SWELLING BEHAVIOUR OF ENGINEERED CLAY SOILS

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ABSTRACT

This article gives an account of experimental investigation of swelling properties of clay soils. The kaolin – bentonite and sand – bentonite soils are mixed to produce specimen for the investigation. These soils are engineered to suit the desired properties. Statically compacted specimens, at their optimum moisture content and maximum dry density, are tested in conventional consolidation apparatus for vertical swelling determination. The results of this study show that the time required to reach maximum swelling varies for each soil mixtures but follows similar swelling path. The swelling of clay soils occurs in three distinct stages: intervoid (initial), primary, and secondary swelling.

1. INTRODUCTION

Expansive clay soils continue to attract the attention of soil researchers. The swelling behavior of expansive clay soils often causes unfavorable problems, such as differential settlement and ground heaving. Further, there are various applications where clays soils have to be engineered to suit the desired properties as back-filling (buffer) materials for high-level nuclear waste (Yong et. al. 1986), and soils barrier for landfill liner, covers, and vertical barrier walls (Daniel and Wu, 1993; Alawaji, 1999). The material is often designed as soil mixtures between expansive clay and non-expansive soils requiring among others low shrinkage and swelling properties.

The study of swelling properties of compacted sand-bentonite mixtures is important since these mixtures are increasingly used in many geotechnical and geoenvironmental application. Thus, further understanding of the mechanism controlling swelling of soil mixtures lead to increasing the confidence level before applying such materials in the field. In this context, this article gives an account of experimental investigation of swelling properties of cohesive soil mixtures. The outcomes of this study can be extended to provide insight into the behavior of soil mixtures in such used as backfill materials or liner materials in waste disposal scheme.

2. MATERIALS AND TEST SCHEME

A conventional oedometer apparatus was used for determination of the swelling and compressibility of soil mixtures. Required quantities of soil mixtures, at optimum moisture content, were transferred to consolidation ring of 50 mm internal diameter and 20 mm height. All the soil mixtures are compacted statically to their maximum dry density. The specimen is positioned in the loading frame with a seating load of 3.89 kPa. The soil samples were then inundated with distilled water and allowed to swell until they reached equilibrium values of swelling. At this point a standard consolidation test is conducted by applying incremental loads starting with 14 kPa and ending with 1600 kPa. The pressure required to revert the specimen to its initial height was determined as the swelling pressure.

The soils used in this study are commercial bentonite clay, kaolin, and fine sand. The particle size distributions of the soils are shown in Fig. 1, and the basic properties are listed in Table 1. The percentage of bentonite by weight is varied between 5% and 100%. The plasticity and potential expansiveness of soil – bentonite mixtures is illustrated in Fig. 2.

Table 1. Physical properties of the soil used

Soils description	Sand %	Silt %	Clay %	D_{50} µm	Liquid Limit	Plastic Limit	Linear Shrinkage	Activity, PI/CF
Bentonite [a]	5.4	2.4	73.2	0.62	307.3%	45.4%	17.4%	3.6
Kaolin	4.3	75.6	19.9	4.1	72.3%	39.8%	6.6%	1.6
Sand [b]	71.5	4.0	0.0	820	NP	-	-	-

Note: [a] Wyoming bentonite,[b] Mining sand (24.5% Gravel), NP = non-plastic, PI = plasticity Index, CF = Clay fraction

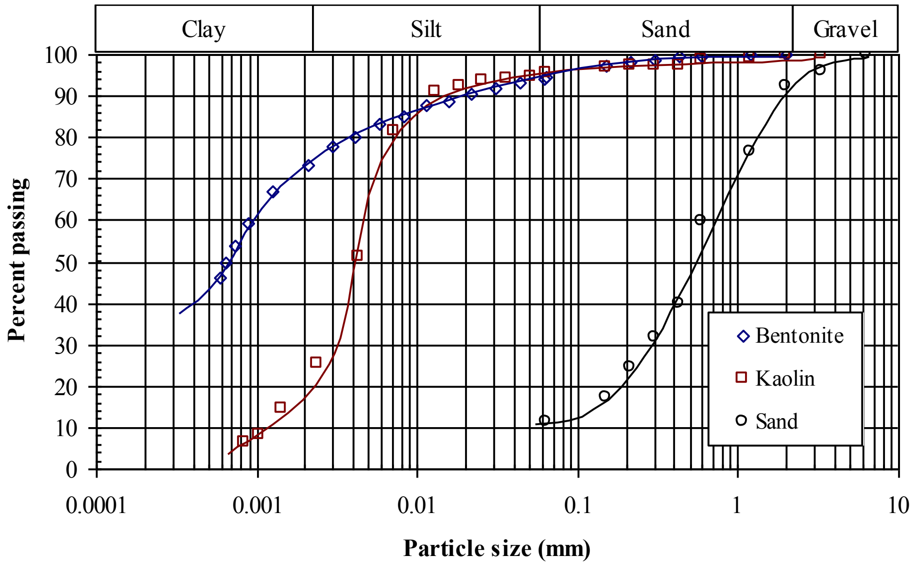

Fig. 1 Particle size distribution of soils

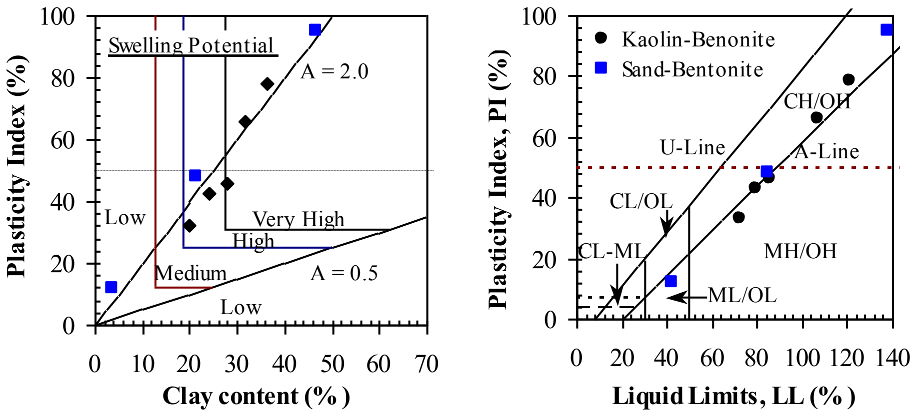

Fig. 2 Potential expansiveness and plasticity chart of soil-bentonite mixtures

Kaolin is predominantly comprised of silt (75.6%), whereas bentonite consists of clay (73.2%). The sand used was comprised of 35.6% coarse, 23.6% medium, and 12.3% fine size. Uniformity coefficient (Cu) and coefficient of curvature (Cc) are 9.08 and 1.19 respectively. Further, the sand can be classified into well-graded sand with gravel (SW). Muntohar and Hashim (2002) reported that the clay fraction in the kaolin-bentonite and sand-bentonite mixtures increased almost linearly with increasing bentonite content.

3. RESULT AND DISCUSSION

3.1 Vertical Swelling

The swell potential, in this study, is defined as the percentage swell of a laterally confined sample, which has soaked under a surcharge pressure of 3.89 kPa after being compacted to maximum density at optimum moisture content according to the compaction test. The results obtained are presented in Fig. 3 in the form of percentage of swell versus time with varying percentage of bentonite content. The swell is expressed as a percentage increase in sample height.

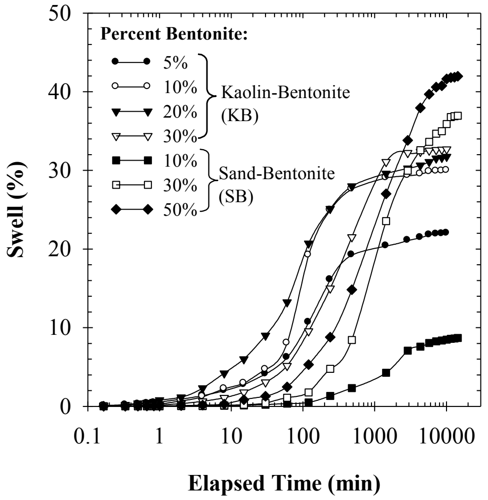

Fig. 3 Swelling behavior (as percent of initial height) of soil-bentonite mixtures

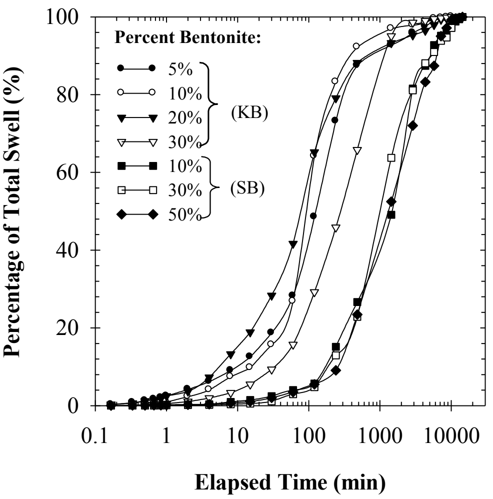

Fig. 4 Swelling behaviour (as percent of total swell) of soil-bentonite mixtures

It is observed that for all the mixtures, increase in swelling with log 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 bentonite and the type and amount of non-swelling fraction. The maximum amount of swelling generally increases with increasing bentonite content. Fig. 5 depict, even at the same percentage of bentonite, that considerable differences exist in the nature of time-swell relationship. At low bentonite content, the rate of swelling is very slow with sand but increases gradually with decrease in the particle size of the non-swelling fraction.

Fig. 4 replots the time-swell relationship as percentage of the maximum swell. Here, the percent swell at a particular time is calculated as the ratio of amount of swell of the mixture at that time to the total swell and is denoted as a percentage. This is observed that for sand – bentonite mixtures, the rate of swelling is very slow and follow a similar swell path. In other hand, it was observed that the swelling almost completed within 1440 min (±24 hrs) for kaolin mixtures for all percentage of bentonite.

It is very limited reference discussing the rate of swelling. However, the rate of swelling may be approached as similar as in the coefficient of consolidation determination as given in Equation 1.

$$c_v = \frac{T_v \cdot \left(H_{avg} / 2 \right)^2}{t_{50}} \tag{1}$$

If T_v and H_{avg} are taken as constants and c_v is symbolized with c_s, then the equation can be expressed as follows:

$$c_s \approx \frac{1}{t_{50}} \tag{2}$$

The t_{50} is the time required to achieve 50% of swell. For all mixtures 50% of swell are achieved within 100 min (±1 hr, 40 min) and 1000 min (±16 hrs, 40 min) for kaolin and sand mixtures respectively.

Dakshanamurthy (1978) notes two stage of swelling. In the first stage of hydration of dry clay particles, water is adsorbed in successive monolayer on the surface of montmorillonite clay apart which referred to as interlayer or intercrystalline swelling. The second phase of swelling is due to double-layer repulsion. Large volume changes accompany this stage of swelling. These occurrences can be approached closer as illustrated in Fig. 5, which the curve can be divided into three phases. Initial swelling is generally less than 10% of the total swelling. This is essentially due to swelling of the bentonite clay particles within the voids of the coarser non-swelling fraction.

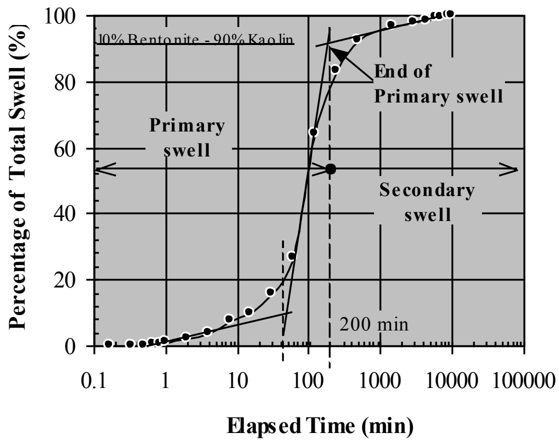

Fig. 5 Typical time-percent swell of total swell curve

Primary swelling develops when the void can no longer accommodate further clay particle swelling. It occurs at a faster rate. After the primary swelling was completed, slow continued swelling occurs. It is observed that the end of primary swelling of kaolin-bentonite mixtures are varies within 200 – 1000 minutes. In general, the time needed for completion the primary swelling increase associated with increase in bentonite content. But, this is not appeared in the sand-bentonite mixtures.

Furthermore, the swelling mechanism of compacted expansive clay can be illustrated by the model as given in Fig. 6. The volume of swelling clay particles such as montmorillonite increase by absorbing water into the interlayers of montmorillonite, and the void in the compacted expansive clay are filled by this volume.

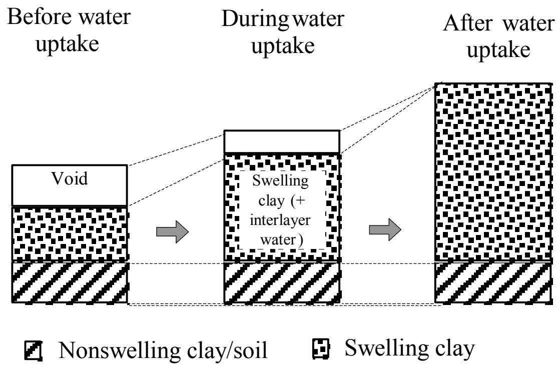

Fig. 6 The model of the swelling deformation of compacted expansive clay

During after uptake, provided, the compacted expansive clay can swell at a constant vertical pressure as in the swelling deformation test. The volume of compacted clay increases as the volume of swelling clay particles increases until the swelling pressure of the clay particles equals the vertical pressure (see Fig. 6).

3. 2 Swelling Pressure

Swell pressure is defined here as the pressure required to compress the specimen, that has been soaked and completed the swell under 7 kPa pressure, back into its original configuration (before swell). The swell pressure was measured by the pre-swelled method for simplicity; however, there is experimental evidence that different methods gave similar results (Borgesson, 1989; El-Sohby & Rabba, 1981) especially at high density.

Fig. 7 shows the change in sample height (%) and pressure (kPa) curves for soil – bentonite mixtures, which is determined from oedometer test. At least two essential values can be attracted from this results i.e. compressibility and swelling pressure of compacted soil.

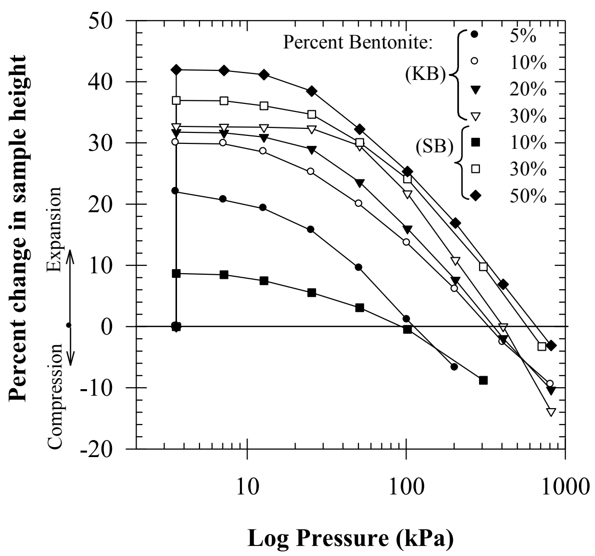

Fig. 7 Percent change in sample height versus loading applied pressure

The figure shows that the swell pressure increase with increasing bentonite content. Sand – bentonite mixtures exhibit greater swelling pressure than other mixtures. It is perhaps caused by the greater initial dry density and lower water content when the specimen was compacted. This is in agreement with El-Sohby and Rabba (1981).

Mathew and Rao (1997) indicate that by increasing the valence of exchangeable cations in homoionized clay, the overall compression in the system is reduced and the pre-consolidation pressure (p_c) is increased. The equilibrium void ratio at any applied pressure is a direct function of the repulsive forces arising from the interaction of adjacent diffuse double layers and pore fluid. As the valence of exchangeable cations in the clay increased, there is a reduction in the diffuse double –layer thickness and in the magnitude of the repulsive forces. These finally result in a lower equilibrium void ratio at any given pressure until higher pressures are reached (Sridharan & Choudhury, 2002).

3. CONCLUSION

Based on the study undertaken thus far it can be concluded that:

1. The swelling, swelling pressure, and compressibility of bentonite mixed kaolinite and sand, generally increases in relation with bentonite percentage. Apart from the mineralogical and clay content, the amount and size of the non-swelling fraction play role in governing the swelling and compression behavior
2. In general, the swelling of soils occurs in three distinct stage: intervoid swelling (initial), primary swelling and secondary swelling.
3. The rate of swelling (c_s) can be approximated based on the t_{50} which is the time required to achieve 50% of swell (Equation 2).

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BIOGRAPHY

Agus Setyo Muntohar *finishes his Sarjana Teknik (ST) in December 1997 at Civil Engineering Department, Gadjah Mada University in Yogyakarta, Indonesia. He is conferred an "Achievement Graduation Award" from Faculty of Engineering in the same university. In 1995 – 1998, he is also an assistant lecturer at his department. He joined with Muhammadiyah Univeristy of Yogyakarta in April*

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