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ULTIMATE BEARING CAPACITY OF COLLAPSING KHON KAEN LOESS

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ABSTRACT: Many researchers have found that Khon Kaen loess is collapsing soil with a severe degree. Khon Khaen loess, as classified as silty sand (SM) or clayey sand (SC), is a windblown deposit with a honeycomb structure. Therefore, the increasing degree of saturation is the cause of decreasing shear strength parameters and increasing settlements of Khon Kaen loess. This study evaluated the bearing capacity of undisturbed Khon Kaen loess between wet and dry conditions by the plate bearing test. Besides, the undrained shear strength parameters (cohesion, c, and friction angle, ϕ) between saturation and dry samples were also examined by the triaxial test under the unconsolidated undrained conditions. The undrained shear strength of undisturbed dry Khon Kaen loess was also investigated from the unconfined compression test. Due to the low degree of saturation, the initial matric suction was observed from soil-water characteristic curves (SWCCs) by the pressure plate test. The plate bearing result showed that the ultimate bearing capacity of Khon Kaen loess, for which the saturation degree is higher than 45%, is about 35 kPa. The ultimate bearing capacity of Khon Kaen loess at 8% of saturation degrees was beyond 1,100 kPa. There is also an excellent relationship between the undrained shear strengths from the triaxial UU-test (c and ϕ) in a residual regime and unconfined compressive strength with a matric suction. Besides, the prediction using Terzaghi's theory and undrained shear strength from the unconfined compression test gives an appropriated ultimate bearing capacity rather than the general bearing capacity equation for soil compressibility.

Keywords: Undisturbed Khon Kaen Loess, Undrained Shear Strength, Ultimate Bearing Capacity, Degree of Saturation, Matric Suction

1. INTRODUCTION

Khon Kaen loess in Thailand is classified as collapsible soil. The structure of Khon Kaen is honeycomb, which is a metastructure. When moisture increases, it causes the loss of the shear strength of the soil and collapses suddenly. Udomchoke [1] found that the shear strength parameters of Khon Kaen loess are decreased with increases in the moisture content as shown in Fig. 1 and 2. Moreover, [1] also found that the collapsing index of Khon Kaen loess illustrated a severe degree of collapsing. Therefore, Khon Kaen loess is called collapsible soil. Therefore, the shear strength testing of Khon Kaen loess was significant.

Khon Kaen Province stands 100 to 200 m above mean sea level on a high plateau, which is called the Khorat plateau. Khon Kaen loess is a windblown deposit that is classified as SM, SC, or SM-SC [2]. Khon Kaen loess is found in the first layer of Khon Kaen soil. The thickness of the Khon Kaen loess is approximately 2 to 10 m [3]. Moreover, the groundwater table is at great depth. Therefore, Khon Kaen loess often experiences an unsaturated condition rather than a saturated condition.

Pientong [4] studied the bearing capacity of Khon Kaen loess by the plate bearing test. The test result showed that the ultimate bearing capacity was 23 and 16 t/m2 at 13.6 and 17% of the moisture content, respectively.

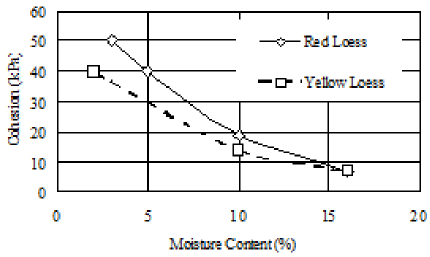

Fig. 1 Variation of the cohesion of Khon Kaen loess with moisture content [1]

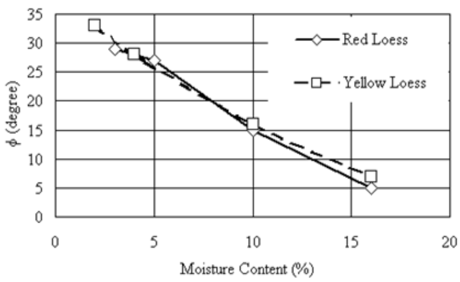

Fig. 2 Variation of the friction angle of Khon Kaen loess with moisture content [1]

Ahmad et al. [5] had a comparison between the ultimate bearing capacity from the plate load test and the prediction of ultimate bearing capacity from the unconfined compressive strength. The study showed a good prediction from the unconfined compressive strength for the ultimate bearing capacity from the plate load test.

According to Terzaghi's bearing capacity theory [6], the bearing capacity of the local shear failure mode for a square foundation can be determined from Eq. (1).

$$q_u = 0.867c'N'_c + qN'_q + 0.4\gamma BN'_\gamma \tag{1}$$

Where
c' = cohesion
q = effective stress at the level of the bottom of the foundation
γ = unit weight of soil
B = width of foundation
N'_c, N'_q, N'_γ = the bearing capacity factors, which are determined from the friction angle, ϕ'.

Moreover, the general bearing capacity equation for soil compressibility [7] can be determined from Eq. (2).

$$q_u = c'N_c F_{cs} F_{cd} F_{cc} + qN_q F_{qs} F_{qd} F_{qc} + 0.5\gamma BN_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma c} \tag{2}$$

Where
N_c, N_q, N_γ = the bearing capacity factors, which are determined from the friction angle, ϕ'
F_{cs}, F_{qs} and $F_{\gamma s}$ = shape factors [8]
F_{cd}, F_{qd} and $F_{\gamma d}$ = depth factors [9]
F_{cc}, F_{qc} and $F_{\gamma c}$ = soil compressibility factors [5]

The objective of this study is to determine the ultimate bearing capacity of collapsing Khon Kaen loess between wet and dry conditions. Moreover, the result from the plate load test was compared to Terzaghi's bearing capacity theory and the general bearing capacity equation by using the shear strength parameter from the triaxial test under the unconsolidated undrained conditions (UU-test) and the unconfined compression test (UC-test).

2. TESTING PROGRAM

The testing program of this study was separated into two parts: the field testing and laboratory testing. The field testing was the plate load test, which was tested on wet and dry conditions. The testing period lasted from September 2018 to March 2019, which was after the rainy season, at three nearby locations. The undisturbed Khon Kaen loess to be used for laboratory testing was extracted as a block sample from the open pit, as shown in Fig. 3, near the location of the plate load test. The block sample was frozen, as shown in Fig. 4, before being trimmed to the required size. The laboratory testing would determine the sample's fundamental and engineering properties. The fundamental properties of soil are type of sample according to [8], specific gravity, chemical analysis, microscopy from a scanning electron microscope (SEM), and soil water characteristic curves (SWCCs). The engineering properties that were investigated are the collapsed index and the undrained shear strength from the triaxial UU-test and the unconfined compression test.

Fig. 3 Sampling block

Fig. 4 Frozen undisturbed sample

3. FUNDAMENTAL PROPERTIES

The Khon Kaen loess in this study was classified as silty sand (SM), according to [2]. The results of the sieve and hydrometer analysis showed that the Khon Kaen loess consisted of 60% sand, 20% silt, and 20% clay [10]. The majority of the Khon Kaen loess was fine sand, as illustrated in Fig. 5. The natural dry density of the Khon Kaen loess was 1.62 t/m^3 and 0.6 of void ratio, which is the loose sand. Atterberg's limit results also presented a liquid limit that was 14.3%, and a plastic limit that was 13.21%. So the plastic index was 1%. The specific gravity was 2.65. The basic properties of Khon Kaen loess were present in Table 1. Moreover, the results from X-Ray spectrometer analyses, which are provided in Table 2, presented the high percentage of Fe. The SEM as presented in Fig. 5 shows that the fine particle is a linkage between a coarse particle.

Table 1 Basic Properties of Khon Kaen loess

Properties	
Liquid limit (LL), %	14.3
Plastic limit (PL), %	13.21
Plasticity index (PI), %	1.09
Specific gravity	2.65
t_o	0.6
Dry density (γ_d), kPa	15.89
Sand (%)	60
Silt (%)	20
Clay (%)	20
USCS classification	SM

Table 2 Chemical analysis

	Weight (%)
C	0.24
O	63.43
Na	0.10
Mg	0.12
Al	6.94
Si	25.45
K	0.30
Ca	0.15
Ti	0.44
Fe	2.83

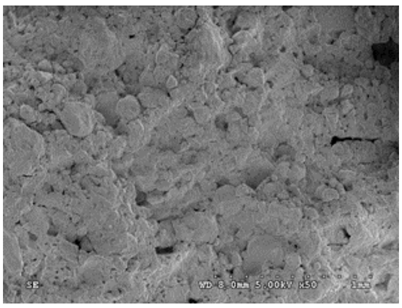

Fig. 5 Soil Particles of Khon Kaen Loess from SEM

The drying soil water characteristics curves (SWCCs) as shown in Fig 6, was determined from the pressure plate method [11]. The initial moisture content and the dry density of the soil sample was 5% and 15.89 kPa, respectively. The test result shows a unimodal of SWCCs. The air entry value is 7.5 kPa, and the residual degree of saturation is 20% [12].

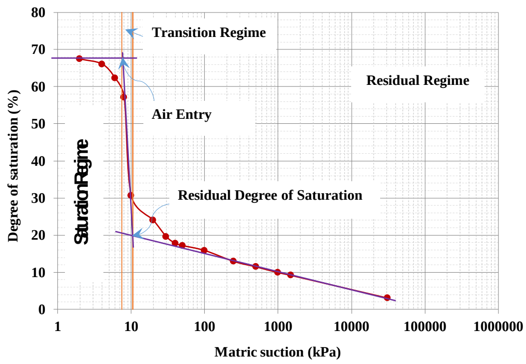

Fig. 6 SWCCs of Undisturbed Khon Kaen Loess

4. COLLAPSE INDEX

The double oedometer method was used to determine the collapse index. The wet sample was soaked before applying the first pressure. The initial and final properties of samples are illustrated in Table 3. The consolidation properties as Cc and Cs and pre-consolidation pressure (σ'_c) are determined from the wet sample. The results are reported in Table 4. The consolidation curves (e-log p) are provided in Figures 7 to 9.

The test result showed that Khon Kaen loess is a normally consolidated sand with a severe degree of collapsing [13].

5. UU-TEST

In this study, the triaxial test under unconsolidated undrained was performed by the multi-stage method according to [14]. The undisturbed soil sample was taken as a block sample from the open pit. Then the block sample was frozen before the trim. The size of the sample was 50 mm in diameter and 100 mm in height, as shown in Fig. 10. The strain rate of this study was 1.00 mm/min. Two conditions were studied as saturation and dry conditions. The samples were saturated before shear for the saturation sample. However, the samples were immediately sheared after the confining pressure was applied to the dry sample. Therefore, the degree of saturation of the dry sample was equal to the field. The test results are shown in Table 5. The matric suction was estimated from SWCCs in Fig. 6 by using the final degree of saturation.

Table 3. Initial and Final Properties of Sample

		BH 1	BH2	BH 3
γ_{dry} (kN/m^3)		1.62	1.62	1.62
w_{ini} (%)		4.4	3.6	3.2
$e_{o,ini}$		0.6	0.6	0.6
w_{fin} (%)	Dry	1.2	1.5	1.3
	Wet	13.6	14.1	13.8
$e_{o,fin}$	Dry	0.3	0.5	0.6
	Wet	0.3	0.2	0.1
$S_{r,fin}$ (%)	Dry	5.4	5.7	4.9
	Wet	56.4	62.4	58.2

Table 4. Result of Consolidation Test

	BH 1	BH2	BH 3
C_c	0.129	0.143	0.13
C_s	0.0068	0.01	0.014
σ'_c (kPa)	35	30	28
OCR	1.43	1.23	1.17
I_e (%)	8.35	17.2	20.14
Degree of Collapse	Moderately Severe	Severe	Severe

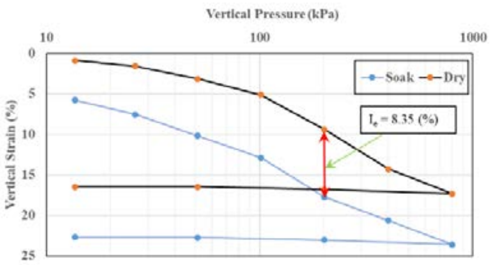

Fig. 7 Consolidation Curve of BH1

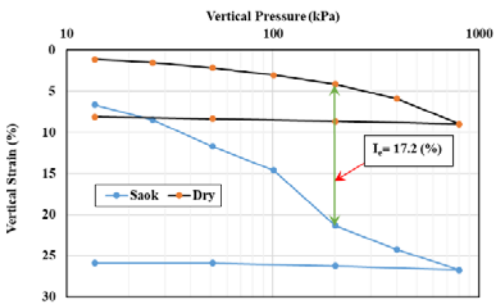

Fig. 8 Consolidation Curve of BH2

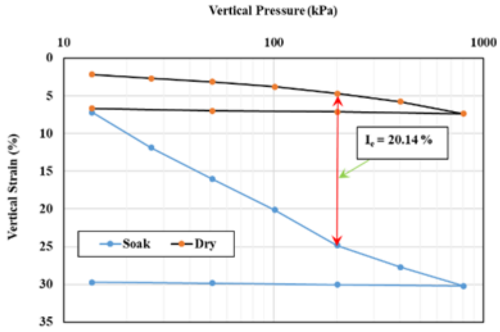

Fig. 9 Consolidation Curve of BH3

Fig. 10 Specimen after trimming for the testing

Table 5. Result of UU- Test

		BH 1	BH2	BH 3
c (kPa)	Dry	47.8	61.5	67.4
	Wet	8	8	8
ϕ (degree)	Dry	26.0	27.0	27.3
	Wet	0	0	0
$S_{r,fin}$ (%)	Dry	19.3	13.9	11.6
	Wet	82.0	81.1	77.0
ψ_m (kPa)	Dry	31.5	185	500
	Wet	-	-	-

The test result shows that the cohesion and friction angle of saturated undisturbed Khon Kaen loess is 8 kPa and 0 degrees, respectively. The cohesion (c) and friction angle (ϕ) of undisturbed Khon Kaen loess in a residual regime are increasing with a matric suction as shown in Fig. 11 and 12, respectively.

6. UC-TEST

Three samples were used to determine the unconfined compressive strength for each borehole. The shearing rate was 1 mm/min. The test results show in Table 6.

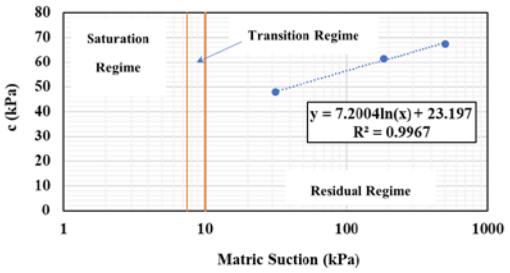

Fig. 11 The relationship between cohesion and matric suction

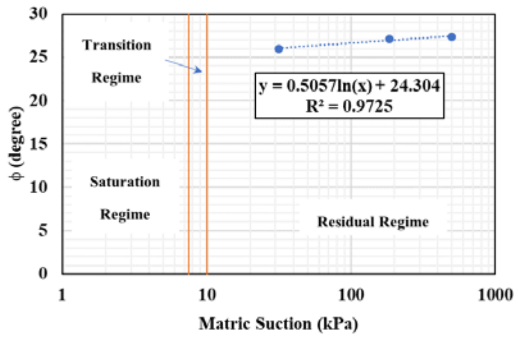

Fig. 12 The relationship between friction angle and matric suction

Table 6 The result of unconfined compressive strength

BH No.	S_r (%)	Matric Suction (kPa)	q_u (kPa)
1	38.12	9	10.99
	30.48	10	12.36
	29.54	10.5	12.39
2	19.66	30	37.31
	19.43	31.5	43.07
	17.81	40	44.99
3	9.03	1500	217.37
	9.96	1000	223.45
	9.95	1000	238.61

The relationship between the unconfined compressive strength and a matric suction as illustrated in Fig 13 shows a good agreement in terms of power relationship.

A comparison of the undrained shear strength in the unconfined compression test with that of the triaxial test found that the undrained shear strength in the triaxial test is greater, as shown in Fig. 14.

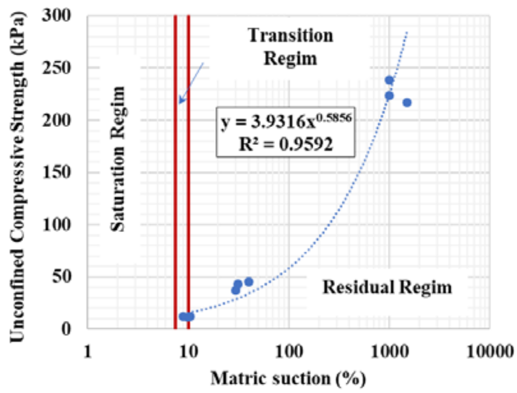

Fig. 13 The relationship between unconfined compressive strength and matric suction

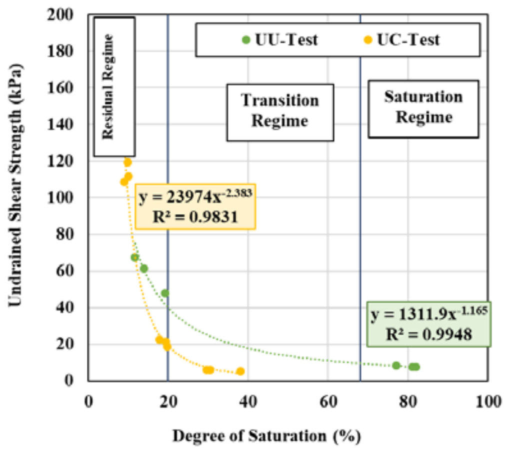

Fig. 14 Comparison of the undrained shear strength

7. PLATE LOAD TEST

The plate size of 0.3 x 0.3 m was installed at a depth of 0.4 m from the ground surface. The 50-ton hydraulic jack capacity was seated over the plate. The nine piles were used as a dead load. Four dial gauges were attached to the reference beam to measure settlement at the corner of the plate. The installation of the apparatus is detailed in Fig 14 [15].

Water was applied in the testing pit for four days to create a wet condition, as shown in Fig. 15. Before the apparatus was installed, water was drained from the testing pit. Both wet and dry conditions were tested in a temperature range of 25ºC to 35ºC.

After loading, the settlement was recorded at 1, 2, 4, 8, 15, 30, and 60 min. The failure was defined as a total settlement of 25 mm or a rate of settlement exceeding 0.2 mm/min.

The test results show that the failure mode of the dry condition is the punching shear, and the failure of the wet condition is the local shear, as shown in Figures 16 to 18. The test result summary is provided in Table 7.

Fig. 14 The installation of the plate bearing test

Fig. 15 Wetting pit (soaking for 4 days)

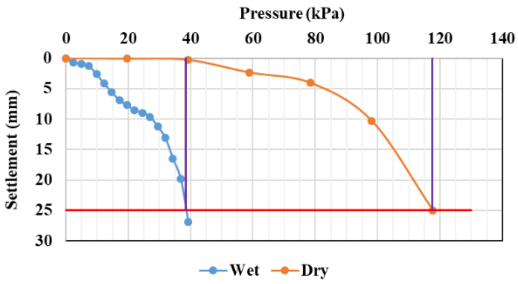

Fig. 16 Plate load test result of BH1

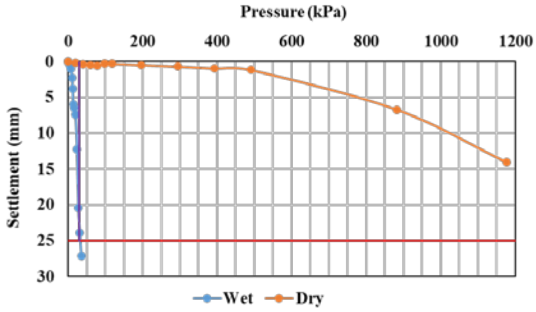

Fig. 17 Plate load test result of BH2

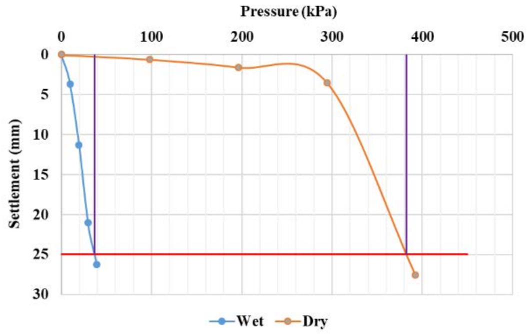

Fig. 17 Plate load test result of BH3

Table 7 Plate load test result

		BH1	BH2	BH3
γ_{dry} (kPa)	Wet	12.85	14.62	14.62
	Dry	15.21	16.38	16.19
$e_{o,ini}$	Wet	1.00	0.78	0.78
	Dry	0.71	0.59	0.61
$w_{,fin}$ (%)	Wet	30.00	14.10	13.85
	Dry	9.76	1.90	3.30
$S_{r,fin}$ (%)	Wet	77.94	47.90	47.05
	Dry	36.43	8.53	14.34
q_{ult} (kPa)	Wet	38.26	33.35	36.3
	Dry	117.72	1177.2*	382.59

Remark: *not failure pressure

The test result shows that the ultimate bearing capacity of the wet Khon Kaen loess was 36 kPa, and the ultimate bearing capacity increased with the decreasing degree of saturation. There is a good relationship between the ultimate bearing capacity and degree of saturation, as presented in Fig.18.

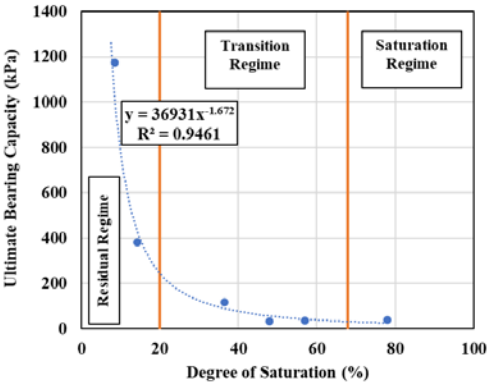

Fig. 18 The relationship between ultimate bearing capacity and degree of saturation

According to Terzaghi's theory and [5], the ultimate bearing capacity can be estimated from the shear strength parameters (undrained shear strength and ϕ) as shown in Eq (1) and (2). In this study, the cohesion (c), friction angle (ϕ), and the unconfined compressive strength (q_u) in the field can be determined from Fig. 11, 12, and 13, respectively. Under the matric suction, (ψ_m) was determined from SWCCs as provided in Fig. 6 based on the degree of saturation. The prediction of the c-value, ϕ-value, and q_u in the field is presented in Table 8. Since the soil samples of the triaxial test were investigated on the saturation and residual regimes, therefore, the prediction of cohesion (c) and the friction angle (ϕ) can be performed on the saturation and residual regimes only. Nevertheless, the unconfined compressive strength was estimated on the transition and residual regimes only because the saturation sample cannot be investigated on the unconfined compression test.

Table 8. The c-value, ϕ-value, and q_u in the field

S_r (%)	ψ_m (kPa)	c (kPa)	ϕ (deg)	q_u (kPa)
77.94	-	8	0	-
47.90	8.5	-	-	6.88
47.05	8.6	-	-	6.93
36.43	9.1	-	-	7.16
14.34	160	59.74	27	38.39
8.53	2000	77.93	28	168.51

According to Terzaghi's theory, the prediction of ultimate bearing capacity by using undrained shear strength parameters from the triaxial UU-test and the unconfined compression test is slightly higher than the result of the plate load test as present in Fig 19. However, the ultimate bearing capacity that predicted from the unconfined compressive strength is higher than the result of the plate load test by about 1.4 times. Meanwhile, the ultimate bearing capacity predicted by using the undrained shear strength from the triaxial UU-test is higher than the result of the plate load test by about 1.65 times.

The prediction of ultimate bearing capacity by using the general bearing capacity equation for soil compressibility [5] shows that the undrained shear strength from the triaxial UU-test and unconfined compression test give a higher value of ultimate bearing capacity than the plate load test result. The ultimate bearing capacity that predicted from the unconfined compressive strength is higher than the result of the plate load test about two times as present in Fig 20. However, the ultimate bearing capacity that is predicted from the results of the triaxial UU-test is higher than the result of the plate load test by about four times as present in Fig 20.

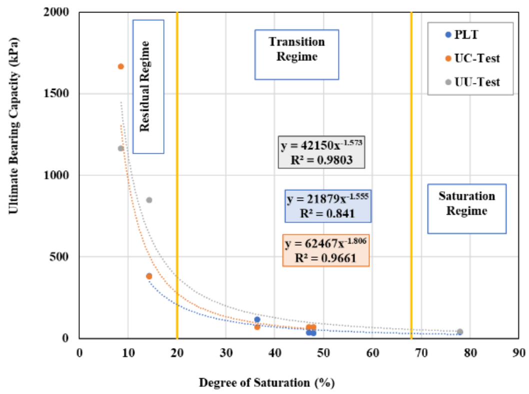

Fig. 19 The comparison of ultimate bearing capacity by Terzaghi's theory

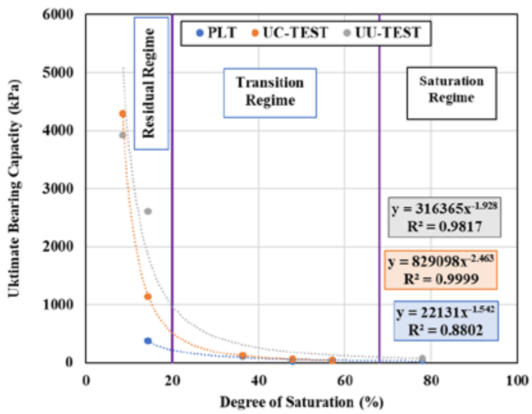

Fig. 20 The comparison of ultimate bearing capacity by general bearing capacity

The prediction of ultimate bearing capacity by using Terzaghi's theory is close to the plate load test result rather than a general bearing capacity equation. Moreover, the prediction that calculates from the unconfined compressive strength is a good fit with the plate load test result rather than the undrained shear strength parameters from triaxial UU-Test.

8. CONCLUSIONS

Khon Kaen loess in this research is classified as silty sand (SM) with a severe degree of collapsing. The binder between sand particles is fine-grained soil (silt and clay). Moreover, Khon Kaen red loess has a high percentage of Fe. In terms of the engineering properties, this research found a good relationship between the ultimate plate bearing capacity with a degree of saturation. The ultimate bearing capacity of wet Khon Kaen loess is about 36 kPa. In the dry season (low degree of saturation), the ultimate bearing capacity is very high about 40 times of wet condition. There is also an excellent relationship between the undrained shear strengths from the triaxial UU-test (c and ϕ) in a residual regime and unconfined compressive strength with a matric suction. Besides the prediction by using Terzaghi's theory and undrained shear strength from the unconfined compression tests give an appropriated ultimate bearing capacity rather than the general bearing capacity equation for soil compressibility.

9. ACKNOWLEDGMENTS

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