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# VARIATION OF ULTIMATE BEARING CAPACITY OF UNSATURATED CLAY WITH SUCTION

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## ABSTRACT
A spread footing is sometimes selected for a shallow foundation design on clay layers. Its ultimate bearing capacity usually fluctuates with seasonal changes. Thus, a series of laboratory bearing tests were performed on compacted kaolin specimens with different values of matric suction, which relates to water content. The values of matric suction within the specimens were measured using the contact filter paper technique. All tests were performed after measurement of matric suction by penetrating the rod on the specimen surface until failure. The test results on the normal scale plot show an increase in ultimate bearing capacity with increasing matric suction for all ranges of suction. The increase rate is high at low suction range and decreases with increasing suction. In the semi-log scale plot, the curve of results can be divided into two parts at the point corresponding to the point separating saturated from unsaturated state.

**Keywords:** clayey soils, foundation, bearing capacity, suction, partial saturation.

## INTRODUCTION
A spread footing is sometimes used as a shallow foundation situated on clay layers in several areas around the world. Several equations for the ultimate bearing capacity of shallow foundation have been proposed during the past several decades (Terzaghi, 1943; Meyerhof, 1963; Hansen, 1968). For the clayey soils, the failure under the foundation is under undrained condition and is dependent of the undrained shear strength. However, the water content in natural soils, particularly under unsaturated condition, usually fluctuates with seasonal changes. Several investigators showed that the shear strength of soils under unsaturated condition varied with suction, which relates to water content (e.g. Vanapalli *et al*., 1996; Khalili and Khabbaz, 1998; Cunningham *et al*., 2003; Thu *et al*., 2006; Zhou and Sheng, 2009; Uchaipichat, 2010).

It has been known that the shear strength of unsaturated soils is controlled by the effective stress and several elasto-plastic model for unsaturated soils have been proposed based on effective stress concept (e.g. Kohgo *et al*., 1993; Loret and Khalili, 2002; Uchaipichat, 2011). In the effective stress concept, total stress in excess of pore air pressure (referred to as net stress) and the difference between pore air pressure and pore water pressure (referred to as matric suction) are combined to give a single effective stress, and only the effective stress is required for the complete characterization of the mechanical behavior of an unsaturated soil. The effective stress for unsaturated soils can be expressed as (Bishop and Blight, 1963):

$$p' = (p - u_a) + \chi s \qquad (1)$$

where $p'$ is the mean effective stress, $p$ is the mean total stress, $u_a$ is the pore air pressure, $u_w$ is the pore water pressure, $s = u_a - u_w$ is the matric suction, and $\chi$ is the effective stress parameter attaining a value of unity for a saturated soil and zero for a dry soil.

The purpose of this study is to illustrate the variation of ultimate bearing capacity of foundation on clayey soils with matric suction using the experimental data obtained from a series of laboratory bearing tests. The test results are carefully presented and discussed.

## EXPERIMENTAL PREPARATION AND TEST PROCEDURE

### Experimental equipment
In this study, the variation on ultimate bearing capacity with matric suction was investigated by performing a series of laboratory bearing tests on compacted kaolin specimens with different values of initial matric suction. The laboratory bearing apparatus similar to that developed by Uchaipichat and Man-koksung (2011) was used in this research. The details of equipment are shown in Figure-1. All tests were performed by penetrating a rod with a diameter of 1.5 cm on the specimen surface.

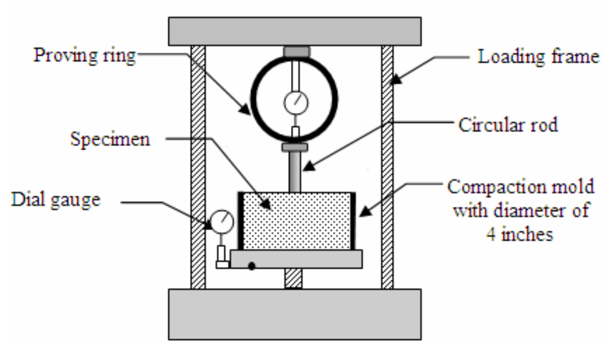


**Figure-1.** Laboratory bearing apparatus (Uchaipichat and Man-koksung, 2011).

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**Sample preparation**

The experiments were performed on a laboratory-compacted-kaolin. The index properties of test soil are given in Table-1. All samples were compacted using standard Proctor test at an optimum water content of 27.5%. Thus, the dry unit weight of compacted specimens is approximately equal to a maximum value of 14.1 kN/m$^3$. The specimens were then split into two equal parts along plane at the mid height of the mold. The specimens were dried or wetted to obtain various water contents within the specimens. Each specimen was then kept in a sealed plastic bag for at least 24 hours for moisture equalization.

**Table-1.** Index properties of sample.

| Property | Value |
|---|---|
| Liquid limit | 52% |
| Plastic limit | 31% |
| Specific gravity | 2.72 |
| Maximum dry unit weight ($\gamma_{max}$) | 14.1 kN/m$^3$ |
| Optimum moisture content ($OMC$) | 27.5% |

**Measurement of matric suction**

After curing process, the specimen was removed from the plastic bag. The values of matric suction within the specimens were then measured using the contact filter paper technique. With using this technique, the moisture within the specimen is allowed to transfer to an initially dry filter paper until equilibrium. This stage took at least 7 days. The matric suction can be determined using the water content of the filter paper and the calibration curves suggested by ASTM D5298. Figure-2 illustrates general set up for the contact filter paper technique which is similar to that used by Uchaipichat and Man-koksung (2011).

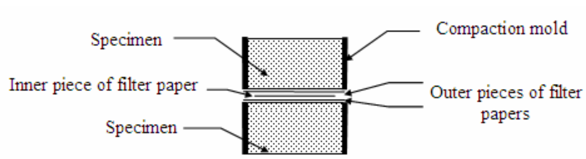


**Figure-2.** General set up for contact filter paper technique (Uchaipichat and Man-koksung, 2011).

**Test procedure**

The laboratory bearing tests were performed on the compacted kaolin with various matric suctions using the experimental equipment shown in Figure-1. All tests were performed after measuring process of matric suction. The rod was penetrated on the specimen surface using a loading frame. The penetration load and depth were recorded during testing until failure.

## RESULTS AND DISCUSSIONS

**Soil water characteristic curve**

The degree of saturation was calculated from the water content and the volume of the specimen after measurement of matric suction. Test result in terms of variation of degree of saturation versus soil suction, which is called a soil-water characteristic curve (SWCC), is shown in Figure-3. The values suction separating saturated from unsaturated state ($s_e$) and the residual suction ($s_r$) are 700 and 7,000 kPa, respectively.

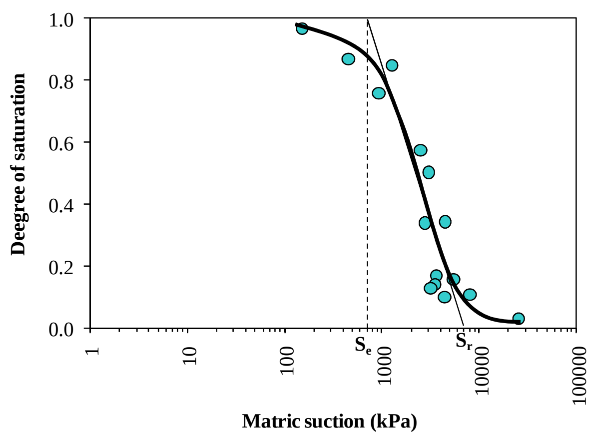


**Figure-3.** Soil water characteristic curve of compacted kaolin.

**Variation of ultimate bearing capacity with matric suction**

Figure-4 shows the plots between the ultimate bearing capacity, obtained from the maximum penetrating load, and initial matric suction within the compacted kaolin specimen. The test results on the normal scale plot (Figure-4a) show that the ultimate bearing capacity increases with increasing matric suction for all ranges of suction. The increase rate is high at low suction range and decreases with increasing suction. It should be noted that, at suction less than $s_e$, the soil sample is under saturated condition and the increase rate of effective stress and shear strength is high at this suction range since the effective stress parameter $\chi$ is equal to unity as shown in Eq.1. At suction greater than $s_e$, the effective stress parameter $\chi$ is less than unity and reduces with increasing matric suction, therefore, the increase rates of effective stress, shear strength and bearing capacity decrease with increasing matric suction.

Figure-4b shows the test results on the semi-log scale plot. The curve can be divided into two parts at the point corresponding to $s_e$. This plot illustrates the different behaviors between the soils under saturated and unsaturated states. It can also be seen from this plot that the ultimate bearing capacity still increases with matric suction at very high suction. This phenomenon can be

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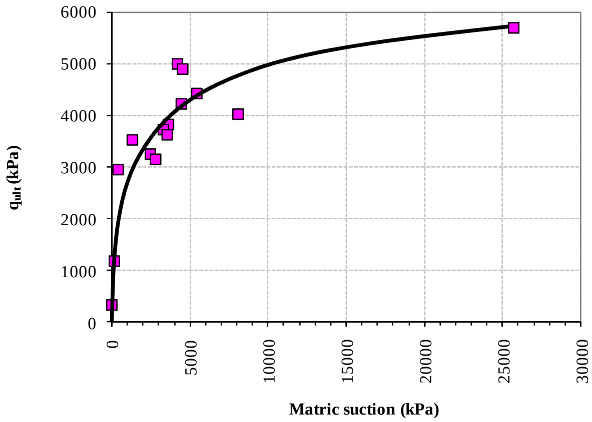
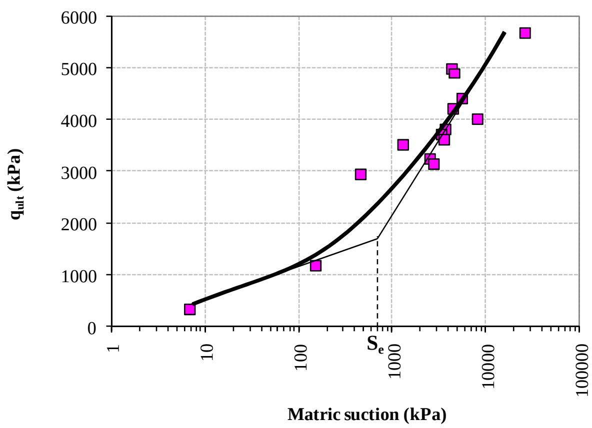
found in very dry clayey soils, which is very strong and hard to break apart.




(a) Normal scale




(b) Semi-log scale

**Figure-4.** Isotropic loading tests on wetted specimens at different matric suctions.

## CONCLUSIONS

A series of laboratory bearing tests were performed on compacted kaolin specimens with different values of initial matric suction. The values of matric suction within the specimens were measured using the contact filter paper technique. All tests were performed after measurement of matric suction by penetrating the rod on the specimen surface until failure. The test results on the normal scale plot show an increase in ultimate bearing capacity with increasing matric suction for all ranges of suction. The increase rate is high at low suction range and decreases with increasing suction. In the semi-log scale plot, the curve of results can be divided into two parts at the point corresponding to the point separating saturated from unsaturated state ( $s_e$ ).

## ACKNOWLEDGMENTS

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