International Journal of GEOMATE, July, 2017, Vol.13, Issue 35, pp.28- 33
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.35.6641

DRAINED SHEAR STRENGTH OF COMPACTED KHON KAEN LOESS

*R Nuntasarn[1] and W. Wannakul[2]

[1,2]Faculty of Engineering, Khon Kaen University, Thailand

* *Corresponding Author, Received: 15 June 2016, Revised: 16 July 2016, Accepted: 27 Nov. 2016

ABSTRACT: The objective of this study was to determine the relationship between drained shear strength and matric suction of compacted Khon Kaen loess. Khon Kaen loess in this study was compacted at 95% by modified method. This soil sample was investigated a soil water characteristic curve (SWCC) from the pressure plate test. Moreover the relationship between drained shear strength and matric suction was determined from the consolidated drained triaxial test (CD Test) under saturated and unsaturated condition. Three saturated specimens were tested to determine an effective friction angle (ϕ´) and an effective cohesion (c´). Another three unsaturated specimens were tested with various matric suction of 30, 180 and 280 kPa, respectively. The net confining pressures of these specimens were constant at 100 kPa. To determined drained shear strength at unsaturated condition, an effective friction angle (ϕ´) was assumed to be constant with a matric suction value. The SWCC of compacted Khon Kaen loess showed a bimodal curve. The first air-entry value and the first residual volumetric moisture content was 4 kPa and 20%, respectively. The results of saturated consolidated drained triaxial test (CD Test) presented that an effective friction angle (ϕ´) and an effective cohesion (c´) was 31 degree and 54 kPa, respectively. Moreover the unsaturated triaxial test showed a linear relationship between drained shear strength and matric suction with the ϕ^b angle of 28 degree.

Keywords: Unsaturated Soil, Compacted Soil, Khon Kaen Loess, Consolidated Drained Triaxial Test, Soil Water Characteristic Curve

1. INTRODUCTION

The unsaturated soil has three phases which are solid, liquid and air. Therefore, the Terzaghi's effective stress law for saturated soil is not appropriate for unsaturated soil. Reference [1] formulated the shear strength equation for an unsaturated soil as given in Eq. (1).

$$\tau_{ff} = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)\tan\phi^b \quad (1)$$

Where τ_{ff} is a shear stress at failure. c' is an effective apparent cohesion, which is the shear strength intercept when the effective stress is equal to zero. σ_f is total normal stress at failure. u_{af} is pore-air pressure at failure. u_{wf} is pore-water pressure at failure. ϕ' is an effective angle of internal friction. And ϕ^b is an angle indicating the rate of increase in shear strength relative to the soil suction at failure.

Reference [2] was investigated the shear strength parameters of unsaturated residual soils by consolidated drained test. This study found that the values of ϕ^b are generally lower than ϕ′.

Reference [3] was studied consolidated drained test on a residual soil, which was classified as CL according to USCS. This study found that the effective friction angle of 31.5 degree and a ϕ^b of 29 degree before air entry value. After Air entry value the relationship between cohesion intercept (c) and matric suction was non-linear as shown in Figure 1.

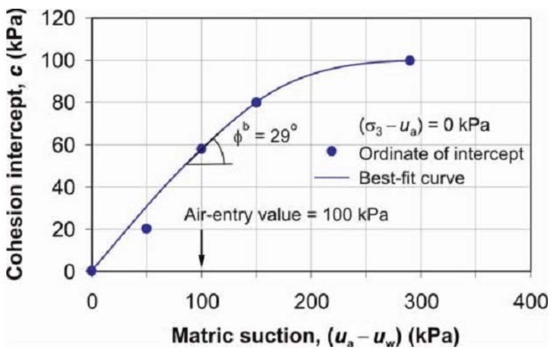


Fig. 1 the relationship between cohesion intercept (c) and matric suction (Ref [2])

2. BASIC PROPERTIES

The soil used in this study was Khon Kaen loess, which was classified as silty sand (SM) according to USCS. The basic properties of Khon Kaen loess were present in Table1. Percent passing sieve No. 4 and No.200 of this soil sample was 100% and 47%, respectively as shown in Fig.2.

Moreover, a liquid limit and a plastic limit of this soil were 13% and of 12%, respectively, which gave the plastic index of 1%. The specific gravity was 2.65.

The maximum dry density and optimum moisture content were 2.06 t/m^3 and 8.5%, respectively, which was determined by standard compaction effort [4]. However, the specimen in this study was prepared at 95% of maximum dry density, which was 1.95 t/m^3, and moisture content of 6.5%.

Table 1 Basic Properties of Khon Kaen loess

Properties	
Liquid limit (LL), %	13
Plastic limit (PL), %	12
Plasticity index (PI), %	1
Specific gravity	2.65
Optimum moisture content (OMC), %	8.5
Maximum dry density (ρ_d), t/m^3	2.06
Sand (%)	53
Silt (%)	27
Clay (%)	20
USCS classification	SM

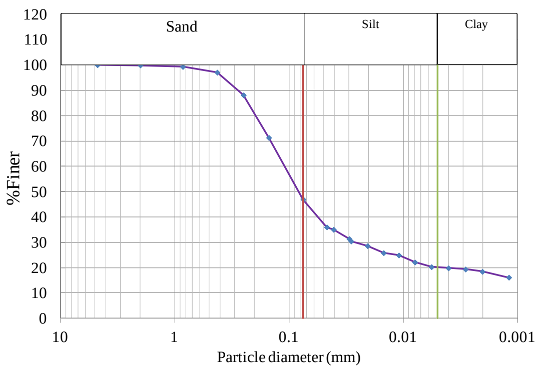


Fig.2 Grain size distribution

3. SOIL WATER CHARACTERISTIC CURVE

The drying soil water characteristics curve (SWCC) for the compacted Khon Kaen loess was determined by two methods. According to [3], the pressure plate method was used to establish SWCC for a suction values between 1 to 1,500 kPa. Moreover, SWCC at suctions above 1,500 kPa were determined from the isopiestic humidity method. In this method, three solutions, which were Copper Sulphate (CuSO4), Ammonium Chloride (NH4Cl) and Sodium Hydroxide (NaOH.H2O), were used to determine SWCC at a suction value of 3,900 kPa, 30,900 kPa, and 365,183 kPa, respectively. Data points above 1,500 kPa were total suction values.

The test result of a pressure plate and isopiestic humidity showed the soil water characteristic curve (SWCC) as illustrated in figure 3. The soil sample was compacted at the dry side of optimum moisture content (6.5% or 95% of OMC). The SWCC of compacted Khon Kaen loess showed a bimodal curve, which indicated two distinct air-entry values and two distinct residual points [6]. The first and second air entry value is 8 and 5,000 kPa, respectively. Moreover, the first and second residual volumetric moisture content are 10 and 2%, respectively. Therefore, the soil suction value of saturation regime and transition regime was between 0 to 8 kPa and 8 to 200 kPa, respectively. The soil suction, which was higher than 200 kPa, was a residual regime.

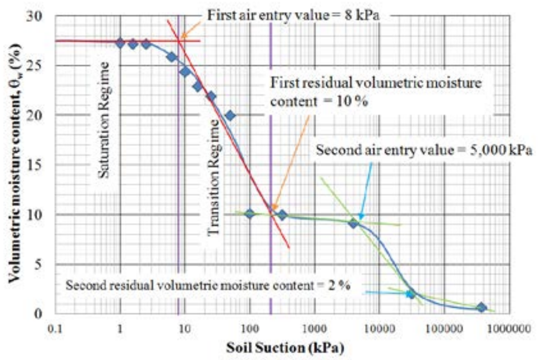


Fig. 3 Soil water characteristic curve of compacted Khon Kaen loess

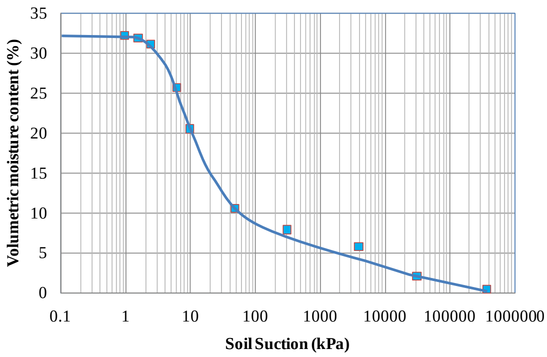


Fig.4 Soil water characteristic curve of undisturbed Khon Kaen loess

According to [7], the cause of bimodal curve might be a bimodal pore size distribution, which is related to gap-graded grain-size distribution. However in this studied the grain size distribution is not gap-grain as shown in figure 2. Moreover the SWCC of the undisturbed sample showed a unimodal curve with two bending points as illustrated in figure 4. Therefore the compaction on the dry side of optimum moisture content might be the cause of bimodal curve. However this study is not observed the structure of the sample.

4. CONSOLIDATED DRAINED TEST

Soil sample was mixed with water to achieve 1.95 t/m^3 in dry density and 6.5% of moisture content. Then soil sample was equally separated in two parts and statically compacted in a mold diameter of 50 mm and 100 mm of height.

Each samples were saturated by applied backpressure, which was lower than confining pressure (i.e. σ'_C = 20 kPa) prior to consolidate and drained shear. B-values were observed to be greater than 98% to complete saturation.

Three net confining pressures of 100, 200 and 300 kPa were investigated in this study. For the saturated series, three specimens were tested to determine the effective friction angle (ϕ') and cohesion (c'). Pore air pressure (u_a) and pore water pressure (u_w) of these three samples were controlled at 20 kPa. For the unsaturated series, three samples were observed at net confining pressures of 100 kPa. Pore air pressures were controlled at 50, 200 and 300 kPa and pore water pressures were controlled at 20 kPa to achieve a matric suction of 30, 180 and 280 kPa as shown in Table 2. The shear rate in this study for both saturated and unsaturated series was 0.01 mm per minute.

Table 2 An unsaturated sample

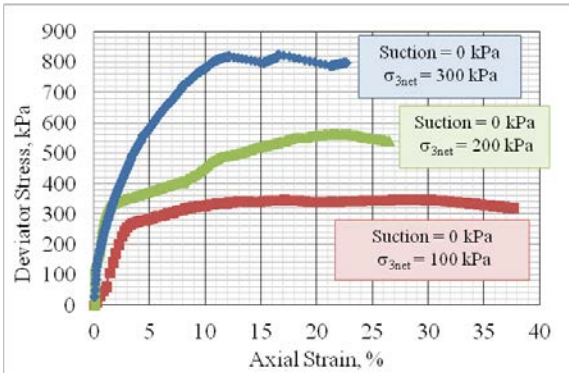
Sample No.	σ_3 (kPa)	u_a (kPa)	u_w (kPa)	σ_{3net} (kPa)	u_a-u_w (kPa)
1	150	50	20	100	30
2	300	200	20	200	180
3	400	300	20	300	280

The failure of both saturated and unsaturated sample showed a failure plane of 60 degree as shown in Fig.5. For both saturated and unsaturated series, the stress-strain relationship showed the strain hardening behavior as illustrated in Fig.6. Thus the failure was defined at 20% strain. The test result of saturated sample was present at Table 3. Then the Mohr's Circle was drawn in Fig.7. The Mohr's circle showed that the effective friction angle and cohesion was found as 31 degree and 44 kPa, respectively.

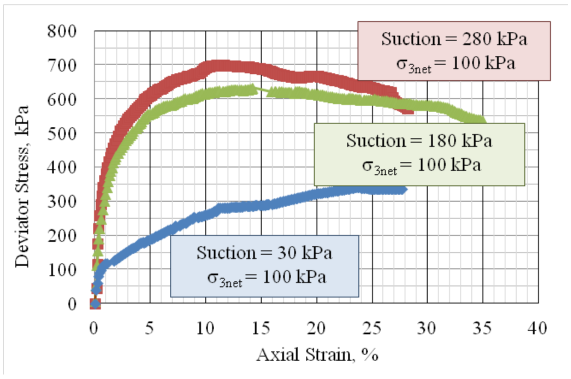
The drained shear strength of unsaturated soil was calculated by assumed constant ϕ' (ϕ' = 31 degree) as present in Fig.8. The shear stress (τ_{ff}) and the net stress (σ_{netf}) at failure plane of unsaturated soil were calculated from the maximum shear stress (τ_{max}) as shown in Eq.(2) and Eq.(3), respectively. Then the cohesion intercepted (c") was determined from Eq.(4). And a ϕ^b angle was determined from Eq.(5).

(a) Saturated series (b) Unsaturated series

Fig.5 A shear failure of compacted Khon Kaen loess



(a) Saturated series



(b) Unsaturated series

Fig. 6 The relationship between stress and strain of compacted Khon Kaen loess

The test results of unsaturated sample and an unsaturated parameters (the cohesion intercepted, c" and a ϕ^b) were present in Table 4 and Table 5, respectively. The plot between drained shear strength and matric suction was illustrated in Fig.9. Fig. 9 showed that the drained shear strength of this study was investigated at saturated, transition and residual regime. In addition, Fig.9 presented a non-linear relationship between cohesion intercept and matric suction. However, the relationship between cohesion intercept and matric suction at the saturated and transition regime showed the linear relationship as presented in figure 10.

Table 5 showed that ϕ^b was slightly lower than ϕ'. Moreover, ϕ^b was constant at 30.5 degrees for the matric suction range between 0 and 180 (ϕ^b was constant before residual regime). Then a ϕ^b angle value was dropped from 30.5 to 28 (ϕ^b was decreased after the transition regime) when matric suction was higher than 180 kPa as illustrated in Fig.11.

The relationship between the total volumetric strain and axial strain showed the dilation behavior of both saturated and unsaturated series as illustrated in Fig.12 and Fig.13, respectively. The dilation behavior is the characteristic of dense soil.

The relationship between the water volume change and axial strain of unsaturated sample as present in Fig.14 showed that water was suction into a specimen.

Table 3 A saturated sample result

σ_3 (kPa)	u_a (kPa)	u_{wf} (kPa)	σ_d (kPa)	τ_{max} (kPa)
120	20	20	350	174
220	20	20	565	282
320	20	20	799	399

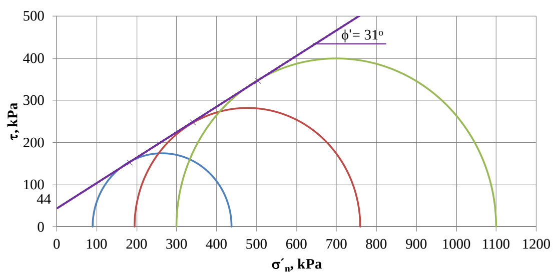


Fig.7 The Mohr's circle of compacted Khon Kaen loess at saturated condition

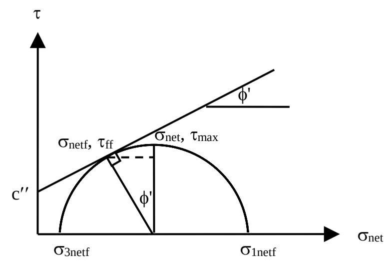


Fig.8 The interpretation of unsaturated drained shear strength

$$\tau_{ff} = \tau_{max}.\cos\phi' \quad (2)$$

$$\sigma_{netf} = \frac{(\sigma_{1netf} + \sigma_{3netf})}{2} - \tau_{max}.\sin\phi' \quad (3)$$

$$c'' = \tau_{ff} - \sigma_{netf}.\tan\phi' \quad (4)$$

$$\phi^b = \tan^{-1}\left[\frac{c'' - c'}{(u_a - u_w)_f}\right] \quad (5)$$

Table 4 An unsaturated sample results

Sample No.	σ_{3net} (kPa)	u_a (kPa)	u_w (kPa)	σ_d (kPa)	τ_{max} (kPa)
1	150	50	20	437	219
2	300	200	20	759	379
3	400	300	20	896	448

Table 5 An unsaturated parameters

Sample No.	τ_{ff} (kPa)	σ_{netf} (kPa)	c'' (kPa)	ϕ^b (°)
1	187	206	63	30.5
2	325	283	154	30.5
3	383	317	193	28.0

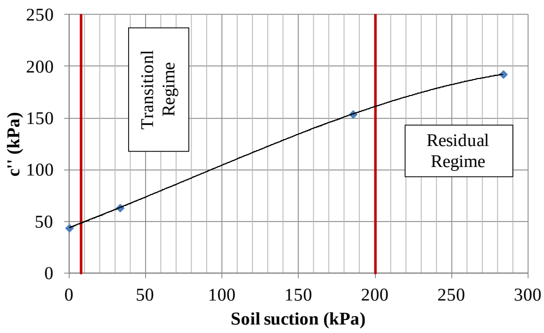


Fig. 9 The relationship between cohesion intercept and matric suction

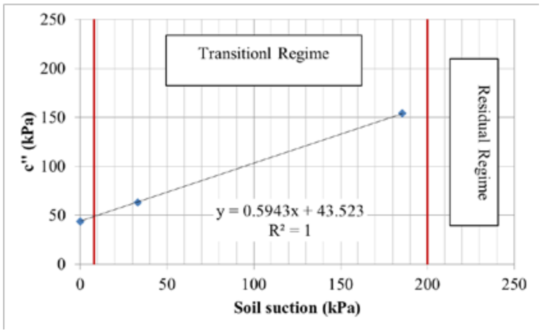


Fig. 10 The relationship between cohesion intercept and matric suction at saturated and transition regime

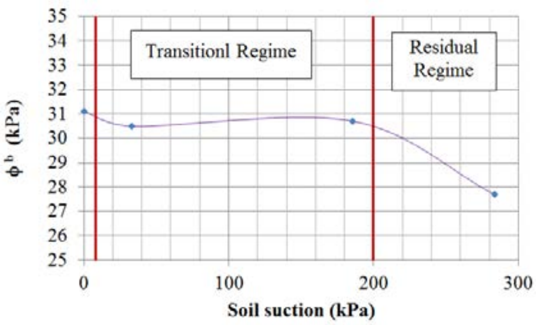


Fig. 11 The relationship between ϕ^b and matric suction

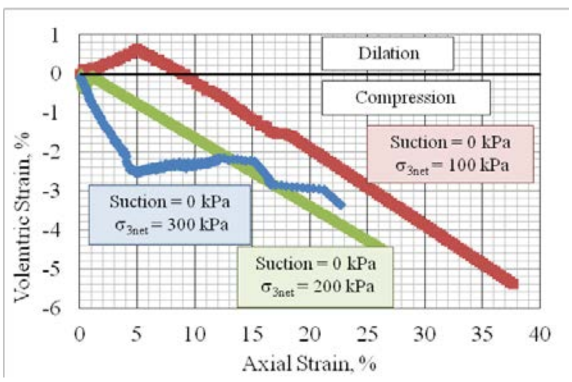


Fig. 12 The relationship between the total volumetric strain and axial strain of saturated sample

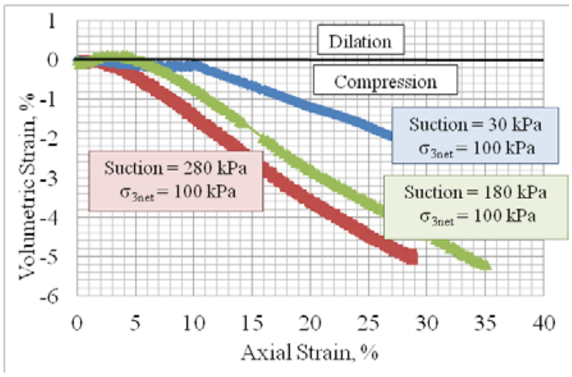


Fig.13 The relationship between the total volumetric strain and axial strain of unsaturated sample

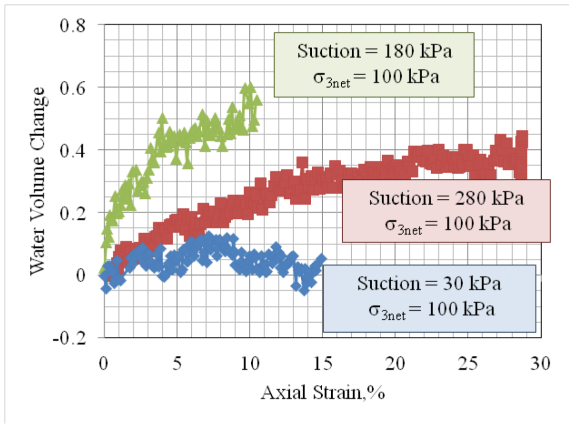


Fig.14 The relationship between the water volume change and axial strain of unsaturated sample

5. CONCLUSIONS

The soil sample in this study was Khon Kaen loess, which was classified as silty sand. This study found that the SWCC of compacted Khon Kaen loess was a bimodal curve. The cause of bimodal curve might be the specimen was compacted at the dry side. The first and second air entry value is 8 and 5,000 kPa, respectively. Moreover the first and second residual volumetric moisture content is 10 and 2 %, respectively. The stress-strain behavior of compacted Khon Kaen loess for both saturated and unsaturated series showed a strain hardening. In addition the relationship between the volumetric strain and axial strain of both saturated and unsaturated series showed the dilation behavior. The consolidated drained triaxial test of saturated compacted Khon Kaen loess presented the effective angle and cohesion of 31 degree and 44 kPa, respectively. The unsaturated drained shear strength was determined by assumed a constant friction angle (ϕ'). ϕ^b was constant before residual regime. After the transition regime, ϕ^b was decreased.

6. ACKNOWLEDGEMENTS

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.

7. REFERENCES

[1] Fredlund, D.G. and Rahardjo, H. Soil Mechanics for Unsaturated Soils. Wiley. New York. 1993

[2] Huat, Bujang BK, Faisal Hj Ali, Affendi Abdullah, Saravanan Mariappan, and Soenita Hashim. Shear Strength Parameters of Unsaturated Residual Soils. Journal Kejuruteraan 17. 2005

[3] Rahardjo, H., Ong, B.H. and Leong, E.C. Shear Strength of Compacted Residual Soil From Consolidated Drained and Constant Water Content Traxail Test. Canadian Geotechnical Journal, 41: 421-436. 2004

[4] ASTM - American Society for Testing Material. Standard Test Method for Laboratory Compaction Characteristics of Soil using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m^3)) (ASTM D698-00a). Ann Arbor. Michigan. 2000

[5] 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). Ann Arbor. Michigan. 1998

[6] Gitirana Jr., Gilson de F.N. and Fredlund, D.G. Soil –Water Characteristic Curve Equation with Independent Properties. Journal of Geotechnical and Geoenvironmental Engineering. 2004. Vol. 130. No.2. pp.209-211

[7] Durner, W. Hydraulic Conductivity Estimation for Soils with Heterogeneous Pore Structure. Water Resour. Res., 30(2), 211-223