Effect of Sand Addition Techniques on the Characteristics of Expansive Clays: A Laboratory Study

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ABSTRACT

Nowadays many measures have been practiced to overcome the problems posed by swelling soils. One of the methods is to modify the macro structure of expansive clays by adding non-expansive materials. A laboratory investigation to reduce the swelling properties of the expansive soils found at Gunung Bentar - Probolinggo is reported in this paper. Three different techniques were studied, e.g. sand layer, sand-soil mixture, and sand column, as alternative methods to improve the swelling characteristics of compacted expansive clays. Each soil samples with various proportion of sand are compacted statically, and then performing zero swell test by using load ring, and wetting process under controlled water inflow instead of inundate the samples. The results of this study indicated that sand column is the most effective techniques in reducing the value of swelling pressure. However the other two techniques were also found to be effective in reducing the swelling behavior of soils to various degrees as discussed in this paper.

Keywords: Expansive clays, Swelling strain, Swelling pressure, Sand inclusion techniques

INTRODUCTION

Excessive heave and settlements that are associated with the volume change of expansive soils can cause considerable distress to civil engineering structures are a worldwide problem that poses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if it is not adequately treated. Such soils swell when given an access to water and shrink when they dry out. The swelling and shrinkage phenomenon depends on several factors, including type and amount of clay minerals and cations, moisture content, dry density, soil structure, and loading conditions.

There are several methods that have been used to minimize or eliminate the effect of expansive soils before and after construction of structures. These methods include chemical stabilization, soil replacement with compaction control, pre-wetting, moisture control, surcharge loading, and use of geo-synthetics. Furthermore, many investigators have proposed several techniques to reduce or even eliminate swelling of expansive clays (Basma 1998, Mowafy et al. 1985, Kennedy, T. W. 1987, Al-Homoud, et al. 1995, Cokca, E., 2002, Al-Rawas et al. 2002, 2006). However, the study of the effect of sand addition to the expansive soil done by some researchers for decades was usually limited to the soil mixing method only (Khan, 2001).

This paper presented a laboratory experimental study of the effect of non-expansive sand addition to the expansive soil with different techniques, e.g.: sand layer, sand-soil mixture, and sand column. The effects of other parameters such as the proportion of mixing are also studied.

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SOIL AND SAND MATERIAL USED

Material

The soil samples for this study were brought from a coastal area at Gunung Bentar - Probolinggo, 100-km Southeast of Surabaya, the second biggest city of Indonesia. Soil samples for laboratory testing were obtained from a test pit at a depth of about one-meter. The expansive formation at the site is grey clay with shell trace that exhibits severe problems associated with its expansive characteristics. The clay deposits in this area were generally formed under a marine environment transitional between purely freshwater and marine condition.

The local commercial non-expansive sands were used in this investigation, and according USCS can be classified as well graded medium to coarse sands (SW), with the maximum dry density of 15.1kN/m^3.

Physical and Engineering Properties

A laboratory-testing program was designed to determine geotechnical and physical properties of the soil as shown in Table 1. The grain-size distribution curves of the studied soils indicated that it is composed of predominantly clay and silt size particles. The Atterberg limit test revealed that examined soil would be classified as high plasticity clayey-silt.

Table 1. Properties of soil and sand material tested

Parameters	*Values*
Depth of sampling (m)	1.00
Color	dark gray
Specific gravity	2.51
Natural water content, %	55
Bulk density (kN/m^3)	1.4
Percent smaller than 75µm	82
Percent smaller 0.002mm	45
Liquid limit (%)	65
Plastic limit (%)	35
Plasticity Index (%)	30
Linear shrinkage limit (%)	16
Unified soil classification	MH
Compaction test	
Modified: □$_{d(max.)}$ (kN/m^3)	16.0
OMC (%)	19.0
Sand properties	
Unified soil classification	SW
Relative density - DR, (%)	90
Max. dry density, kN/m^3	1.51

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Based on Casagrande plasticity chart, the soil was classified as inorganic silt of high plasticity (MH), and showed a high plasticity index (30%). Generally, the higher the plasticity indexes of soil, the higher the swelling potential. According to the classification systems developed by Chen (1988) as shown in Table 2, the soil as compacted was classified as medium to high swelling potential.

Table 2. Correlation with common soil test after Chen (1988)

% passing 75μm sieve	*Liquid limit*	*Swelling*	
		Pressure (kPa)	*Potential*
< 30	< 30	50	Low
30 - 60	30 - 40	150 - 250	Medium
60 - 90	40 - 60	250 - 1000	High
> 95	> 60	> 1000	Very High

Sample PREPARATION

In this investigation the soil sample were first compacted according to the ASTM Standard (D 1557 - 78) known as heavy or modified compaction test, and give the results as follows: OMC (Optimum Moisture Content) of 19 %, and $\gamma_{d(max.)}$ of 16.0 kN/m^3. The specimen then prepared to the initial water content of - 2 % to the OMC or 17%, which correspond to dry density of 15.5kN/m^3.

In order to minimize variations in swelling test data, compacted samples were used in the testing program. To ensure uniformity of testing, the soil samples were air-dried, pulverized using a plastic hammer into a powder and screened through the 2.36 mm sieve, followed by thoroughly mixed with the calculated amount of water to give the required initial water content. The soil then was stored in air-tight plastic bags to avoid loss in moisture content, and finally allowed to cure at room temperature for at least 24 hour to achieve a uniform distribution of moisture content.

The specimen then statically compacted until the required height corresponded to the specified density. Static compaction was chosen in favour of other compaction methods such as impact compaction and kneading, because it gives the most uniform and repeatable samples (Booth 1976, quoted by Al-Shamrani 1999).

A series of specimens were prepared according to the ASTM Test Method for One Dimensional Swell/Settlement Potential of Cohesive Soils (D 4546-85). Table 3 below, shows the proportional weight of soil and sand that were used to prepare specimen.

Table 3. Sand-soil composition for each test specimen

Specimen No.	*Weight (gram)*		*Sand -soil ratio (%)*
	Soil	*Sand*	
1	247	-	0
2	230	14.22	7.23
3	220	22.58	12.00
4	204	36.44	20.94

Note: Specimen no.1 is untreated or virgin soil
Three identical specimens were prepared for each specimen category

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The method of mixing the sand and soil for the three proposed techniques can be explained as follows:

- Sand layering (SL); soil samples were first compacted statically in the mould to specify density then followed by pour the calculated weight of sand on the top.
- Sand-soil mixture (SM): weight of soil and sand for each specimen was blended thoroughly then compressed to specified density.
- Sand column (SC): weight of untreated specimen (247 gram) was compacted then the holes are made at the center filled with specified weight of sand.

LABORATORY TESTING PROGRAM

Equipment

The swelling tests were carried out in an equipment setup as shown in Figure 1 below. The equipment consists of two main components:

- Loading system: the test specimen was placed on the base platen in the loading machine and equipped with proving/load ring and dial gauge at the top, to measure swelling pressure and deformation respectively.
- Watering system: distilled water in a container was placed on the electronic balance, and connected to the specimen at the base through flexible plastic pipe. If the valve is open, the water will flow into the specimen, where the amount of that water during the test can be measured directly from the balance readings.

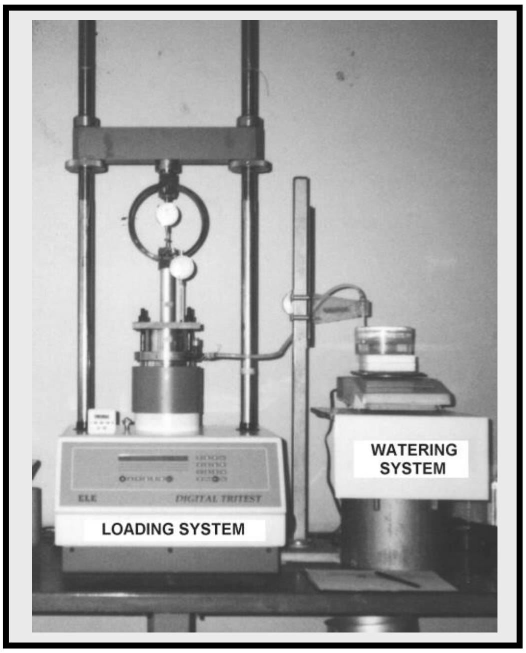

Figure 1. Equipment setup

To measure swelling pressures, the load ring with the capacity of 10 kN was used, while the vertical displacements were measured with a dial gauge (0.002mm/div). Electronic balance with readability of 0.001 gram was used to record the amount of water inflow in wetting process.

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Unlike the conventional consolidation cell that is commonly used, this system has several advantages, e.g. loads can be gently applied to the sample without shock impact and the saturation progress during test can be monitored.

However, care must be taken to some aspects:

- Load ring capacity must be selected so that it is appropriate to the range of swell pressure that will be generated.
- Load ring readings must be corrected to count its spring constant properties.
- Avoid leaking and air trapped along the flexible pipeline, because it will impede the flow of water to the sample.
- The water level at the water container must be maintained around the top level of specimen.

Test procedure

Having prepared the specimen, the compacted soil sample was then placed in a tested cell between wire screen covered with filter paper (will functioned as a porous stone) at the base, and an impervious plastic at the top. A seating pressure of 5 kPa was applied using 10 kN load ring capacity and waited until the system stable. Set the watering system that connects the base of the specimen and distilled water container that is placed on the electronic balance, as depicted in Figure 1. Keep the water level in the container close to the top level of the specimen.

After setting the vertical deformation dial gauge, the valve was opened to allow distilled water flowing into the base of the specimen. As soon as the water wetted the base of the specimen, the pressure and vertical deformation of the specimen were recorded. Readings were taken at 0, 0.5, 1.0, 2, 4, 8, 15, 30, 60, 120, 240, 480, and 1440 minutes, or would be stopped when the plotted curve indicated the primary swelling had occurred.

After the swelling was completed, the specimen was recompressed to its original void ratio. Loading machine with relatively low constant rates (0.01 to 0.001 mm/minutes) was used to generate the load. The corresponding pressure was termed the swelling pressure. The next step was to unload the specimen to obtain the swell curves. The above procedures were known as the constant volume swell (CVS) test, (Johnson and Stroman, 1976 quoted by Coduto, 1994). At the end of the test, dismantling the specimen from the cell and measures the final water content at two different points to obtain its average value.

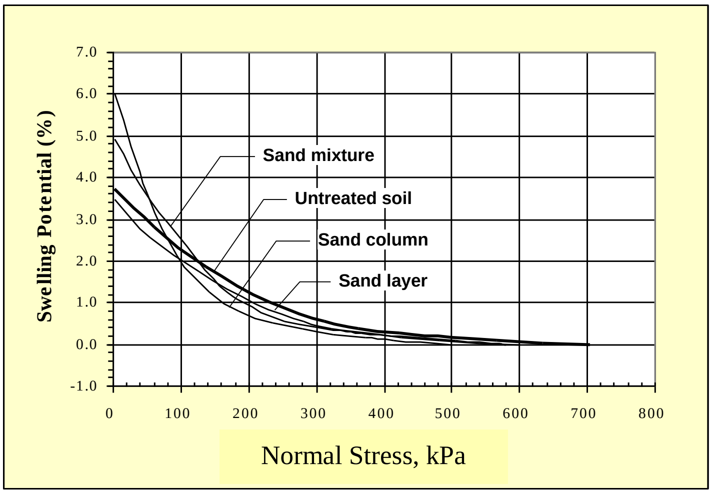

Figure 2. Normal stress vs. swelling pressure

RESULTS AND DISCUSSION

The most pertinent information that resulted from this investigation is shown in Table 4 and Figure 2-3. Figure 2 shows the relationship between the normal stress and the swelling pressures for sand-soil dry weigh ratio of 7.23%. The maximum swelling potential appears at the sand column method and it might cause by less side friction compared to the others two techniques. However for the normal pressure greater than 150 kPa all three techniques give lower magnitudes compared to untreated soils. Especially for sand column method significant lower value for the normal pressure start of 100 kPa.

Table 4. Swelling pressure for different sand-soil ratio

Sand-soil dry weight ratio, %	Swelling Pressure, kPa			
	SV	SC	SL	SM
0.00	704	-	-	-
7.23	-	500	580	610
12.00	-	460	560	580
20.94	-	420	535	565

Note: SV = Virgin or Untreated soil, SC = sand column, SL = sand layering, SM = sand-soil mixture

Table 4 and Figure 3 presents the dry weight ratio of sand and soil in percent versus swelling pressure for all tested samples. Figure 3 shows the relationship between the swelling pressure and the sand soil ratio in percent of untreated (virgin) soil and the other three sand inclusion techniques. It clearly demonstrates that the sand percent by dry weight of the soil and the selected technique has a great influence on the magnitude of swell pressure.

As the sand percentage increase, the swelling pressure decreases. The effect of sand addition to the soil on the swelling properties is attributed to the larger capillary canals in the soil pores and the corresponding reduction in soil suction. Similar results were reported by Mowafy and others (1985).

It is interesting to point out that swelling pressure decrease dramatically for sand column methods compared to the other two methods and untreated soil at the same sand-soil ratio. For example at sand-soil ratio of ± 21 %, the swelling pressure of sand column reduces 40 % from the untreated soils and ± 24 % from the other two methods.

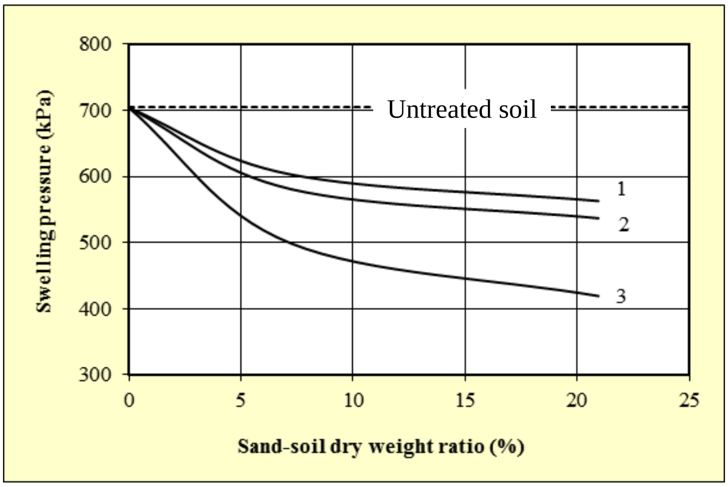

Figure 3. Swelling pressure vs. sand-soil ratio: (1) sand mixture, (2) sand layering, (3) sand column

SUMMARY AND CONCLUSIONS

Tests were carried out on samples of an expansive soil excavated from Gunung Bentar - Probolinggo located around 100 km Southeast of Surabaya. The soil specimens were treated with sand to a various proportion in three different ways, e.g. sand layer, sand mixture, and sand column, then tests were performed to obtain the swell pressure and swell potential.

Based on the analysis of the experimental results presented in this study, the following conclusions are given:

- All of the three techniques; sand layer, sand mix, and sand column, were found to be effective in reducing the swelling characteristics of expansive soil to various degrees.
- The obtained data certify to the fact that the sand column method gives the most reduction in swelling pressures.
- The amount of swelling pressure decreases with the increase of sand - soil ratio.
- It may be more convenient to use a combination of those techniques in order to reduce the swelling potential of the expansive soil.

Further researches are still needed to study the effectiveness of those techniques, and especially the sand column diameter, pattern, and spacing in relation to the change of its strength behavior.

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