Int. J. of GEOMATE, March, 2012, Vol. 2, No. 1 (Sl. No. 3), pp. 166-170
Geotec., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

The Relationship between Soil Suction and the Maximum Unsaturated Undrained Shear Strengths of Compacted Khon Kaen Soil

R. Nuntasarn and Veerawat Wannakul
Khon Kaen University, Thailand

ABSTRACT: The objective of this study was to evaluate the maximum unsaturated undrianed shear strengths of compacted Khon Kaen soil, which were determined from UU triaxial tests. The samples were compacted at 85% of maximum dry density by standard method. The samples were not measured soil suction during the test, but rather estimated soil suction from the soil water characteristic curve (SWCC) based on the volumetric water content of the sample during the test. The drying SWCC for the compacted Khon Kaen loess was determined from three methods, which were a hanging column method, a pressure plate method and an isopiestic humidity method. The maximum unsaturated undrained shear strength of compacted Khon Kaen loess was investigated in the Transition Zone. The relationship between soil suction and the unsaturated undrained shear strength of compacted Khon Kaen soil was a good related in the form of exponent of the value of $R^2 = 0.98$.

Keywords: Unconsolidation undrained triaxial test, Soil water characteristic curve, Soil suction, Maximum unsaturated undrained shear strength

1. INTRODUCTION

The objective of this study was to evaluate the unsaturated undrianed shear strengths of compacted Khon Kaen soil, which were determined from unconsolidated undrained triaxial tests.

The samples were not measured soil suction during unconsolidated undrained triaxial tests, but rather estimated soil suction from the soil water characteristic curve (SWCC) based on the volumetric water content of the sample during the test. The drying soil water characteristics curve (SWCC) for the compacted Khon Kaen loess was determined from three methods, which were a hanging column method, a pressure plate and an isopiestic humidity method.

The volumetric water content during UU test was calculated from an initial moisture content of sample and a volume change of soil during shear as presented in (1).

$$\theta_w = \frac{V_w}{V} = \frac{w.Ws}{V_i - \Delta V} \tag{1}$$

Where θ_w = volumetric water content; V_w = volume of water; V = total volume of soil; w = moisture content; V_i = initial volume of specimen; ΔV = volume change of specimen; and W_s = mass of dry soil.

Due to both of pore water and pore air pressures were not measured during unconsolidated undrained triaxial tests. Therefore the unsaturated undrained shear strength of compacted Khon Kaen loess was related to the total stress by assumed that a slope angle between total stress and shear strength, ϕ, is constant value with soil suction.

2. BASIC PROPERTIES

The basic and engineering properties of Khon Kaen soils are presented in Table 1.

The USCS classifications of Khon Kaen soil based on the results of soil particle distribution curves and Atterberg limits as SM-SC.

The maximum dry density and optimum moisture content Khon Kaen soil was determined by standard compactive effort (ASTM D698 – 00a).

Table 1. The basic and engineering properties of Khon Kaen soils

Particle Size Distribution	
Clay (%)	13
Silt (%)	31
Sand (%)	56
Atterberg Limit	
LL (%)	20.3
PL (%)	14.5
PI (%)	5.8
USCS Classification	SM -SC
Gs	2.65
Standard Compaction	
OMC (%)	8.25
Maximum dry density (t/m^3)	2.00

3. SOIL WATER CHARACTERISTIC CURVE

The initial dry density, moisture content and void ratio of compacted Khon Kaen samples were 1.7 t/m^3 (or 85% of maximum dry density), 14 % and 0.47, respectively.

The drying soil water characteristics curve (SWCC) for the compacted Khon Kaen loess was determined from three methods, which were a hanging column method, a pressure plate and an isopiestic humidity method.

According to ASTM D6836 - 02(2008) e2, the hanging column method was used to determine suctions in the range of 0 to 9.81 kPa.

The pressure plate method (ASTM D2325-98) was used to determine SWCC for a suction values between 10 to 1,500 kPa.

Finally, SWCC at suctions above 1500 kPa were determined from the isopiestic humidity method. In this method three solutions, which were Copper Sulphate ($CuSO_4$), Ammonium Chloride (NH_4Cl) and Sodium Hydroxide ($NaOH.H_2O$) were used to determine SWCC at

3,900, 30,900 and 365,183 kPa for a suction value, respectively. Data points above 1500 kPa were total suction values.

The relationships between soil suction and volumetric moisture content are illustrated in Fig. 1.

Fig 1 showed that the projected air entry value for compacted Khon Kaen loess was equal to 12 kPa and a very low residual volumetric moisture content of 1.0%. Therefore the suction range of transition regime was between 12 to 45,000 kPa.

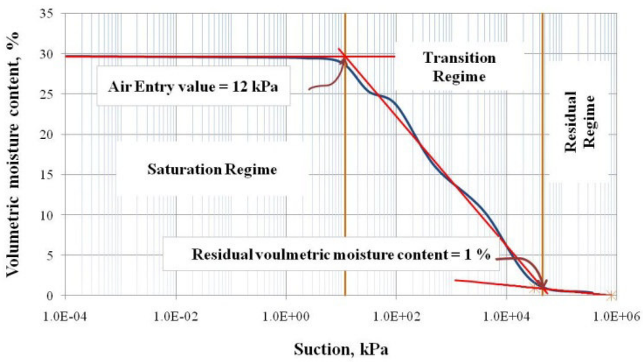

Fig. 1. The relationship between soil suction and volumetric moisture content of compacted Khon Kaen soil

4. UNSATURATED UNDRAINED SHEAR STRENGTH

Ten samples of Khon Kaen loess were compacted into a mold with a diameter of 50 mm and 100 mm high to obtain the initial dry density, moisture content and ratio of 1.7 t/m^3, 14%, and 0.47, respectively as Shown in Fig 2.

Fig. 2. Sample preparation

All samples were determined an undrained shear strength by the unconsolidated undrained test (UU test) at a confining pressure of 100 or 200 kPa. Two samples were tested immediately after compaction. Another eight samples were air dried for 2, 12, 24 or 72 hours prior to undrained shear. The initial moisture content was measured after shear to determine the initial soil suction by assumed the moisture content during testing was not changed.

The volume changes of soil samples were monitored as the sample was loaded at an axial strain rate of 0.1 % via the volume of water flowing out of, or into, the triaxial chamber. The volumetric water content during UU test was calculated from an initial moisture content of sample and a volume change of soil during shear as presented in (1).

From the saturated unconsolidated undrained test, the total friction angle, ϕ, of compacted Khon Kaen soils was 0^o. This study was assumed that ϕ is constant value with soil suction. Since the shear stress at failure was equal to the maximum shear stress.

The summaries of initial test condition and result of UU test for unsaturated compacted Khon Kaen loess is provided in Table 2 and 3, respectively.

Table 2. The initial condition of unconsolidated undrained test for compacted Khon Kaen loess

Sample	Initial moisture content (%)	Initial volumetric moisture content (%)	Initial soil suction (kPa)
CP =100 kPa (0 hrs-air dry)	14.9	25	53
CP =200 kPa (0 hrs-air dry)	14.4	21	188.5
CP =100 kPa (2 hrs-air dry)	14.3	24	87
CP =200 kPa (2 hrs-air dry)	13.6	20	245
CP =100 kPa (12 hrs-air dry)	10.8	18	419
CP =200 kPa (12 hrs-air dry)	9.6	16	705
CP =100 kPa (24 hrs-air dry)	8.8	15	1000
CP =200 kPa (24 hrs-air dry)	7.2	12	2026
CP =100 kPa (36 hrs-air dry)	4.7	6	9263
CP =200 kPa (36 hrs-air dry)	3.1	4	15230

Table 3. The summaries of unconsolidated undrained test for compacted Khon Kaen loess

Sample	$(u_a - u_w)_f$ (kPa)	σ_{3f} (kPa)	σ_{1f} (kPa)	τ_f (kPa)
CP = 100 kPa (0 hrs-air dry)	41	100	170	35
CP = 100 kPa (2 hrs-air dry)	67	101	183	41
CP = 100 kPa (12 hrs-air dry)	351	98	259	81
CP = 100 kPa (24 hrs-air dry)	852	98	344	123
CP = 100 kPa (36 hrs-air dry)	8240	101	1281	590
CP = 200 kPa (0 hrs-air dry)	165	201	304	52
CP = 200 kPa (2 hrs-air dry)	204	199	348	75
CP = 200 kPa (12 hrs-air dry)	570	199	487	145
CP = 200 kPa (24 hrs-air dry)	1748	198	647	225
CP = 200 kPa (36 hrs-air dry)	15254	198	1560	681

Relationship between stress and strain of the unsaturated compacted Khon Kaen loess for UU test in Fig. 3 showed the strain hardening behavior, except that soil samples were air dried for 72 hours prior to shear. Therefore the failure was defined as 15% axial strain except that soil samples with 72 hours air dried. The failure of soil samples with 72 hours air dried was defined as the maximum deviator stress. The relationship between axial and volumetric strain, as presented in Fig. 4, indicated that the sample, which was air dried for 72 hours and subjected to confining pressure of 200 kPa, exhibited dilation. The initial moisture content and volumetric moisture content of this sample was 3 % and 4 %, respectively, which was corresponded to soil suction of 15,230 kPa.

The plot between deviator stress and soil suction for samples with high soil suction as provided in Fig. 5 indicated that the soil suction dropped significantly after the peak deviator stress had been reached as presented in Fig. 3 due to the behavior of soils as a strain-softening. On the other hand, the stress-strain behavior of samples with low soil suctions indicated the strain hardening (see Fig. 3). Therefore the soil suction remained constant thereafter the residual soil suction had been reached as presented at Fig. 6.

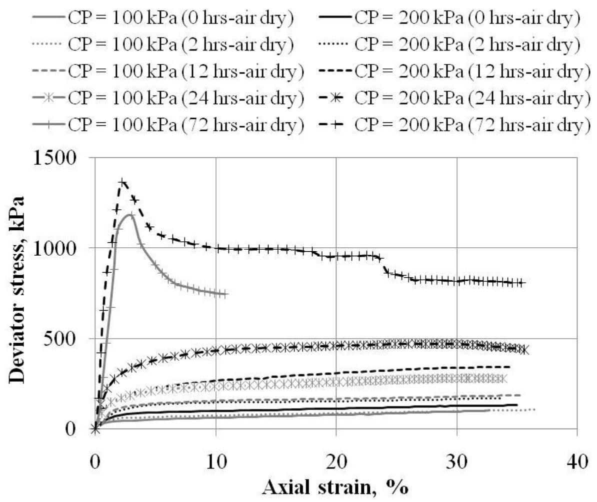

Fig. 3. The stress-strain curve of unsaturated compacted Khon Kaen loess from UU testing

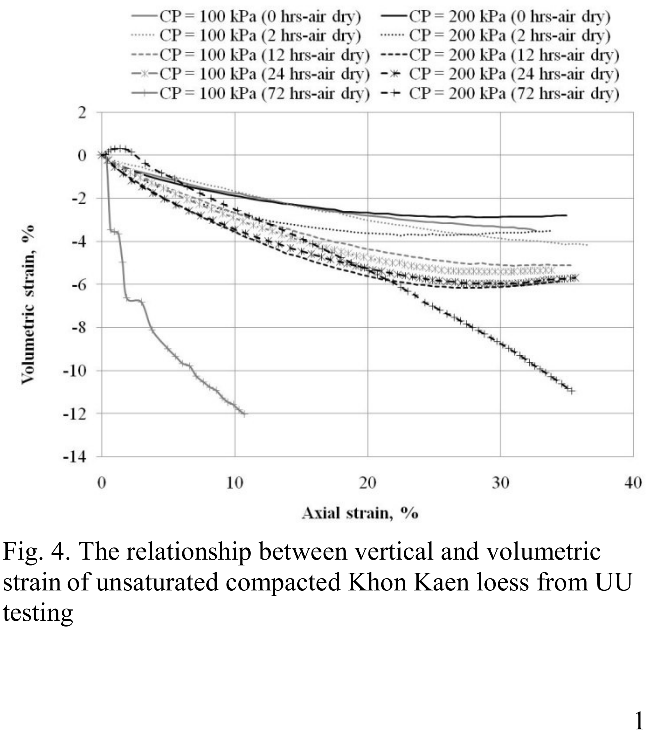

Fig. 4. The relationship between vertical and volumetric strain of unsaturated compacted Khon Kaen loess from UU testing

Fig. 7 and 8 presented that the soil suction of unsaturated compacted Khon Kaen loess with a high initial soil suction value was deceased continuously with axial strained. Meanwhile the soil suction of the other soil samples was quite constant with axial strain.

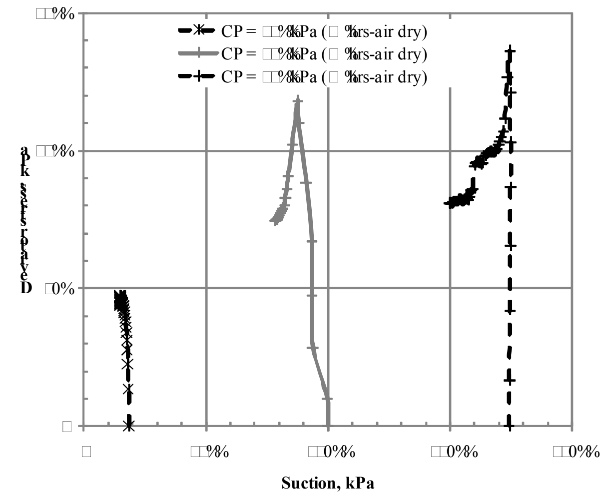

Fig. 5. The relationship between a high suction and deviator stress of unsaturated compacted Khon Kaen loess from UU testing

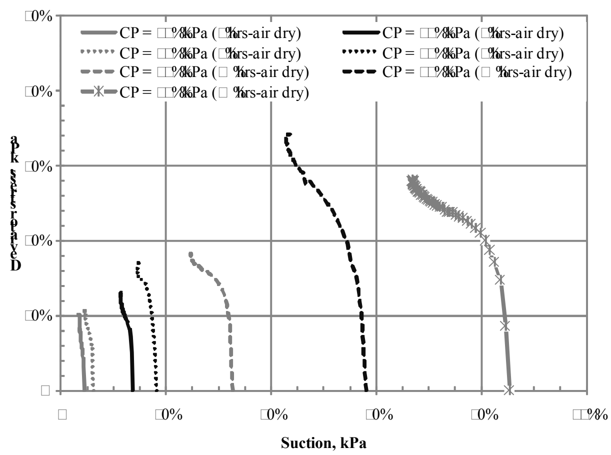

Fig. 6. The relationship between a low suction and deviator stress of unsaturated compacted Khon Kaen soil from UU testing

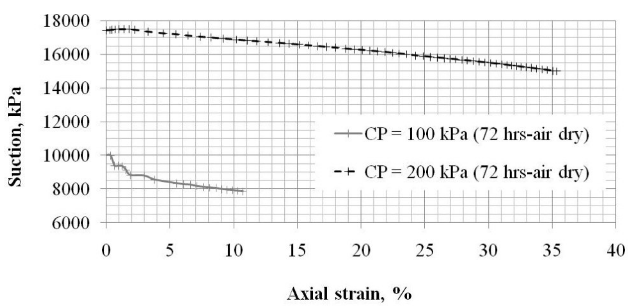

Fig. 7. The relationship between a high suction and axial strain of unsaturated compacted Khon Kaen loess from UU testing

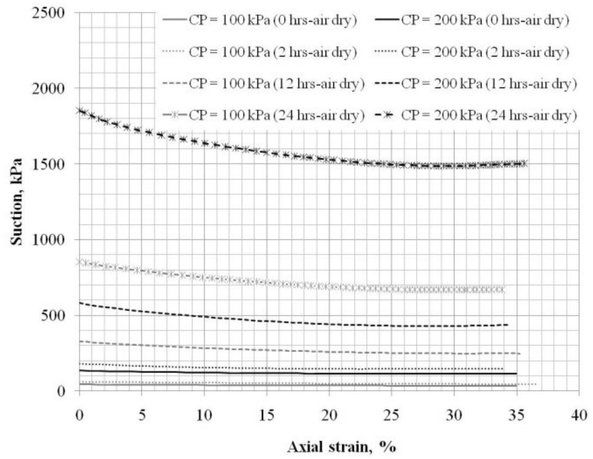

Fig. 8. The relationship between a low suction and axial strain of unsaturated compacted Khon Kaen loess from UU testing

5 DISCUSSION

The soil suction range, which used in this experiment, was between 35 to 17,500 kPa. This range of soil suction was on the transition zone. This indicated that the samples were unsaturated. According to [4] the soil suction range between 100 to 10,000 kPa is on the adsorbed film regime. The bonding between water and the soil particle on this regime is short-range solid-liquid interaction mechanism. A soil suction value of the samples, almost all is in the adsorbed film regime. This explained that the bonding between water and soil particle of the compacted Khon Kaen soils was short-range solid-liquid interaction mechanism.

Fig. 8 showed the extended Mohr circles at failure as total confining pressure of 100 and 200 kPa. The typical Mohr circles at failure of compacted Khon Kaen soils as total confining pressure of 100 and 200 kPa was presented in Fig. 9 and 10, respectively. Fig. 9 and 10 was illustrated the total stress path of various soil suctions. Then the plot of maximum shear versus soil suction on a log scale as 100 and 200 kPa total confining pressure was illustrated in Fig. 11 and 12, respectively. Fig. 11 and 12 was provided the path of soil suction in term of total stress. These paths showed a good non-linearly correlation between the maximum undrained shear strength and soil suction. However, a soil suction value of this study was not measured but it was estimated from SWCC.

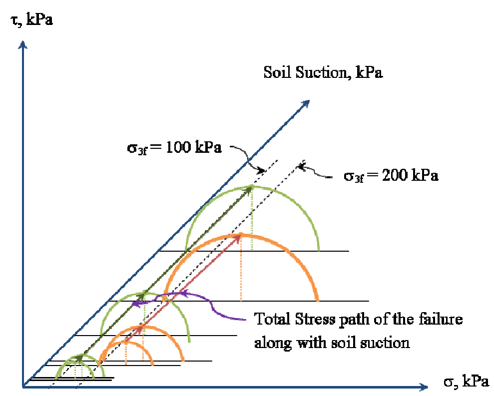

Fig. 9. The extended Mohr circles of compacted Khon Kaen loess

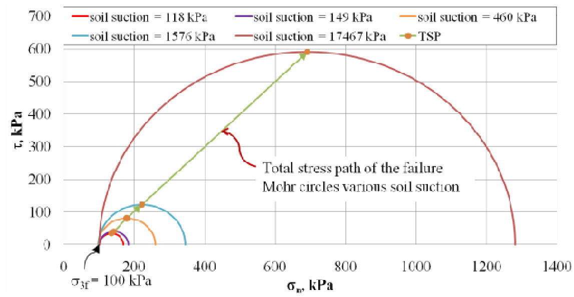

Fig. 10. Typical Mohr circles at failure with various soil suctions for compacted Khon Kaen soils as 100 total confining pressures

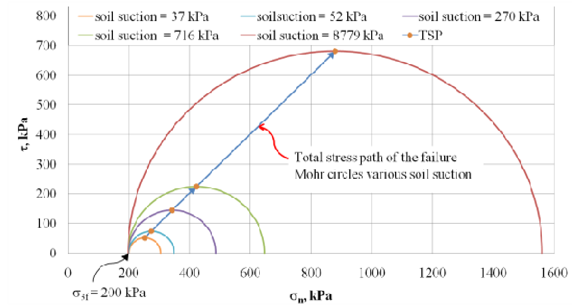

Fig. 11. Typical Mohr circles at failure with various soil suctions for compacted Khon Kaen soils as 200 total confining pressures

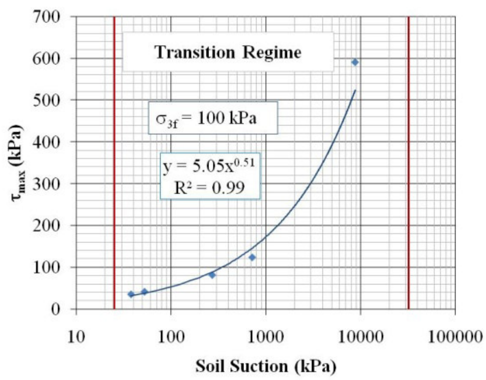

Fig. 11. The soil suction path of compacted Khon Kaen loess as 100 kPa total confining pressure

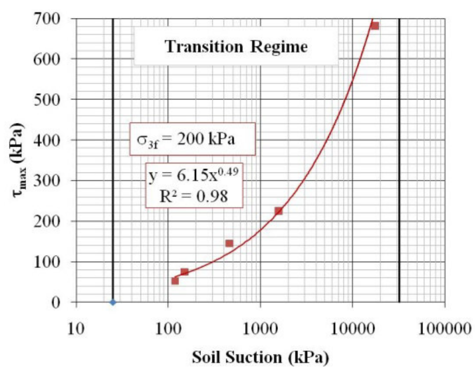

Fig. 12. The soil suction path of compacted Khon Kaen loess as 200 kPa total confining pressure

6 CONCLUSION

Khon Kaen loess was compacted at 85% of maximum dry density by standard compactive effort to determine the unsaturated undrained shear strength parameter from the unconsolidated undrained test. Due to the pore water and pore air pressure did not measure during test, since the soil suction was estimated from SWCC.

The SWCC of compacted Khon Kaen loess showed the residual volumetric moisture content of 1.0 % and the air entry value of 12 kPa.

Finally, the path of soil suction during undrained unconsolidation test in term of total stress showed a good non-linearly correlation between the maximum undrained shear strength and soil suction.

7 ACKNOWLEDGMENT

Acknowledgement is given to Faculty of Engineering, Khon Kaen University for the support of this re-search. Sincere thanks are extended to Dr. Ketsuda Dejbhimon and Mrs Pornpis Chuson, for the favor of using instruments in this study. Special thanks to Ms. Nichapat Banreangthong, Mr.Tanakorn Dua-ngkantai, Mr. Nanthiwa Soontararuk, Mr. Piyanat Jantosut, Mr. Veeraphon Tansa, Ms. Pemiga Thong-tan, and everyone who have been involved directly and indirectly in the preparation of this research.

8 REFERENCES

[1] ASTM - American Society for Testing Material, ‘Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge1’, (ASTM D6836 – 02), West Conshohocken, PA., 2002

[2] ASTM - American Society for Testing Material, ‘Standard Test Method for Capillary-Moisture Relationships for Coarse- And Medium-Textured Soils by Porous-Plate Apparatus’, (ASTM D2325-98), West Conshohocken, PA., 1998

[3] Lu, N. and Likos, W.J., Unsaturated Soil Mechanics, John Wiley & Sons, Inc., Hoboken, New Jersey., 2004, ch. 10

[4] McQueen, I.S. and Miller, R.F., ‘Calibration and Evaluation of Wide-Range Gravimetric Method for Measuring Soil Moisture Stress’, Soil Science, 10(3), 1968, pp 521-527.

International Journal of GEOMATE, March, 2012, Vol. 2, No. 1 (Sl. No. 3)
MS No. 1249 received August 31, 2011, and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in the March 2013 if the discussion is received by Sept. 2012.
Corresponding Author: R. Nuntasarn