Effect of Organic Pore fluids on Swelling Behavior of Bentonite-sand mixtures

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Abstract: In this study swelling behavior of bentonite-sand mixtures has been studied inpresence of organic pore fluids having a wide range of dielectric constants. The organic pore fluids of different dielectric constants are prepared by mixing alcohols (methanol and ethanol) with distilled water at different proportions. A series of laboratory experiments are done to determine the free swell and oedometric swell. The free swellings of the bentonite-sand mixtures are determined as per Indian standard and the oedometric swellings are determined by using a conventional consolidometer. Efforts are given to establish the relationship between free swell and oedometric swell of the bentonite-sand mixtures. Moreover the effects of dielectric constants of the pore fluids on the free swelling and oedometric swelling behavior of the bentonite-sand mixtures are also investigated. The results obtained from the laboratory test indicated good linear relationship between the free swell and oedometric swelling of thebentonite-sand mixtures in presence of organic pore fluids having different dielectric constants. Good linear correlations have been also observed between the dielectric constants of the pore fluids and free swell and oedometric swell of the bentonite sand mixtures.

Keywords: Swelling, Free swell, Bentonite-sand mixtures, Pore fluids

1 Introduction

Designing and construction of landfill becomes a very important issue in present day scenario due to the enormous growth of waste production around the world. Clay, especially bentonite is considered as very effective material to construct the landfill liners to obstruct the migration of leachate to sub soils due to its excellent adsorption and swelling characteristics. However during drying cycles bentonite develops shrinkage cracks, thus bentonite is mixed with sand to improve the mechanical as well as hydraulic properties of the landfill liners. Landfill liners are generally designed keeping water as pore fluid in the mind. When water is mixed with the organic pollutants present in the landfill, it becomes fluids having properties different than water, due to which the liner materials may behave differently upon coming in contact of such organic fluids. Swelling of the liner is a very important mechanical property and it plays a very crucial role in effective functioning of the landfill. From the study of the swelling characteristics of compacted expansive soils, semi-empirical equations had been derived for the prediction of swelling behavior. The proposed equations were based on consideration of osmotic and mechanical swelling phenomena andhave been found to give accurate predictions of swelling pressure and swelling potential for a wide range of soil types (Nayak and Christensen, 1971).Consolidation characteristics of bentonite in different organic fluids with different dielectric constants have showen that the void ratio decreases with the decrease of dielectric constant(Mersi and olson, 1971). Swell potential, swell time, swell pressure, and volume compressibility decreases with increase of chemical concentrations for the different types of bentonite sand mixtures (Hussain A. Alawaji, 1999).The influence of clay mineralogy and pore medium chemistry on clay sediment formation showed that increases in dielectric constant or decrease in electrolyte concentration of the pore medium favours an increase in double layer repulsive force, which results in reduction in modified effective stress in montmorillonitic soils equilibrating at higher sediment volume with a dispersed fabric (Sridharan and Prakash, 2004). The behavior of compacted bentonite in presence of different salt solution showed that the liquid limit and free swelling of bentonite decrease with the increase of salt concentrations, the swelling potential and swelling pressure also decreased with the increase on salt concentration (Mishra et.al., 2014). The amount of swelling (expressed in percentage) and swelling pressure decreased with addition of sand (Sharma and Deka, 2016). There is good linear relationship between dielectric constant of pore fluid and free swell of bentonite sand mixtures irrespective of the type of pore fluid (Rahman, Sharma and Sridharan, 2021).The time-swell percentage study showed that higher bentonite-containing samples have higher swell percentages irrespective of pore fluids. However, for the same bentonite-sand proportions, the swell percentage is higher for distilled water and consequently, the swell percentage reduce with the increase of organic component of the pore fluid. The swell percentage-dielectric constant study showed that swelling percentage decrease linearly with the dielectric constant of the pore fluids (Rahman and Sharma, 2022). The present study is to investigate the relation between free swell and oedometric swell of bentonite sand mixtures in presence of organic pore fluids having wide ranges of concentrations. Effort is also made to estab- lish correlations between the free swell and oedometric swell of the bentonite-sand mixtures in presence of organic pore fluids having wide ranges of concentrations.

2 Materials and methods

2.1 Bentonite and sand

Commercially available highly expansive sodium bentonite and locally available dry sand sieved through 425µ sieve were used for the study. An x-ray diffraction spec- trum of the bentonite showed that it is predominantly montmorillonite with presenceof quartz mineral. Six samples of soils were prepared by mixing bentonite and sand at different proportion by weight. The proportions consist of 100% bentonite, 90% bentonite and 10% sand, 80% bentonite and 20% sand, 70% bentonite and 30% sand, 60% bentonite and 40% sand and 50% bentonite and 50% sand by weight.

2.2 Pore fluids

Commercially available methanol and ethanol were used as the organic pore fluids for the studies. To obtain pore fluids of different proportions of ethanol and methanol concentration, ethanol and methanol are mixed with distilled water at an increment of 20% by volume for each trial of experiments. The dielectric constants of the pore fluids were determined in the laboratory. The values of dielectric constants of the pore fluids 100% distilled water, 20% ethanol, 40% ethanol, 60% ethanol, 20% methanol, 40% methanol and 60% methanol were 77.8, 62.28, 48.3, 39.1, 67.4, 55.1 and 44.8 respectively.

2.3 Determination of free swell and oedometric swell

The free swell tests were performed on the six types of bentonite-sand mixtures in the laboratory as per IS: 2720Part (XL)-1977. 10 gm oven dried soil specimen passing through 425µ sieve was poured in two glass graduated cylinders of 100 ml capacity. One cylinder was filled with the pore fluid which was considered for study and the other cylinder was filled with kerosene oil up to 100 ml mark. After removal of en- trapped air by gently shaking and stirring with a glass rod, the soils were allowed to settle and attain equilibrium state of volume for sufficient time (< 24 hrs.). The final volumes of the soils in each of the cylinders were noted for further calculations.

The free swell index (FSI) was determined as per the equation given in IS: 2720 Part (XL)-1977.

$$FSI= (V_d-V_k)/VkX\ 100 \quad (1)$$

Where V_d= Sediment volume of 10 gm oven dried soil in a 100 ml cylinder con- taining pore fluid

V_k= Sediment volume of 10 gm oven dried soil in a 100 ml cylinder containing kerosene.

The modified free swell index (MFSI) was determined as per the equation pro- posed by Sridharana et.al. (1985)

$$MFSI= V_d/10 \quad (2)$$

Where V_d= Sediment volume of 10 gm oven dried soil in a 100 ml cylinder con- taining pore fluid.

The oedometric swell tests were performed for the same six types of bentonite- sand mixtures in a conventional one-dimensional consolidometer apparatus. The di- mensions of the cutter were 20 mm in height and 60 mm in internal diameter. A dry mixture of bentonite-sand mixtures (by weight) was placed in the consolidometer cutter at 1 gm/cm^{3}density up to 2/3rd height (13.33 mm) of the cutter. The swelling test was performed as per IS 2720 (Part XV)-1965. The consolidometer was assem- bled by placing filter papers at the top and bottom of the soil specimen. The porous stones were placed at the top and bottom after boiling for 15 minutes. A seating load of 5 kN/m^2 was applied on the loading hanger and horizontal inclination was corrected, then the initial reading of the dial gauge was noted. The saturation of the dry soil samples was done by applying pore fluids (distilled water and different methanol-distilled water and ethanol-distilled water mixtures). After saturation, the samples started swelling and dial gauges started showing swelling. Dial gauge readings were taken at different time intervals till the swelling ceases.

$$\text{Swelling (\%)} = (\Delta H / H_0) \times 100\% \quad (3)$$

Where $\Delta H = H_f - H_0$; H_f= Final height after swelling after every 24 hrs.
H_0= Initial height before swelling (13.33 mm)

3 Results and discussions

3.1 Relation between free swelling index and oedometric swelling

The free swell indices and oedometric swelling of all six bentonite sand mixture samples have been observed in case of distilled water, mixtures of ethanol-water and methanol-water solutions as pore fluids. The free swell indices for all the six types of bentonite sand mixtures were plotted against the oedometric swelling of same bentonite sand mixtures for the different pore fluids in Fig. 1.In case of 100% bentonites samples, the free swelling index and oedometric swelling in presence of distilled water were 468% and 35.7% respectively. Both the free swell index and oedometric swelling reduces consistently as the pore fluid changes to 20% methanol, 20% ethanol, 40% methanol, 40% ethanol, 60% methanol and 60% ethanol respectively. Similarly free swell index and oedometric swelling reduced consistently as the percentage of sand in the bentonite sand mixture increases. For the same bentonite sand mixtures, for all the six mixtures, there is good linear relation between oedometric swelling and free swell index. Again it is observed that both oedometric swelling and free swell index increases linearly with the increase in dielectric constant of the pore fluids. The correlation of free swelling index and oedometric swelling for 50% bentonite-50% sand showed best fit with a correlation coefficient of 0.96.

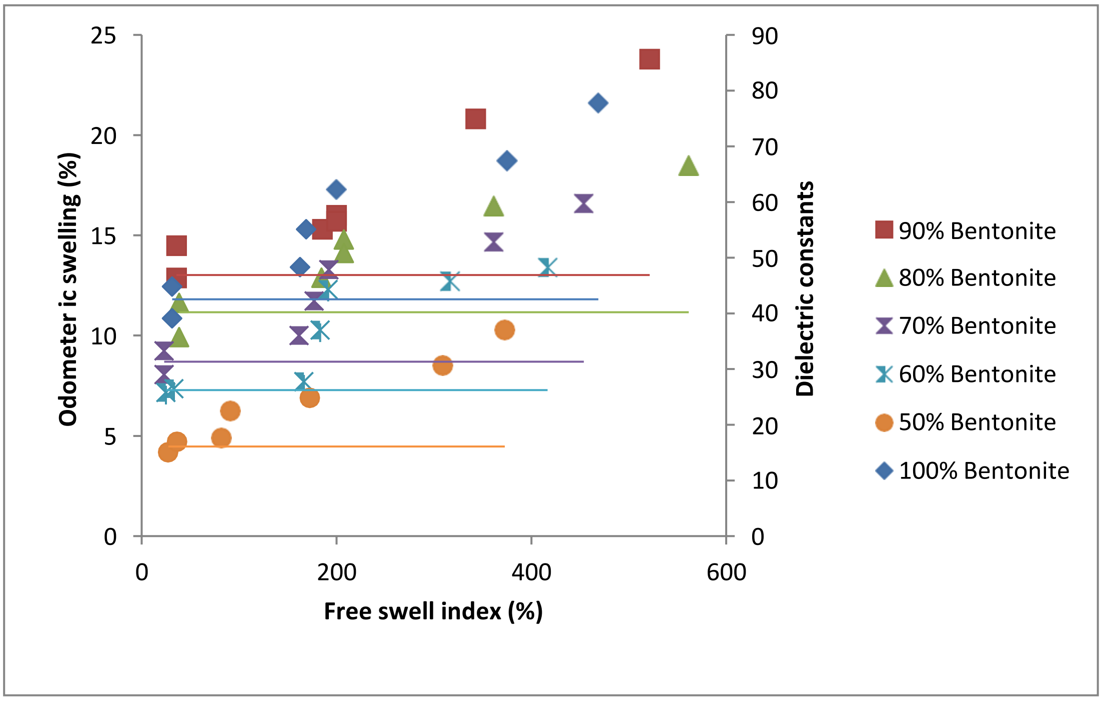

Fig. 1 Plot between Oedometric swell vs. Free swell index

The correlation equations between free swell index and oedometric swelling for all six bentonite sand mixtures using pore fluids having different dielectric constants are tabulated below in table 1.

Table 1: Correlation equations for Free swell index and Oedometric swelling

Bentonite-sand mixtures	Correlation equation	Correlation coefficient
100:0	OS = 0.041 FSI + 14	0.92
90:10	OS = 0.022 FSI + 12.24	0.94
80:20	OS = 0.015 FSI + 10.59	0.92
70:30	OS = 0.018 FSI + 8.28	0.92
60:40	OS = 0.017 FSI + 6.9	0.92
50:50	OS = 0.016 FSI + 4.04	0.96

OS= Oedometric swelling FSI= Free Swelling Index

3.2 Relation between modified free swell index and oedometric swelling

The results of the modified free swell index and oedometric swell from the tests were plotted against each other to determine any relationship between them. The plots between the modified free swell index and oedometric swelling are shown in fig. 2. For 100% bentonite, modified free swell index and oedometric swell in presence of distilled water were 9.1% and 35.7% respectively, which were uppermost irrespective of the pore fluid. Then both modified free swell index and oedometric swell reduces with the increase of organic content and decrease of the dielectric constant of the pore fluid. It has already been established that swelling of bentonite sand mixture had a linear relationship with the dielectric constants of the pore fluids (Rahman and Shar- ma, 2022). Both modified free swell and oedometric swelling decreases with the in- crease of sand content in the mixtures. For the same bentonite sand mixtures, for all the six mixtures, there is good linear relation between oedometric swelling and modi- fied free swell index. Again it is observed that both oedometric swelling and modifiedfree swell index increases linearly with the increase in dielectric constant of the pore fluids.

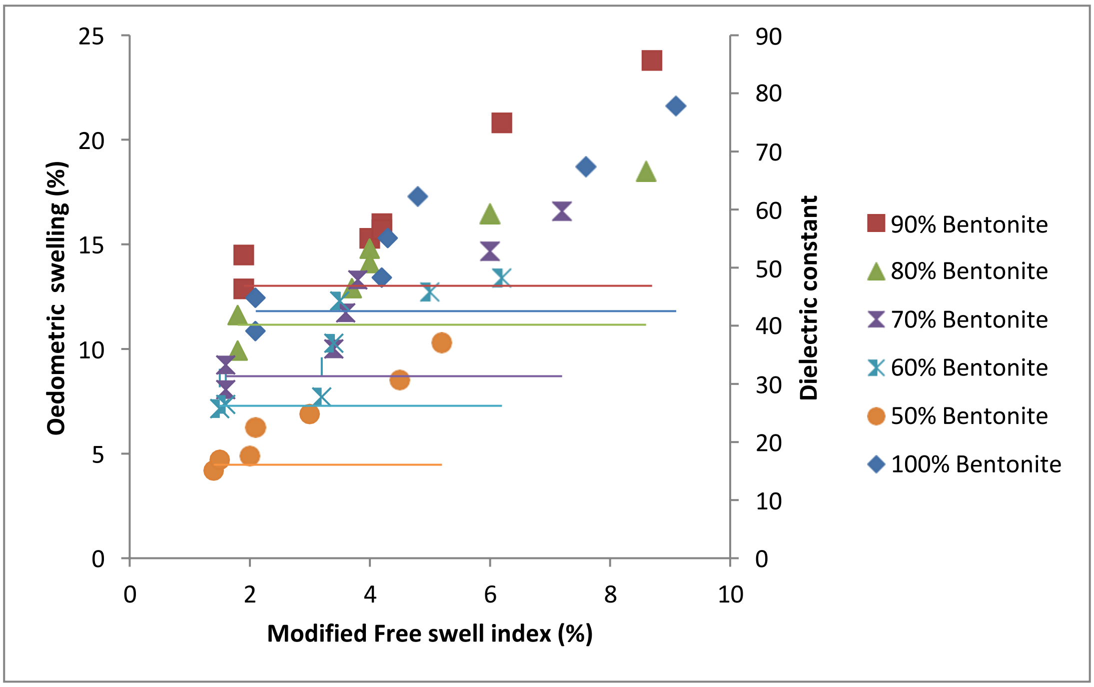

Fig.2 Plot between oedometric swell vs. modified free swell index

The correlation equations between oedometric swelling and modified free swell index for all six types of bentonite sand mixtures using pore fluids having different dielectric constants shown in Table 2 below

Table 2: Correlation equations for modified free swell index and oedometric swelling

Bentonite-sand mixtures	Correlation equation	Correlation coefficient
100:0	OS = 2.54MFSI + 10	0.92
90:10	OS = 1.56 MFSI + 10.06	0.94
80:20	OS = 1.16 MFSI + 9.08	0.92
70:30	OS = 1.42 MFSI + 6.43	0.92
60:40	OS = 1.41 MFSI+ 5.2	0.92
50:50	OS = 1.46MFSI + 2.43	0.96

OS = Oedometric Swelling MFSI = Modified Free Swelling Index

These correlations will be applicable for the pore fluids having the range of dielectric constants as given.

4 Conclusions

In between the six bentonite sand mixtures, highest free swell (both free swell index and modified free swell index) and oedometric swelling was observed in case of 100% bentonite samples. Both free swell and oedometric swelling decreases with the increase of sand proportion in the bentonite sand mixtures. The relation between free swell indices and modified free swell indices with the oedometric swelling of each type of bentonite sand mixtures is linear irrespective of the pore fluids.

There is good linear relationship between both free swelling and oedometric swelling with the increase in dielectric constants of the pore fluids. Swelling behavior of bentonite sand mixtures used in landfill liners plays a very important role in its efficient design. Thus determination of swelling is very important. Normal determination of oedometric swelling need more time. With the use of the correlation equation determined in this study, oedometric swelling can be determined within 24 hours by determining free swell index and modified free swell index.

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