A STUDY ON COMPRESSIBILITY, SWELLING AND PERMEABILITY BEHAVIOUR OF BENTONITE- SAND MIXTURE

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ABSTRACT: In geotechnical engineering field, bentonite - sand mixtures have been proposed and used as engineered barriers for containing the waste. This paper presents the laboratory evaluation of compressibility by performing one dimensional consolidation tests on six different mixtures of bentonite with sand. The bentonite- sand mixtures were formed by varying sand content in bentonite in increments of 5% from 5% to 25% by dry weight. Dry bentonite- sand mixtures were placed initially in the consolidation cell at their loosest dry state and then allowed to saturate. Swelling characteristics and swelling pressures of the bentonite- sand mixtures were also evaluated. This paper also presents the laboratory evaluation of permeability of the bentonite- sand mixtures by performing falling head test after every load increment during the consolidation test. This study arrived at the conclusion that amount of swelling (expressed in percentage) and swelling pressure decreased with addition of sand. Moreover changes were observed for the consolidation parameters upon addition of sand to bentonite. The void ratio versus log of permeability plots were found to be linear and permeability was found to increase with increase in sand content.

Keywords: Bentonite - sand mixture, Compressibility, Swelling pressure, Permeability, Consolidation test.

1 INTRODUCTION

Bentonite - sand mixtures are used as engineered barriers for containing the leachate produced from waste. Bentonite has high swelling capacity and this makes it suitable for producing low permeability barriers. If clay content is too high shrinkage occurs in bentonite. To avoid shrinkage in bentonite on drying, sand is added to it thus providing mechanical stability to the mixture (Mollins.et al.(1996)). Bentonite-enhanced sand (BES) mixtures are widely used as barriers to control the movement of liquid from waste disposal facilities because BES can combine relatively high strength and low compressibility with very low hydraulic conductivity (Stewart et al. 2003).Based on studies conducted on swelling behaviour of bentonite and coarser fractions of different shapes and sizes, Sivapullaiah et al.(1996) reported that the swelling occurs only after the voids of the non swelling particles are filled up with swollen clay particles. Permeability of sand-bentonite mixture was found to reduce after addition of bentonite to sand (Otoko et al.2014)) and they also observed that the permeability values from falling head and one dimensional consolidation tests were in good agreement.

Su-Li Cui et al.(2012) have reported that even for the same ratio of sand, in sand- bentonite mixture, considerable differences exists in the nature of time and swelling pressure relationships if initial dry densities are different. At low density range, rate of swelling is low but increases gradually with increase in initial dry density. Most of the works on swelling, compressibility and permeability behaviour in literature are at optimum moisture content and at the maximum density state of the soils. In this research work, the swelling, compressibility and permeability characteristics of bentonite - sand mixtures were studied using one- dimensional consolidation test at very low density.

2 MATERIALS AND TESTING METHODS

Commercially available bentonite and dry sand were used for the study. The sand is uniformly graded, fine silica sand; and is classified as SP according to the Unified Soil Classification System (USCS).The X-ray diffraction spectra for the bentonite, (Fig.1) show that it is predominantly a montmorillonite with some amount of sand i.e. the quartz mineral. The liquid limits and the plastic limits of the bentonite sample were determined according to the code IS 2720 (Part 5) 1985. The physical properties of the bentonite- sand mixtures are shown in Table 1. The bentonite - sand mixture was mixed in the following proportion by percentage of dry weight as B:S = 100:0, 95:5, 90:10, 85:15, 80:20 and 75:25 (B: bentonite , S: sand).

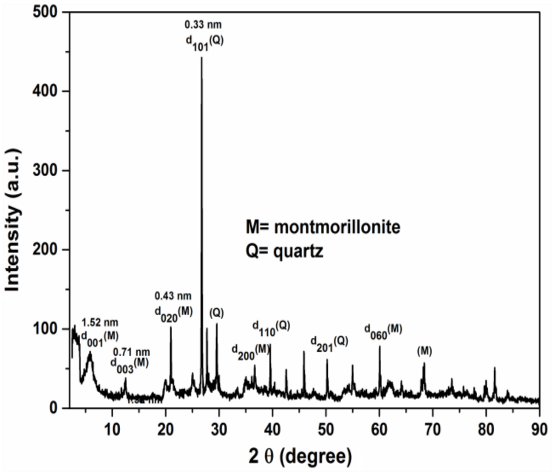

Fig. 1 The X-ray diffraction pattern for the bentonite

Table 1 Properties of bentonite - sand mixture

Bentonite :Sand ratio	Liquid Limit (%)	Plastic Limit (%)	Plasticity index	Specific gravity	Initial Dry Density (g/cm^3)
100:0	195	72	123	2.75	0.60
95:5	160	65	95	2.75	0.65
90:10	140	60	80	2.72	0.72
85:15	137	60	77	2.7	0.8
80:20	133	57	76	2.7	0.95
75:25	127	52	75	2.6	1.1

2.1 Consolidation tests

The consolidation test was done in standard fixed-ring consolidometers using stainless steel rings of 60 mm diameter and 20mm height (part 15, method 2720, Indian standard Institution 1986). In this work, the dry mixture was placed in the cutter of the consolidometer ring at the loosest state upto 2/3rd the height of the cutter i.e., 13.33 mm and seating load of 5 kN/m^2 was placed. The sample was then allowed to saturate. As a result of saturation, the sample started swelling. The dial gauge reading was taken after every 24 hours till the dial gauge reading showed a constant value. The swollen sample was then subjected to small pressure increments until the swelling pressure was obtained which is indicated by returning back of dial gauge to its initial reading before saturation. After obtaining the swelling pressure, double incremental loading was applied upto 640 kN/m^2 as per IS code of practice.

2.2 Permeability test

Permeability characteristics of the mixtures were determined by performing falling head test in the conventional fixed ring consolidation cell in the laboratory. At each pressure, after equilibrium was achieved, falling head permeability tests were performed to determine the coefficient of permeability of the mixture. To prevent evaporation from the burette a thin layer of kerosene over the water was placed. The flow was assumed to be vertical and permeability coefficient was determined from the experimental data.

3 RESULTS AND DISCUSSIONS

The swelling percentages of the various mixtures were calculated using equation (1)

$$\text{Swelling (\%)} = \Delta H/H_0 \times 100\%. \quad (1)$$

Where, $\Delta H = H_f - H_0$; H_f = Final height after swelling after every 24 hours.

$H_f = H_0 + 0.01x$ (dial gauge reading after every 24 hours).

H_0 = initial height before swelling = 13.33 mm.

The swelling percentage (%) versus log of time plot is shown in Figure 2.Bentonite shows very high swelling because of its prominent cation exchange capacity. Moreover it had been observed that for all the mixtures, increase in swelling with time is slow initially, increases steeply, and then reaches an asymptotic value. The time required to reach an asymptotic value varies considerably, depending upon the percentage of sand. Table 2 shows the swelling pressure, total swelling percentage (G) and other swelling characteristics of the various mixtures. As reported by Su-Li Cui et al.(2012) that even for the same ratio of sand in bentonite, considerable differences exists in the nature of time and swelling pressure relationships if initial dry densities are different. The values shown in this work are for very low density ranges.

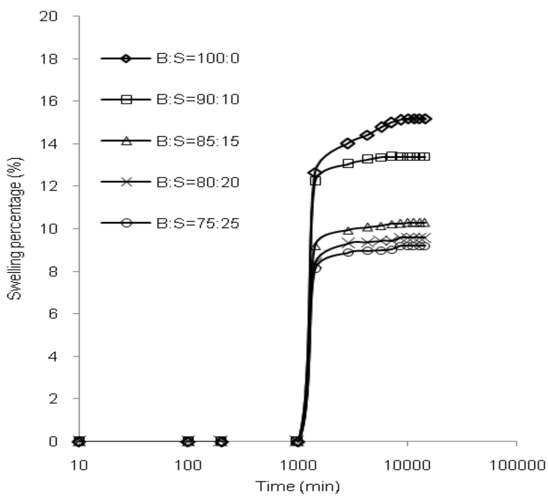

Fig. 2 Swelling percentage(%) versus log of time plot

The Coefficient of consolidation, C_v , was obtained by the square root of time fitting method. The C_v values(to the power of 10^{-4} cm/s) plotted against the percentage of bentonite is shown in Figure 3.

Table 2 Swelling characteristics of various mixtures.

Bentonite: Sand	**Swelling pressure (kN/m^2)**	**Total days taken to obtain full swelling**	**Total swelling percentage (G) (%)**
100:0	77.5	7	15.2
95:5	Not done	Not done	Not done
90:10	57.5	6	13.4
85:15	55	6	10.3
80:20	47.5	5	9.6
75:25	Not done	5	9.2

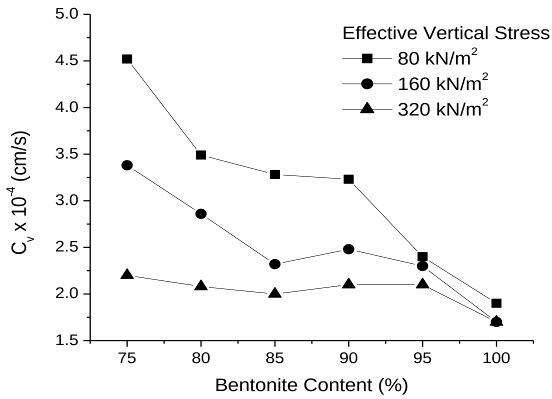

Fig. 3 Coefficient of consolidation versus bentonite content

There is a slight increase in $C_v$value with addition of sand for low pressure ranges, but at high pressure of 320kN/m^2, the $C_v$values remain the same. Compression index, has been determined from the linear portion of the void ratio (e) versus log of effective stress (σ'_v) plot and its values for the different mixtures are shown in Figure 4.

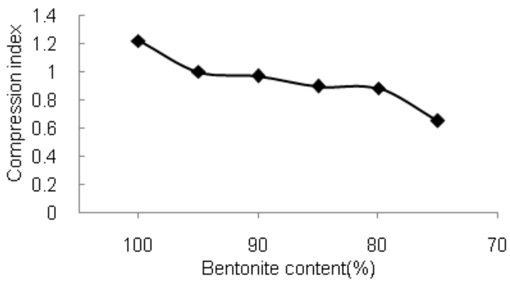

Fig. 4 Compression index versus bentonite content

It is observed that C_C decreases with addition of sand content. The void ratio (e) versus log of effective stress (σ'_v) plot without including the expansion and recompression part is shown in Figure 5.

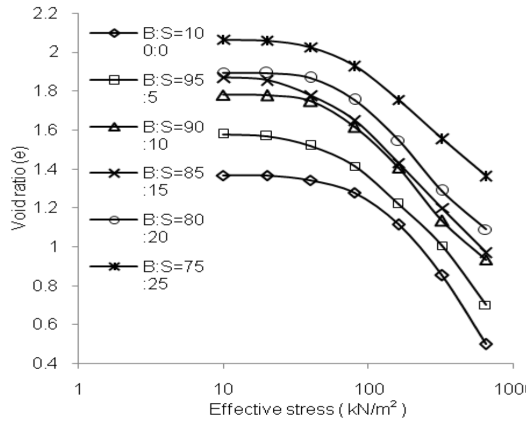

Fig. 5 Relationship between void ratio and effective stress (σ'_v) plot for the six samples.

It has been observed from the plot that with the addition of sand to bentonite, the void ratio has increased.

The permeability range of compacted clay liners should be very low. For many engineering projects the permeability values usually lies between 10^{-9} to 10^{-7}cm/s. In this present study, the permeability behaviour of the bentonite-sand mixtures were studied in the laboratory using the oedometer test set ups after full swelling was achieved.

Evaluation of permeability of bentonite-sand mixture as function of loading pressures on basis of experimental results by performing falling head permeability tests has been plotted graphically in Figure 6.

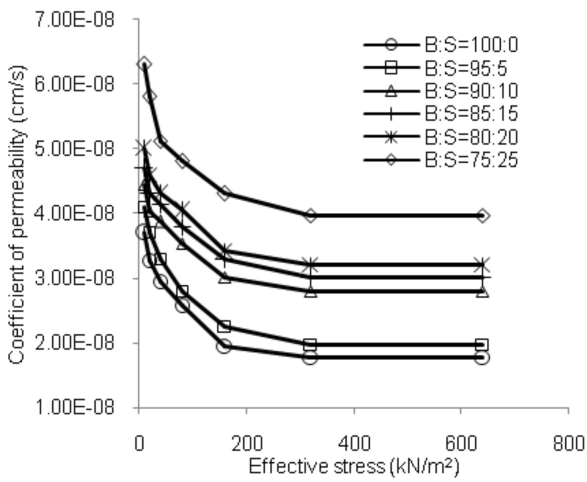

Fig. 6 Relationship between effective vertical stress and coefficient of permeability calculated experimentally.

It is observed for all the specimens, that the permeability varies inversely with the loading pressures. The effect of effective vertical pressure on permeability is less significant once it crosses 320 kN/m^2. The coefficient of permeability(k) for pure bentonite lies between 3.7 x 10^{-8} cm/s to 1.78 x 10^{-8} cm/s whereas for mixture obtained by adding 25% sand to 75% bentonite the value ranges from 6.3 x 10^{-8} cm/s to 3.97 x 10^{-8} cm/s. Here it is observed the k values of the mixtures are in a narrow range. This is because the bentonite content is more than which can be accommodated within the voids of the sand fractions and the permeability is controlled by the bentonite content alone. Permeability values were also calculated for various pressure increments for the various mixtures using the experimentally determined c_v and m_v values. It was observed for each mixture, $\log_{10}k$ was found to vary linearly with void ratio over the full range of pressure increments to which it was subjected to. Figure 7 shows the $e - \log_{10} k$ relationship for the six mixtures. The slope of the $e - \log_{10}k$ lines decreases with an increase in the percentage of bentonite.

The indirect evaluation of permeability from consolidation test data may be unreliable. However in this study there is a good agreement between the experimental permeability with those determined theoretically from C_v and m_v. These are shown in Figure8a and Figure 8b.

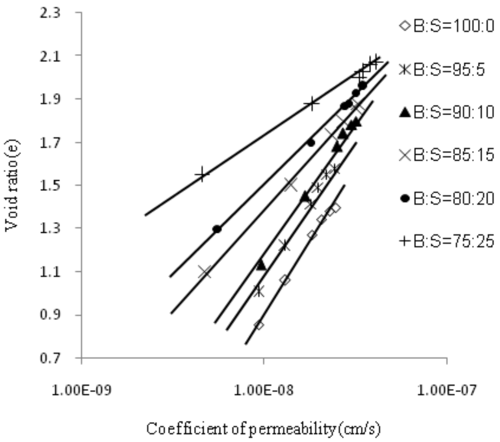

Fig. 7 Void ratio Vs coefficient of permeability (k)

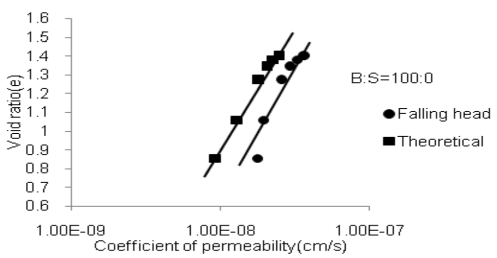

Fig.8a Comparison of permeability calculated experimentally and theoretically for pure bentonite

4 CONCLUSIONS

Liquid limit and Plastic limit decreased with addition of

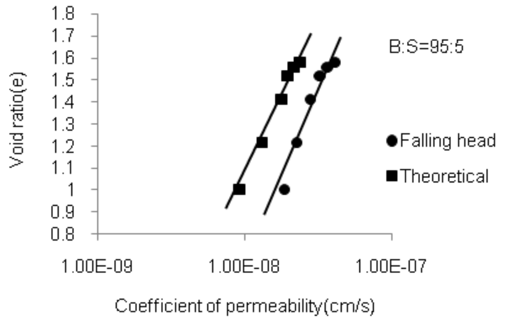

Fig.8b Comparison of permeability calculated experimentally and theoretically for B:S=95:5

sand to bentonite content. Coefficient of consolidation (C_v) showed a small increase with increase in sand content for low stress ranges whereas for high stress range of 320kN/m^2, it is found to remain constant. Compression index (C_C) decreased with increase in sand content. Addition of sand decreases the swelling pressure, total number of days taken for full swelling and amount of swelling percentage (%).The e- log σ'_v plot also shows that with the addition of sand to bentonite, the void ratio increases. The coefficient of permeability for pure bentonite is least and increases with addition of sand to bentonite. Moreover there is a good agreement between the experimental permeability obtained through falling head permeability test with the theoretically calculated permeability values.

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