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A study on the suction characteristics of compacted bentonite-zeolite mixtures

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ABSTRACT: Soil suction is one of the most essential parameters describing soil moisture condition for unsaturated soils. However, rare studies were conducted on suction characteristics of zeolite-bentonite mixtures which are lately proposed for use of liner materials. Nevertheless, zeolite is known with its microporous skeleton including cages and tunnels in it which has great physical affiliation to water uptake. Zeolite and bentonite, in a mixture, are tought to be in competition for water uptake and this condition may alter the distribution of water content for each soil in the mixture. This paper reports a study on determining the suction parameters of compacted zeolite-bentonite mixtures with varying mixing ratios at varying compaction water contents. The soil suction measurement technique was the filter paper method, by using Whatman no.42 type filter papers. Initially, the total and matric suction for powdered zeolite and zeolite blocks having a diameter of 5 cm were determined. Consequently, suction characteristics of compacted zeolite, 10% (10% bentonite + 90% zeolite) and 20% (20% bentonite + 80% zeolite) bentonite zeolite mixtures of which compacted at their dry of optimum, optimum and wet of optimum water contents were determined and compared to each other. Finally, contaminated compacted bentonite zeolite mixtures are compared to that of uncontaminated mixtures at optimum water contents for 10% and 20% mixtures. The results of this study show that Zeolite block is found to have more suction capacity than powdered zeolite at the same water content. Matric and total suction are found to be also related to the bentonite content. As bentonite content increases both matric and total suction increases. Total suction values of contaminated samples are found to be higher than the uncontaminated samples due to the increase in dissolved ion concentration.

1 INTRODUCTION

The behavior of unsaturated soils is affected by the both negative and positive pore-water pressures in the soil. The negative pore water pressures have significant effect on the shear strength and volume change behavior of a soil. In geoenvironmental problems, the effect of negative pore-water pressures becomes important especially on the hydraulic conductivity behavior of the compacted specimens (Fredlund et al., 1995).

Soil suction of unsaturated soils describe the potential with which a given soil at given water content adsorbs and retains pore water. Total suction of a soil has two components. A matric component associated with interparticle capillary menisci and particle surface hydration mechanisms, and an osmotic component arising from the presence of dissolved solutes in the pore

fluid. The pore-water in a soil generally contains dissolved salts, and the decrease in relative humidity due to the presence of dissolved salts in pore-water is referred to as the osmotic suction. The free energy of the soil water (total suction) can be determined by measuring the vapor pressure of the soil water or the relative humidity in the soil. The direct measurement of relative humidity in a soil can be conducted using a device called a psychrometer (Fredlund and Rahardjo, 1993). The relative humudity in a soil also can be indirectly measured using a filter paper as a measuring sensor. The filter paper will come to equilibrium with the soil both through vapor flow or liquid flow, and at equilibrium, the suction value of the filter paper and the soil will be the same. When the psychrometer method is compared to the filter paper method, the filter paper method gives more consistent results (Bulut et al., 2001). Filter paper method can be applicable over a wide range of suctions. If the filter paper is allowed to absorb water through vapor flow (non-contact method) then total suction is measured. After equilibrium is established between the filter paper and soil in a constant temperature environment, the water content of the filter paper disc is measured. Then, by using a filter paper calibration curve of water content versus suction, the corresponding suction value is found from the curve.

Compacted natural soil mixtures have been widely used in landfill liners because of their low permeability characteristics. The compacted bentonite zeolite mixtures were proposed for landfill liners with favorable characteristics such as high cation exchange capacity of zeolite (Kaya and Durukan, 2004). Compacted bentonite zeolite mixtures are normally unsaturated and therefore suction can be used as indicator of their engineering behavior (Agus et al., 2010). This study focused on investigating suction characteristics of compacted bentonite zeolite mixtures, powdered and blocks zeolite samples. The suction behavior of bentonite zeolite mixtures was investigated in the presence of leachate of the landfill in order to determine the contamination effect on the suction behavior of these mixtures.

2 MATERIALS AND METHOD

Commercial zeolite (Gördes zeolite from Rota Madencilik) and its mixtures with Na-bentonite (Karakaya Bentonite) are used in this study where their suction characteristics are determined by using filter paper method. The mixtures are stated as the dry weight of bentonite over dry total weight of the mixture and named as "% BEZ". Powdered zeolite (-no.40 sieve opening), zeolite blocks and 0%, 10% and 20% compacted BEZ samples are investigated for their suction parameters that are matric and total suction. The basic geotechnical properties of zeolite and Na-bentonite are given in Table 1.

Table 1. Properties of the tested soil samples

Properties	**Bentonite**	**Zeolite**
Mineralogy	Montmorillonite Kristabolite Quartz	Clinoptilolite Feldispat Montmorillonite
Particle size distribution (ASTM D422)		
Gravel	0%	0%
Sand	0%	98% (-no.16 sieve)
Silt	8%	2%
Clay	92%	0%
Atterberg limits (ASTM D2487)		
Liquid limit	405 %	58 %
Plastic limit	57 %	NP
Plasticity index	348 %	NP
Specific gravity (ASTM D854)	2.71	2.31

The compacted samples having a diameter of 4 cm are prepared according to results of compaction curve composed by using standard effort in the plexiglass tubes. Suction parameters for compacted samples are investigated both at dry of optimum (dry), optimum (opt) and wet of optimum (wet) water contents except for dry of optimum 0% BEZ due to stability factors. The wet unit weights of the samples varied in a very narrow range between 1.34 and 1.59 g/cm^3. The initial water content conditions for each soil sample are given in Table 2. It's seen that for each compaction water contents (dry, opt and wet) similar values of initial water contents are valid which permitting comparison between mixtures. For powdered zeolite and zeolite blocks (having a diameter of 5 cm.), the samples were prepared at of half liquid limit water content. Tests for all samples are run by using distilled water and are also run by using leachate for 10% and 20% BEZ samples at their optimum water contents. The leachate characteristics are given in Table 3.

Table 2. Water contens of soil samples

	Powdered zeolite	Zeolite blocks	0% BEZ		10% BEZ			20% BEZ		
			opt.	wet	dry	opt.	wet	dry	opt.	wet
Water Content, w (%)	30	30	40	48	32	40	48	32	40	47

Suction measurement by filter method is a common, inexpensive and easy technique from which matric and total suction of samples can be measured. In this study, Whatman no.42 type filter papers are used and the system, which is made of soil specimen and filter paper, is held closed at a constant temperature of 21^{0}C for 7 days to reach the equilibrium in the incubator. The view of the test specimen and filter papers which are to be placed in a sealed glass jar in an incubator can be seen in Figure 1.

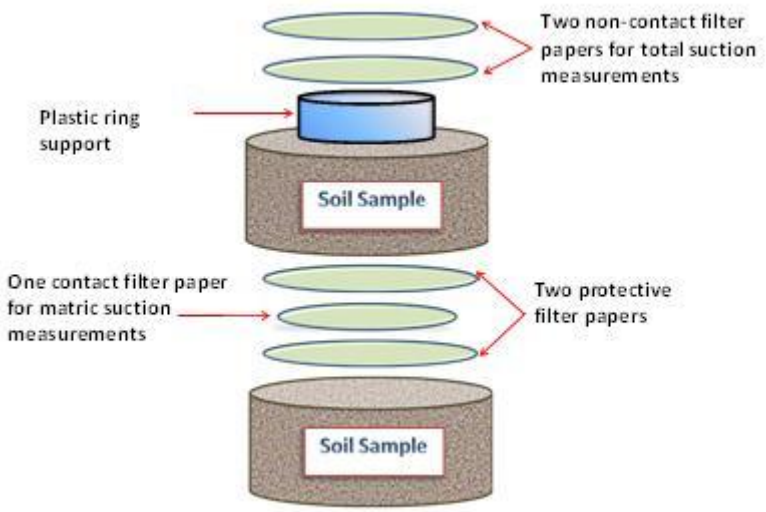

Figure 1. Soil suction system by filter paper method

Table 3. Ion concentrations of the landfill liner leachate

Sample	Al (mg/L)	As (mg/L)	B (mg/L)	Cr (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)
Leachate	0.50	0.11	60	0.53	3.31	17	1.76	0.53

The test procedure and calibration curves for filter papers are defined and given in ASTM D 5298. The ASTM procedure offers a single calibration curve for both matric and total suction calculation which is given in Figure 2. However, researchers proposed different calibration curves for matric and total suction calculation (Chao, 2007). In this study, ASTM procedure is followed.

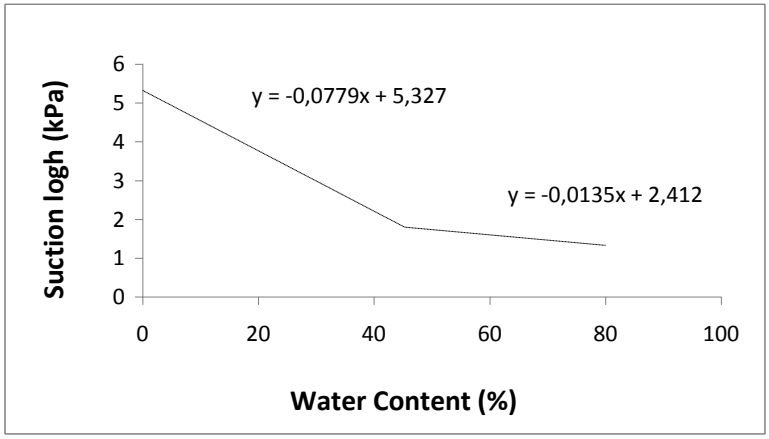

Figure 2. ASTM D-5298 Calibration Curves for Whatman No.42 Filter Paper

3 RESULTS AND DISCUSSION

In this study, the suction behavior of powdered zeolite, zeolite blocks and compacted bentonite zeolite mixtures for varying water contents was investigated. The matric and total suction of powdered and block zeolite are given in Figure 3. Both matric and total suction of the block sample are higher than the powdered zeolite sample. The reason of this situation may be due to the higher void ratio of the block sample which is known to have tunnels and cages in its structure. Moreover these voids in block sample may be in contact with each other resulting in higher void ratios, which gives higher matric suction.

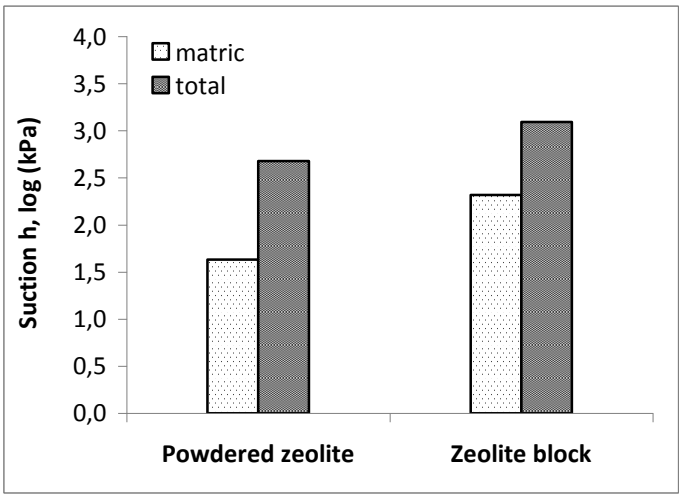

Figure 3. Matric and total suction of powdered and block zeolites

The matric and total suction of compacted bentonite zeolite mixtures are given in Figure 4. From Figure 4, it's seen that as water content increases both matric and total suction of the samples decreases. However, the effect of water content is more significant on matric suction. Besides,

similar trend is valid for increasing bentonite content. Similar results were also found by Agus et al. (2010). They observed that the total suction of bentonite-sand mixtures is primarily a function of bentonite content. However, for bentonite zeolite mixtures matric suction is a primarily function of bentonite content but not for total suction.

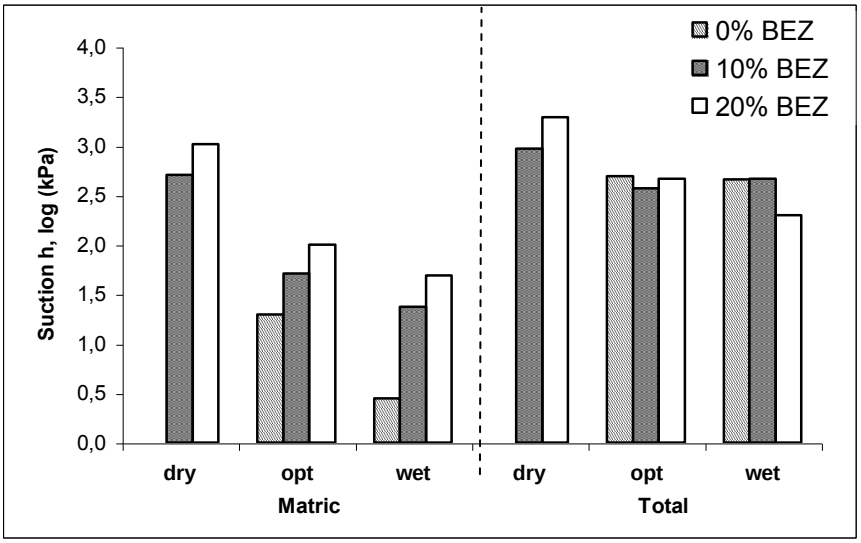

Figure 4. Matric and total suction of compacted bentonite zeolite mixtures

The osmotic suction of the soils is related with the dissolved ion concentration in the pore water. As can be seen in Figure 5, the total suction values of the contaminated samples are higher than the uncontaminated ones. On the other hand, though there is no effect of contamination on the matric suction as it's related to physical properties, the matric suction values found to be varying. It's known that, for bentonite sand mixtures it's reasonable to assume that the water content is only absorbed by bentonite. However, when bentonite zeolite mixtures are concerned, bentonite has to share some of the water with zeolite and so that may not be able to swell enough to fill the pores. In this case, it's not distinct which of the soil governs the mixture behavior. The water content distribution between bentonite and zeolite needs further investigation to determine at which water content and/or bentonite content, bentonite governs the mixture behavior.

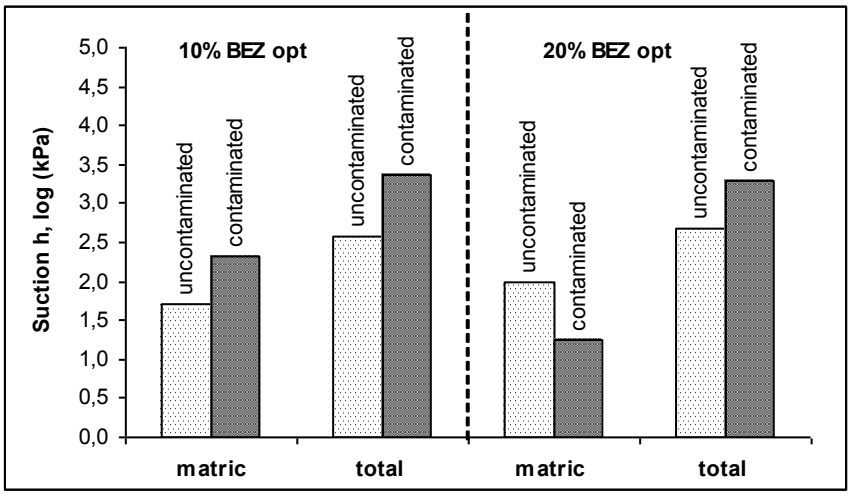

Figure 5. Matric and total suction of contaminated compacted bentonite zeolite mixtures

4 SUMMARY AND CONCLUSIONS

- Zeolite block is found to have more suction capacity than powdered zeolite at the same water content. This situation is attributed to the presence of the tunnels and cages in zeolite structure. Moreover, it's concluded that these pores may be continous which causes higher matric suction values.
- Matric and total suction are found to be related to the water content. As water content increases both matric and total suction decrease.
- Decrease in matric suction values while water content increases are found to be more significant than total suction values.
- Matric and total suction are found to be also related to the bentonite content. As bentonite content increases both matric and total suction increase.
- Similar to water content relation; increase in matric suction values while bentonite content increases are found to be more significant than total suction values.
- Total suction values of contaminated samples are found to be higher than the uncontaminated samples due to the increase in dissolved ion concentration.
- Total suction of 0%, 10% and 20% BEZ samples at different water contents are found to be very similar which may be a result of the uncertain water content distribution between bentonite and zeolite. Unlike bentonite sand mixtures, bentonite may not be able to find enough water because of zeolite's water uptake affinity.

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