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Contribution of osmotic suction to shear strength of unsaturated high plasticity silty soil

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HIGHLIGHTS

- Soils were compacted at three water contents with different pore water.
- Matric suction ranges from 50 and 250 kPa; osmotic suction was about 5000 kPa.
- Unconfined compression tests were conducted at various elapsed times.
- Shear strength of the soil was similar at the same compaction water content.
- Shear strength was unaffected by osmotic suction or osmotic gradient.

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ABSTRACT

The engineering behaviour of unsaturated soils is affected by suction. It is widely accepted that soil suction consists of two major components: matric and osmotic suctions. Matric suction is associated with the capillary effects whereas osmotic suction is associated with the salt content of the pore water. Soil suction has been incorporated as "effective" stress or suction stress when describing the engineering behaviour of unsaturated soils. Usually, the suction component that is incorporated is matric suction while the contribution of osmotic suction is seldom investigated. In this paper, the contribution of osmotic suction to shear strength of unsaturated soils is investigated through unconfined compression tests on three series of compacted soil prepared using distilled water and sodium chloride solution. Specimens were prepared at three water contents corresponding to dry densities at dry of optimum, optimum and wet of optimum on the standard Proctor compaction curve. Series one and two consist of specimens compacted using distilled water and sodium chloride solution, respectively. In series three, one half of the specimen was compacted using distilled water and the other half compacted using sodium chloride solution. Unconfined compression tests were conducted on the soil specimens at various elapsed times after compaction to allow for ionic equilibrium due to the osmotic gradient in the third series of soil specimens. The test results show soil specimens have similar strength at each compaction water content regardless of elapsed time and type of pore water. No effect of osmotic suction or osmotic suction gradient on shear strength of the compacted soil specimens was found. It was concluded that the salt content of the pore water affects the soil structure of clayey soils and does not act like matric suction. Hence, matric suction should be measured in order to quantify the engineering behaviour of unsaturated soils.

1. Introduction

It is widely recognised that suction plays an important role in governing the engineering behaviour of unsaturated soils.[1] It is also widely accepted that soil suction consists of two major components: matric and osmotic suctions.[1–5] Matric suction is associated with the capillary effects whereas osmotic suction is closely related to the salt content or ionic concentration of the pore water. It has been suggested that adsorption on solid surfaces may also contribute to matric suction.[6] Richards et al.[7] suggested that most engineering parameters of clay soils can be related to its total suction rather than its suction components. The contribution of soil suction has been incorporated as "effective" stress or suction stress when describing the engineering behaviour of unsaturated soils.[8–11] Usually, the soil suction that is incorporated is matric suction while the contribution of osmotic suction is less investigated.

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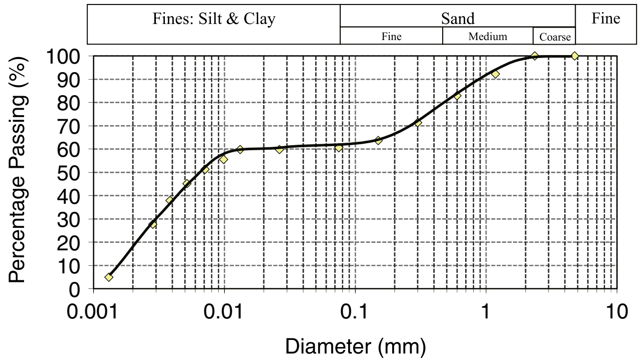

Fig. 1. Grain size distribution of soil used in study.

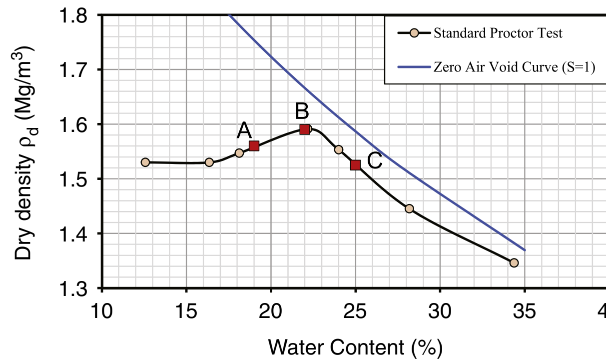

Fig. 2. Standard Proctor compaction curve.

The objective of this paper is to investigate the contribution of osmotic suction to shear strength of unsaturated soils.

Osmotic suction arises from the salt content in the pore water. Hence, osmotic suction is present in both saturated and unsaturated soils. Osmotic suction has been measured using the electrical conductivity of pore water as proxy.[1,4,12] Osmotic suction can also be indirectly determined as the difference between total and matric suction measurements. Krahn and Fredlund,[2] Edil and Motan[4] and Thyagaraj and Salini[13] showed experimentally that total suction is the summation of matric and osmotic suctions. The contribution of osmotic suction to shear strength so far has shown mixed results. As osmotic suction increases, Ho and Pufahl[14] and Peterson[15] showed that strength increases; Blight[16] and Katte and Blight[17] showed that strength remained constant; and Yong and Warkentin,[18] Tang et al.,[19] and Mokni et al.[20] showed that strength decreases. Fredlund et al.[1] reasoned that it is generally unnecessary to account for osmotic suction effects as laboratory test procedures simulate changes in osmotic suction that occur in the field. However in the case where there is a change in salt content, the effect of osmotic suction on the soil behaviour may be significant. Fredlund et al.[1] further suggested that osmotic suction may be algebraically combined with matric suction to analyse some geotechnical problems as shown by Bailey[21] and Chattopadhyay.[22]

One common thread in the literature investigating the effect of osmotic suction is that the soil specimens were prepared with different pore fluids or different concentrations of pore fluid to provide the different osmotic suctions. Osmotic suction has also been used to control suction in a constant suction test. In such tests, a semi-permeable membrane is placed between the soil specimen and the solution providing the osmotic suction.[23,24] It has been suggested that clay soils act as a weak semi-permeable membrane.[25–27] Rao et al.[26] investigated the swelling behaviour of an expansive clay and found that increase or decrease in effective stress due to osmotic suction gradient is transient and reduces to zero with dissipation of osmotic suction gradient. Hence, this paper also attempts to investigate the effects of osmotic suction gradient by preparing soil specimens with two different pore fluids.

2. Testing soil and experimental procedures

In this study, a granitic residual soil from the Bukit Timah Granite of Singapore was used. The soil was air dried and then sieved through sieve #8 (2.36 mm). The basic properties of the soils are summarised in Table 1. The grain size distribution of the soil is shown in Fig. 1. The soil is classified as MH[28]. The standard Proctor compaction curve of the soil obtained in accordance to ASTM D698-12e2[29] is shown in Fig. 2.

Table 1
Basic soil properties.

Soil property	Result
Specific Gravity, G_s	2.63
Liquid Limit, LL (%)	56
Plastic Limit, PL (%)	29
Plasticity Index, PI (%)	27
USCS Classification	MH

2.1. Specimen preparation

Three series of soil specimens were prepared by static compaction. Soils were first prepared at three water contents (19%, 22% and 25%) and sealed in plastic bags for moisture equilibration for at least 24 h. Distilled water and sodium chloride (NaCl) solutions were used for preparing the soil. The concentration of the NaCl solution used was 50 g/l or 0.855M. The electrical conductivities of the distilled water and NaCl solution measured using an electrical conductivity meter are 0.01 and 79.0 mS/cm, respectively. The soils were then statically compacted to the dry densities on the dry of optimum (1.56 Mg/m^3), optimum (1.59 Mg/m^3) and wet of optimum (1.53 Mg/m$_3$) of the standard Proctor compaction curve as indicated by points A, B and C in Fig. 2. The first series of specimens was prepared from soil mixed with distilled water, the second series of specimens was prepared from soil mixed with NaCl solution and the third series of specimens was prepared where one half of the specimen was soil mixed with distilled water and the other half was soil mixed with NaCl solution. All the soil specimens were 38 mm in diameter and 76 mm in height.

2.2. Suction measurements

Suctions of the compacted soil specimens at various water contents were determined by several methods. The matric suctions of the soil specimens at the compaction water content were determined from their respective SWCC.[30,31] Soil–water characteristic curves (SWCCs) of the compacted soils were obtained by using pressure plate and salt solutions in vacuum desiccators. The compacted soil specimens were first saturated before commencing the tests. Contact filter paper method was used to determine the matric suction of the compacted soil specimens.[32] The Whatman No. 42 filter papers were left in contact with the soil specimens for 21 days instead of the 15 days as recommended in ASTM D5298-16[32] to achieve equilibrium condition. The matric suction was determined from the filter paper water content using the Whatman No. 42 calibration equations for matric suction by Leong et al.[33]. The above tests were conducted for the compacted soil specimens prepared using distilled water.

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