surcharge load increase, particles tend to rearrange in a way that least voids could be available, in this process bentonite works as a lubricant gel in between the sand particles and let a better, denser pack of particles form to carry the surcharge load without breaking the particles.

Table 2 Saturated hydraulic conductivity.

	15b-85s	10b-90s	5b-5c-90s	15b-5c-80s
k_{sat} (7-200 kPa) m/s	0.92E-09	0.62E-09	0.47E-09	0.353E-10
k_{sat} (200-1570 kPa) m/s	0.36E-10	0.31E-10	0.25E-10	0.700E-11

b:Bentonite, c:Cement, s: Sand

3 CONCLUSIONS

From the experiments carried out and analyses of the results it can be concluded that:

1. In all of the samples, addition of more bentonite to the mixture increases the optimum water content and maximum dry density. Fine particles of bentonite work as a lubricant between the sand grains and by making a decent matrix, lead to a better compaction and hence higher dry densities
2. Addition of cement to the mixture increases the maximum dry density drastically. Cement containing samples demonstrate high sensitivity to water content variations and small increments of moisture cause visible reductions in dry density
3. 15% bentonite content samples swelled up to 32% while 10% bentonite content samples have strains of 12% under 7 kPa loads.
4. Addition of cement to the mixtures leads to strong bonding between the soil particles and prevent swelling.
5. The volume change of cement containing samples were very low in both swell and consolidation parts. Small changes of void ratio under different loads is a noticeable character of stable dense cement containing samples.

6. The bilinear characteristic of sand-bentonite is clearly visible in graphs of void ratio versus pressure. The slope change point is exactly about the same values of initial void ratio. In sand-bentonite composites bentonite part of soil absorbs the water and swells leading to higher void ratio. Subsequently, the same part of sample gets compressed when it is exposed to stress and gradually leaves out the water till it reaches the initial void ratio, the point at which sand particles appear to be the main part of mixture. From this point onward the sand particles are the dominant structure of soil tolerating the stress and therefore, slope of curve decreases.
7. All samples displayed low hydraulic conductivity due to presence of bentonite. The very fine particles of bentonite reduce the permeability of the mixture by filling the voids between the sand particles.
8. Addition of cement slightly reduces the hydraulic conductivity by making bonds between the particles and reducing the connected pores which can lead the water flow.
9. The hydraulic conductivity of samples under higher ranges of pressure is less than the hydraulic conductivity of the same sample exposed to lower pressures.

REFERENCES

Adaska S.W. (1985). Soil–cement liners. In Hydraulic Barriers in Soil and Rock, ASTM. Special Technical Publication No. 874, 299–313.

Bellezza I. & Fratalocchi E. (2006). Effectiveness of cement on hydraulic conductivity of compacted soil–cement mixtures, Ground Improvement 10, No. 2, 77–90.

Bielinski, A., Class, H., Jakobs, H., & Helmig, R. (2001). Numerical Simulation of Desiccation Processes in a Mineral Liner of a Waste-Disposal Site, Proceedings of 3. Workshop, Weimar, Germany, 2001, Heft 06: 113-128.

Das, B. M. (2006). Principles of Geotechnical Engineering, PWS-Kent, Boston.

Kumar, S., & Yong, W.L. (2002). Effect of Bentonite on Compacted Clay Landfill Barriers, J. Soil and Sediment Contamination, 11(1):71-89.

Kazimoglu, Y.K., McDougall, J.R., & Pyrah, I.C. (2003). Moisture Retention Curve in Landfilled waste, Proceedings of the International Conference "From Experimental Evidence towards Numerical Modeling of Unsaturated Soils", Weimar, Germany, Vol. 1: 59-67.

Mitchell, J.K. (1993). Fundamentals of Soil Behavior, Second Edition, John Willey and Sons, New York, 30-39.

Stavridakis E. I. & Hatzigogos T. N. (1999). Influence of Liquid Limit and Slaking on Cement Stabilized Clayey Admixtures, Geotechnical and Geological Engineering Volume 17: 145-154

Stewart D.I., Studds P.G., & Cousens, T. W. (2003). The factors controlling the engineering properties of bentonite-enhanced sand, Applied Clay Science, 23 (1–4): 97–110.

Tchakalova B. & Todorov K., (2008). Plastic soil-cement mixtures for isolation barriers, Geologica Balcanica, 37. 1-2: 91-96.