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DRAINED SHEAR STRENGTH PARAMETERS OF COMPACTED KHON KAEN LOESS BY DIRECT SHEAR TEST

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ABSTRACT: This study aims to determine the relationship between drained shear strength and matric suction of compacted Khon Kaen loess soil from a consolidated drained method by a direct shear test. All soil samples were compacted by a modified method at the wet side. The initial dry density of samples was 1.95 t/m^3, which was 90% of the maximum dry density and the initial moisture content was 11.85%. The shear rates of 0.005 mm/min, which was determined by a consolidation test. Moreover, soil samples of this study were tested under soaked and unsaturated conditions. Soaked samples were infiltrated with water for seven days in the direct shear box prior to the test. Unsaturated soil samples had been divided into three series. The first series was air-dried for 30 minutes. The second and the third series was air-dried for 60 minutes and 90 minutes, respectively. Then all unsaturated samples were wrapped up for one day to stabilize the moisture content. The results presented that the drained shear strength was increasing with the matric suction, but the slope of graph or the ϕ^b value was not constant with matric suction. The slope of graph or the ϕ^b value was increasing with net stress. Moreover, the friction angle (ϕ) was slightly increasing (2 degrees) with matric suction from the saturation regime to the first translation regime. Then the friction angle at the first translation regime was constant of 26 degrees.

Keywords: Direct Shear, Unsaturated, Consolidated Drained, Compacted Khon Kaen Loess, Matric Suction

1. INTRODUCTION

In the present, there are many constructions in Khon Kaen province. Moreover, Khon Kaen soil was used as construction material for landfill. Therefore the engineering should know the shear strength parameters for design the foundation. The shear strength parameters can be evaluated by the consolidated drained method (CD). This method can test by triaxial and direct shear test. This study used a direct shear test to determine shear strength parameters of this method as mention previously.

In this study, Khon Kaen loess had been investigated at the compacted and saturated condition. Soil samples for CD method were compacted at 90% of maximum dry density by a modified method. 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. Fredlund and Rahardjo [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 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 the 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 degrees and a ϕ^b of 29 degrees 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.

Reference [4] was studied the consolidated drained test of unsaturated Adobe soil by a direct shear test. The test result showed that the shear strength was increasing with decreased of soil moisture content. Moreover, the relationship between matric suction and shear strength is a non-linear. The slope of the graph was decreasing when increasing the matric suction. However, the slope of the graph in the saturation regime was equal to the effective friction angle.

This study used KU-tensiometer to measure the matric suction during shear. KU-tensiometer was developed by [5]. This equipment can determine the range of matric suction is between 0 to 100 kPa.

Therefore the range of matric suction of this is study is between 0 to 100 kPa.

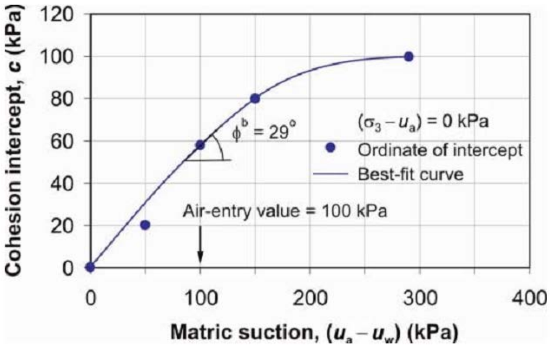

Fig. 1 the relationship between cohesion intercept (c) and matric suction (Ref [3])

2. BASIC PROPERTIES

Khon Kaen loess, which was used in this study, was classified as silty sand (SM) according to [6]. The results of sieve and hydrometer analysis showed that Khon Kaen loess consists of 55% sand, 30% silt, and 15% clay [7]. The majority of Khon Kaen sand size was fine sand as illustrated in Fig. 2. The natural density of Khon Kaen loess was 1.65 t/m^3, which is the loosed sand. Atterberg's limit results also presented a liquid limit was 16.5% and a non-plastic limit. The specific gravity was 2.65. The basic properties of Khon Kaen loess were present in Table1.

Also, the modified compaction was decided to use in this project because Khon Kaen loess was used in pavement construction rather than another construction. The maximum dry density was 2 t/m^3, and the optimum moisture content was 9%.

3. DIRECT SHEAR: CONSOLIDATED DRAINED METHOD

Soil samples were compacted at 90% of maximum dry density at the wet side (moisture content of 11.85%) by a modified method. Soil samples were trimmed by cutting ring as shown in Fig 3. The unsaturated sample was air-dried at the room temperature 25°c as shown in Fig 4. Then the sample was wrapped for stabilized the moisture content for one day prior to testing as shown in Fig 5. Meanwhile, the KU-tensiometer has to be de-aired by vacuum pump until no bubble on equipment before setup as shown in Figure 6. After that KU-tensiometer was set up at the top of the sample, then the plastic and the wet towel was wrapped on the sample to protect the loss of moisture content as shown in Figure 7 and 8.

The soaked specimen had to be infiltrated for seven days before being consolidated for 24 hours. But the unsaturated specimen was air dry before consolidating. Three series of air dry sample, which are 30, 60 and 90 minutes, was studied in this project.

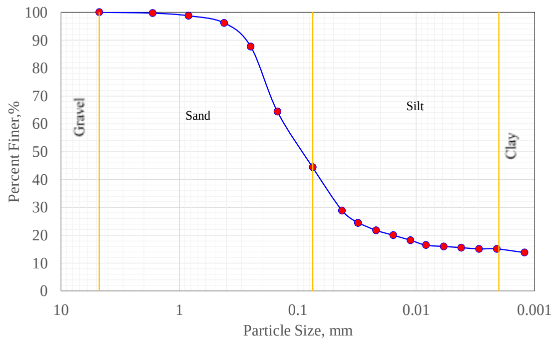

Fig. 2 Grain Size Distribution

Table 1 Basic Properties of Khon Kaen loess

Properties	
Liquid limit (LL), %	16.5
Plastic limit (PL), %	NP
Plasticity index (PI), %	-
Specific gravity	2.65
Optimum moisture content (OMC), %	9
Maximum dry density (ρ_d), t/m^3	2.0
Sand (%)	55
Silt (%)	30
Clay (%)	15
USCS classification	SM
Pre-consolidation pressure (P_c)	56

Fig. 3 Preparation specimen

The shear rate of this method has to determine from the consolidation test as shown in Table 2. Three vertical stress of 200, 400 and 800 kPa were used to study — the failure time of 200, 400, 800 kPa vertical load as shown in Table 2, 3, 4, 5, respectively. However, the consolidation results found that that pre-consolidation pressure (P_c) was 56 kPa and OCR was 1.74, which was less than 2. Therefore the failure time has to determine t_{50} or t_{90} as shown in Eq. [2] and [3], respectively. The shear rate was calculated from the maximum value of the failure time as shown in Eq. [3]. The failure time, which was derived from t_{50} was higher than t_{90}. The shear rate of this study equaled to 0.005 mm/min.

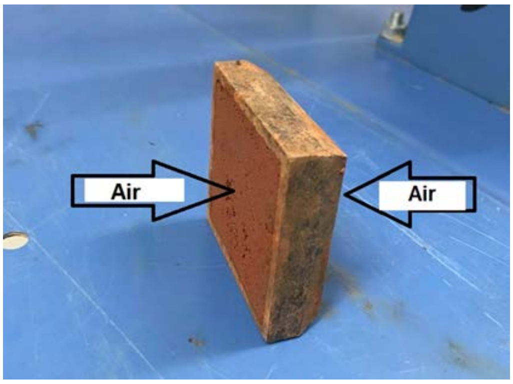

Fig. 4 Air-dried stage

Fig. 5 Wrapped sample for stabilized moisture content

Fig. 6 De-aired KU-tensiometer

Fig. 7 Wrapping Plastic

Fig. 8 Wet towels over a sample

$$t_f = 50t_{50} \tag{2}$$

$$t_{50} = 11.6t_{90} \tag{3}$$

$$R_d = \frac{d_f}{t_f} \tag{4}$$

Where d_f equal to 0.2 inches according [8] because Khon Kaen loess was coarse grain soil. Moreover, t_f is a failure time, which equaled to 60 min.

Table 2 Failure time of soaked sample

Vertical Stress (kPa)	t_{50}(min)	t_f (min)	t_{90}(min)	t_f (min)
200	7.5	375	5.9	68.44
400	7.8	390	6.9	80.04
800	8	400	4.6	53.36

Table 3 Failure time of 30 minutes air-dry sample

Vertical Stress (kPa)	t_{50}(min)	t_f (min)	t_{90}(min)	t_f (min)
200	1.5	75	5.8	67.28
400	6.5	325	3.3	38.28
800	0.45	22.5	16	185.6

Table 4 Failure time of 60 minutes air-dry sample

Vertical Stress (kPa)	t_{50}(min)	t_f (min)	t_{90}(min)	t_f (min)
200	1.357	67.5	3.5	40.6
400	0.857	42.85	8.5	98.6
800	0.55	27.5	9	104.4

Table 5 Failure time of 90 minutes air-dry sample

Vertical Stress (kPa)	t_{50}(min)	t_f (min)	t_{90}(min)	t_f (min)
200	1.07	83.5	3.5	40.6
400	0.85	42.5	2.5	29
800	1.71	85.5	8.6	99.76

3.1. Test Result of Direct Shear Test

The initial and final properties were shown in Table 6.

Table 6 The initial and final properties of soil sample

Sample Condition	Air- dried		
	30 mins	60 mins	90 mins
Initial moisture content (%)	11.3	10.8	10.5
Final moisture content (%)	10.1	10.6	9.8
Initial S_r (%)	64	61	60
Final S_r (%)	63	59	59

The relationship between the shear stress and net stress was present in Figure 9, and the summaries of the test result were present in Table 7. The total friction angle and cohesion of soaked soil was 24.5 degree and four kPa, respectively, as shown in Fig. 9. Moreover the relationship between horizontal displacement and shear stress of soaked sample and unsaturated sample for 30 and 60 mins air dry showed the strain hardening as shown in Fig. 10, 11 12 and 13, respectively. But the relationship between horizontal displacement and shear stress of unsaturated sample for 90 min air dry showed the strain softening as shown in Fig. 13.

Besides, the relationship between vertical displacement and horizontal displacement of both conditions as present in Fig. 14 to 17 showed a compression behavior.

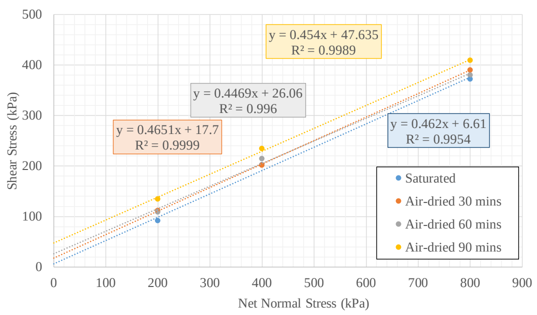

Fig. 9 The relationship between shear stress and net stress

Table 7. The summaries of the test result

Sample	ϕ	c
Soaked	24.5	4
Air dry for 30 min	26.3	14
Air dry for 60 min	26.7	23.5
Air dry for 90 min	26.3	26.0

The effective friction angle of soaked condition was 2 degrees lower than an unsaturated condition. The effective cohesion of unsaturated is 35 degree. However, the cohesion was increased with decreasing of soil moisture dramatically.

4. SOIL WATER CHARACTERISTIC CURVE

Two methods determined the drying soil water characteristics curve (SWCC). According to [9], 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 Sulfate ($CuSO_4$), Ammonium Chloride (NH_4Cl) and Sodium Hydroxide ($NaOH.H_2O$), 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 [10].

The test result of a pressure plate and isopiestic humidity showed the soil water characteristic curve (SWCC) as illustrated in Fig 18. The SWCC of compacted Khon Kaen loess showed a bimodal curve, which indicated two distinct air-entry values and two distinct residual points [11]. The first and second air entry value is 3 and 450 kPa, respectively. Moreover, the first and second residual volumetric moisture contents are 42 and 16%, respectively. Therefore, the soil suction value of saturation regime and the first transition regime was between 0 to 3 kPa and 3 to 27 kPa, respectively. The soil suction, which was higher than 27 kPa, was the first residual regime.

5. DISCUSSION

The relationship between matric suction and shear stress as shown in Fig.19 showed a quite linear relationship. The shear stress was increasing with matric suction. However, the slope of graph or ϕ^b were not constant with the net stress. The slope of graph or ϕ^b is increasing with the net stress (σ_{net}) as shown in Table 8. The ϕ^b value is too high and higher than the friction angle (approximately-3 times), which disagreed with [2] and [3]. The ϕ^b value of this study is too high because the KU-tensiometer was on the top surface of the sample where the water was bleeding as shown in Fig.20. Therefore the matric suction was too low. The tensiometer should be in the soil sample to get the right value of matric suction.

However, the final degree of saturation was also shown a low-value of matric suction, which was determined from the SWCC (Fig. 18). The matric suction of air-dried sample for 30, 60 and 90 mins was 5, 5.5 and 6, respectively, which was a slightly lower from KU-tensiometer measurement.

Moreover, the friction angles (ϕ) were not also constant. The friction angles were slightly increasing with matric suction from the saturation regime to the transition regime (about 2 degrees increasing). However, the friction angle of the sample, which was tested at the transition regime, was quite constant of 26 degrees as shown in Fig. 21.

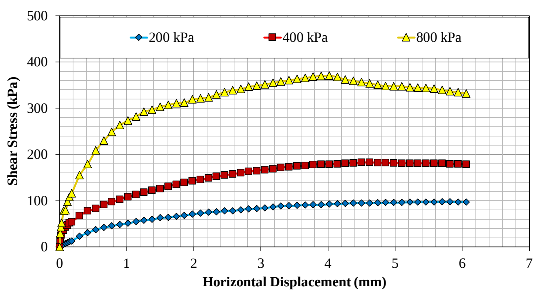

Fig. 10 The relationship between the horizontal displacement and shear stress of the soaked sample

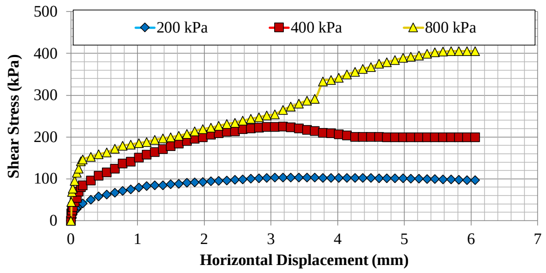

Fig. 11 The relationship between the horizontal displacement and shear stress of 30 mins air-dry sample

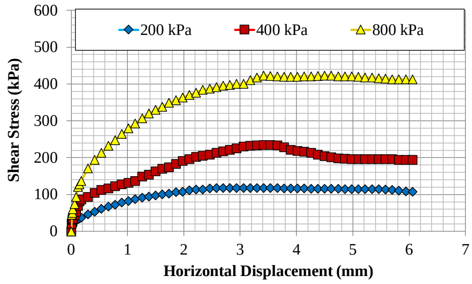

Fig. 12 The relationship between the horizontal displacement and shear stress of 60 mins air-dry sample

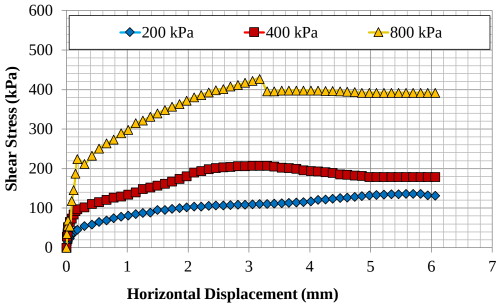

Fig. 13 The relationship between the horizontal displacement and shear stress of 90 mins air-dry sample

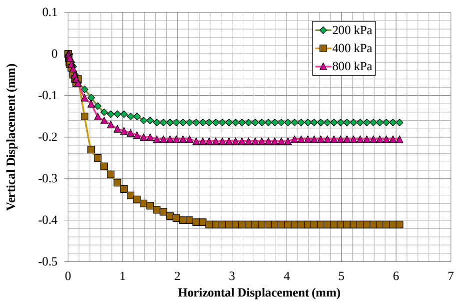

Fig. 14 The relationship between the vertical and horizontal displacement of the soaked sample

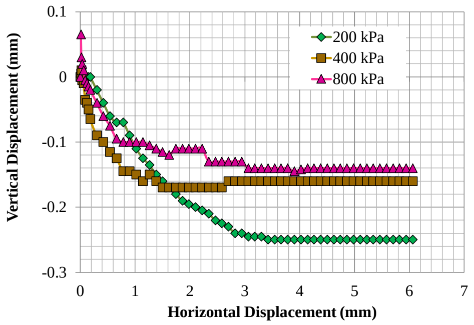

Fig. 15 The relationship between the vertical and horizontal displacement of 30 mins air-dry sample

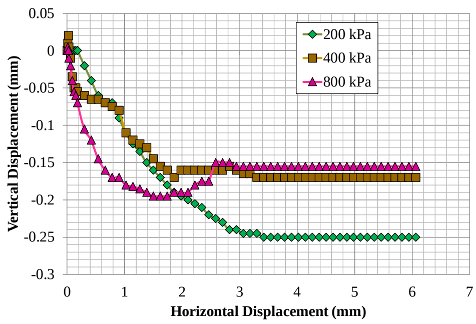

Fig. 16 The relationship between the vertical and horizontal displacement of 60 mins air-dry sample

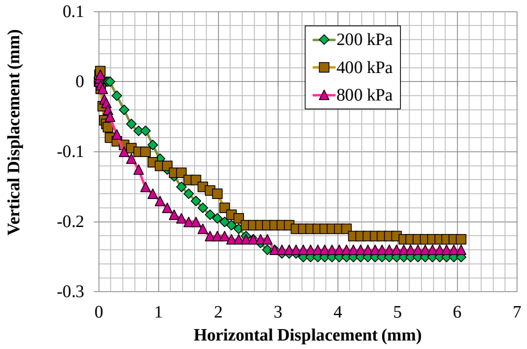

Fig. 17 The relationship between the vertical and horizontal displacement of 90 mins air-dry sample

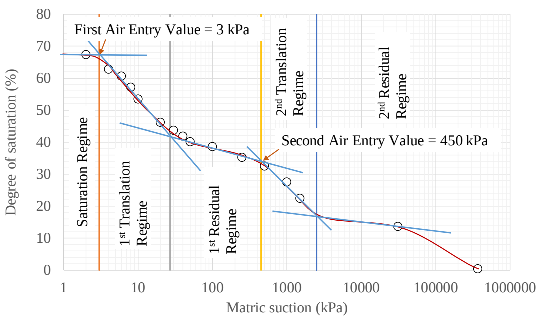

Fig. 18 Soil Water Characteristic Curve

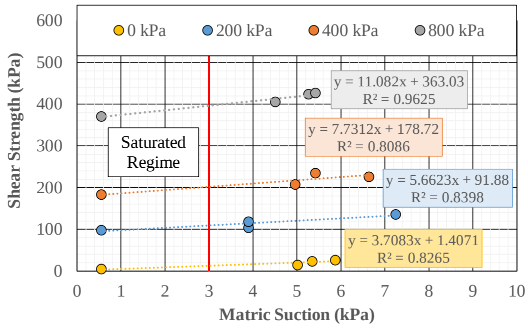

Fig. 19 The relationship between the matric suction and shear strength

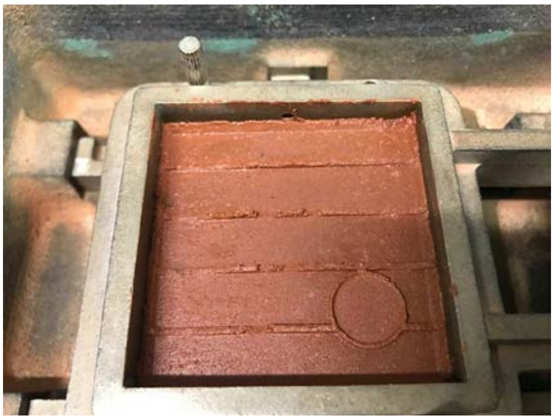

Fig. 20 The top surface after shearing

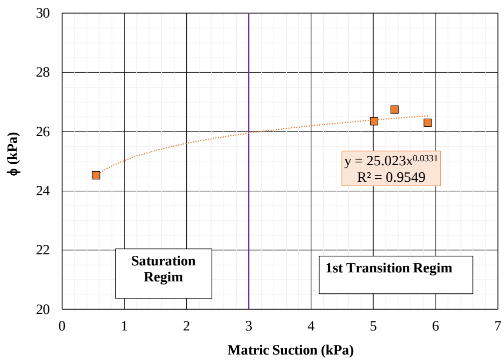

Fig. 21 The relationship between matric suction and friction angle

Table 8 The ϕ^b-value

σ_{net} (kPa)	ϕ^b (deg)
0	75
200	80
400	83
800	85

6. CONCLUSION

In this study, the compacted Khon Kaen loess as classified as SM was investigated the relationship between the drained shear strength and the matric suction by the consolidation and drained method from the direct shear test. The test result showed that the shear strength was increasing with the matric suction quite linearly. However, the slope of the graph or the ϕ^b-value was not constant — the ϕ^b-value increasing with the net stress. Moreover, the ϕ^b-value was 3 times higher than the friction angle. Because the tensiometer was located at the bleeding surface that makes the matric suction was too low. Therefore the tensiometer should be plug in the soil sample to get the right value of matric suction (close to the failure plane). The friction angle (ϕ) of the soaked sample was 24 degree, which was on the saturated regime. Then the friction angle was 2 degree increasing to be 26 degrees on the first transition regime.

7. ACKNOWLEDGMENTS

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