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THE SETTLEMENT BEHAVIOR OF ISOLATED FOUNDATION ON KHON KAEN LOESS

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ABSTRACT: This research presents the settlement behavior of isolated foundations on Khon Kaen loess, classified as collapsible soil. The pressure sequence was applied to the center of the cast foundation, in which the maximum applied pressure was 200 kPa. The test was conducted in the field. The effect of the foundation's size and depth on the settlement were investigated. Three foundation sizes, 1.0x1.0, 1.2x1.2, and 1.5x1.5 meters, were installed at a 1.0 meter depth. Moreover, 1.0x1.0 m foundation sizes were installed at 0.5, 1.0, and 1.5 meter depths. The saturation degree's effect was also studied by testing in the rainy and the summer seasons. The initial and final saturation degree was used to classify the soil condition using the SWCC obtained from laboratory tests.The study found that the foundation size affects the foundation settlement, as the larger foundation showed large settlement. Conversely, this study encountered no foundation depth effect on the settlement. However, the Khon Kaen loess condition affected the settlement more. The foundation on the wet Khon Kaen loess presented a larger settlement than it did on the dry Khon Kaen loess. Therefore, the design of an isolated foundation on Khon Kaen loess must consider the foundation settlement on wet Khon Kaen loess. Moreover, this study had also soaked the foundation at 200 kPa to apply pressure for three hours. The test showed that the settlement increased by approximately 1 to 1.5 times.

Keywords: Isolated Foundation, Khon Kaen Loess, Settlement, Collapsible Soil, Soil Water Characteristic Curve

1. INTRODUCTION

This research is to simulate the isolated foundations used in various buildings on Khon Kaen loess. Khon Kaen loess is a wind-blown deposit that is covered in the Korat plateau. The structure of this soil is a honeycomb structure, which has a high porosity. The iron-oxide (Fe_2O_3), clay, and silt bind the sand particles. Khon Kaen loess color is red because of iron oxide (Fe_2O_3). Moreover, Khon Kaen loess is classified as collapsible soil. In a dry state, this soil can be subjected to a large load. The increase in moisture content is the cause of increased settlement.

Udomchoke (1991) [1] explained that Khon Kaen loess, a wind-blown deposit, was classified as collapsible soil with a severe degree of collapsing. This type of soil is found in the arid area to the semi-arid area. Soils in this climate are mostly unsaturated because the underground water level is quite deep. Besides, the soil's moisture content in the field is about 3–5% and 10–12% in the summer and rainy seasons, respectively.

Ahmad et al. (2009) [2] presents the estimation load capacity of stiff brown silty clay soil at Erbil governorate—north of Iraq from the field test and the laboratory. Then, the load-carrying capacity of soil from the field test was compared to the laboratory tests. The field test was investigated in 3 different areas—a circular steel sheet with an area of 1,000 square centimeters seated on 2.5 meters depth. The field's soil sample was determined the shear strength from the unconfined compression test—the results from field and laboratory tests, as shown in Table 1. The load-carrying capacity, which was obtained from the laboratory, was matched with the field tests. Hence, the foundation's load capacity can be predicted from the shear strength parameter obtained from the laboratory to save both cost and time.

Table 1 Result from field and laboratory tests [2]

Result	BH		
	1	2	3
Field Test q_{all} (kPa)	302.6	317.3	340.5
Laboratory Test (kPa)	276	320	401

Briaud and Gibbens (1999) [3] used five concrete footings sized: 1x1 m, 1.5x1.5 m, 2.5x2.5 m, 3x3 m (South), and 3x3 m (North), all at a thickness of 1.5 m., and embedded 0.75 m in silty sand with a relatively constant profile of SPT blow count equal to 20 blows per foot. The water table has a depth of 4.9 m. The pressure versus settlement curves obtained from the load tests are shown in Fig. 1. The pressure under the footing was normalized by the average limit pressure of pre-boring pressure-meter tests performed within the depth of influence of the footing next to the footing. The settlement was normalized by the footing width. Fig. 2 illustrated that the normalization brings the five normalized curves into a narrow band. Therefore, the normalized curves are independent of footing width and can be represented by a unique curve.

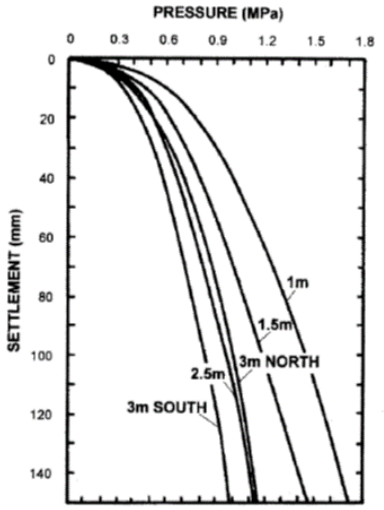

Fig.1 The pressure versus settlement curves [3]

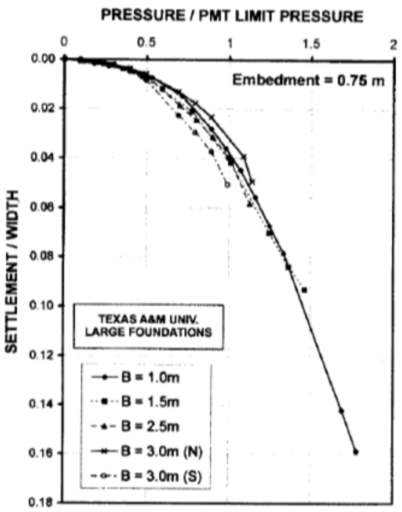

Fig.2 The pressure/PMT versus settlement/width curves [3]

Sanjeev et al. (2013) [4] study the bearing capacity and settlement characteristics of footings. This research aimed to predict the ultimate bearing capacity of the granular soil from physical modeling. Three sizes of square plates were used for testing: 200x200, 250x250, and 300x300 mm. The first experiment, all three plates were seated on the surface of homogenous sand 25 mm thick. The second experiment, these plates were seated on the surface of the gravel 25 mm thick, which was above the sand layer. Moreover, these plates were embedded in the homogenous gravel at a depth of 0.5B, B, and 1.5B. The study found that the ultimate bearing capacity increased with the plate size and gravel thickness. However, the settlement of the plate decreased with the increasing plate size and gravel thickness. The depth of the plate does not affect bearing capacity.

Kim et al. (2017) [5] investigated the influence of rainwater infiltration on shallow foundations located in unsaturated areas with low groundwater levels. The experimental data from the field load test was compared to the numerical analysis. There was good agreement of load capacity and subsidence between the numerical and field-testing methods. The parameterized study results showed that rainfall density is essential in shallow foundations' subsidence behavior. The changing moisture content of unsaturated soil has also affected subsidence values. The groundwater levels are affected by the matric suction between soil grains. Moreover, the load capacity of the soil was reduced with rising rainfall. Figures 3 and 4 show the relationship between settlement and stress occurring with rainfall under two types of soil conditions.

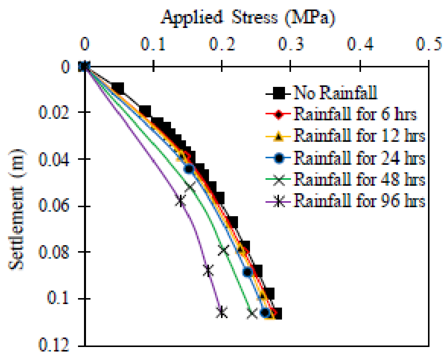

Fig.3 Footing 5x5 m. settlement and stress occurring with rainfall for soil type A [5]

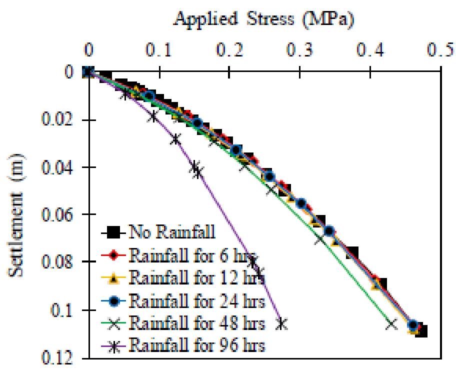

Fig.4 Footing 5x5 m. settlement and stress occurring with rainfall for soil type B [5]

Prommin and Nuntasarn (2019) [6] present that Khon Kaen loess shows collapsing soil at a severe degree. Khon Khaen loess, 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 settlement of Khon Kaen loess. This study evaluated the bearing capacity of undisturbed Khon Kaen loess between wet and dry conditions using a plate bearing test. Moreover, the undrained shear strength parameters (cohesion, c, and friction angle, ϕ) between saturated and dry samples were also examined using a triaxial test under unconsolidated undrained conditions. The undrained shear strength of undisturbed dry Khon Kaen loess was also investigated using an unconfined compression test. The plate-bearing result showed that Khon Kaen loess's ultimate bearing capacity, for which the saturation degree is higher than 45% (or Khon Kaen loess in the saturation regime), is about 35 kPa. Meanwhile, Khon Kaen loess's ultimate bearing capacity at 8% saturation (or Khon Kaen loess in residual regime) was beyond 1,100 kPa. There is an excellent relationship between the undrained shear strengths from the triaxial UU-test (c and ϕ) in a residual regime with matric suction. Beside the relationship between the unconfined compressive strength ϕ) in a residual regime and matric suction is also excellent. Moreover, 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, as shown in Figure 5.

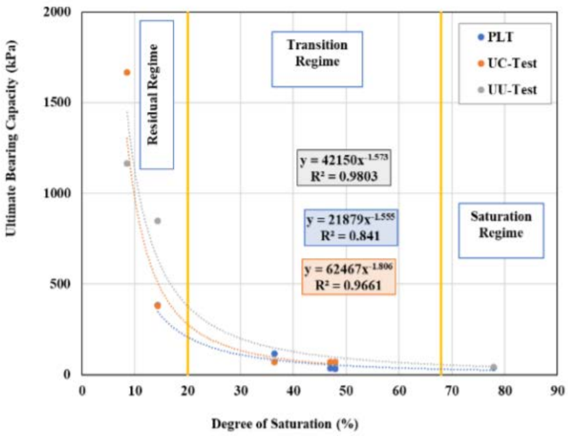

Fig. 5 The comparison of ultimate bearing capacity by Terzaghi's theory [6]

Changjutturas and Punrattanasin (2007) [7] studied the bearing capacity of shallow foundations on loess. The study was performed only in the laboratory using the 1 g physical modeling test. The equipment was newly designed and developed to observe the soil failure type after performing the loading test. The load-settlement relationship can indicate the soil's bearing capacity. In this study, the Khon Kaen loess was selected as the first project for this new equipment. The undisturbed samples were excavated from the field and tested under natural water content and wet conditions. The results show that water addition can dramatically reduce loess bearing capacity, and the image recorded during the test shows the soil deformation shape under the shallow footing. The study also experimented with the treated loess by adding cement to the soil. The results show that cement can dramatically increase soil's bearing capacity, as shown in Figure 6.

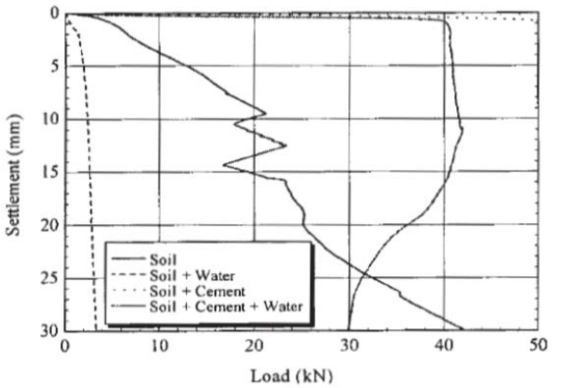

Fig. 6 The load – settlement curve of all test results [7]

Consoli et al. (1998) [8] studied the interpretation of plate load tests on residual soil. The round steel plates ranging in size from 0.30 to 0.60 m and square concrete foundations from 0.40 to 1.00 m were used to determine the load capacity of homogeneous soil. This research presents the comparison between subsidence behavior and load capacity of the foundation. The test result showed no size effect on the settlement and load capacity of the foundation. Moreover, the settlement–load capacity relationship was in accordance with the elastic and elastoplastic theory.

Cerato and Luteneger (2007) [9] presented the scale effects on the bearing capacity of shallow foundation on coarse-grained soils. A rectangular and a circular foundation model, ranging in width from 0.025 to 0.914 m, was installed on the compacted sand layer. Moreover, this study compared the foundation bearing capacity of the physical model and field in the past. The physical model of this research is shown in Figure 7. The test found that the bearing capacity from the physical model was higher than the field. Therefore, the soil parameters from the physical model should be reduced.

The scope of this research is to study the isolate footing, which was subjected to a centric vertical load, on Khon Kaen loess between wet and dry conditions. Moreover, the objective of this study is:

1. To study the effect of foundation size on the settlement behavior of isolated foundations on Khon Kaen loess.
2. To study the effect of foundation depth on the settlement behavior of isolated foundations on Khon Kaen loess.
3. To study the effect of saturation degree on the settlement behavior of isolated foundations on Khon Kaen loess.

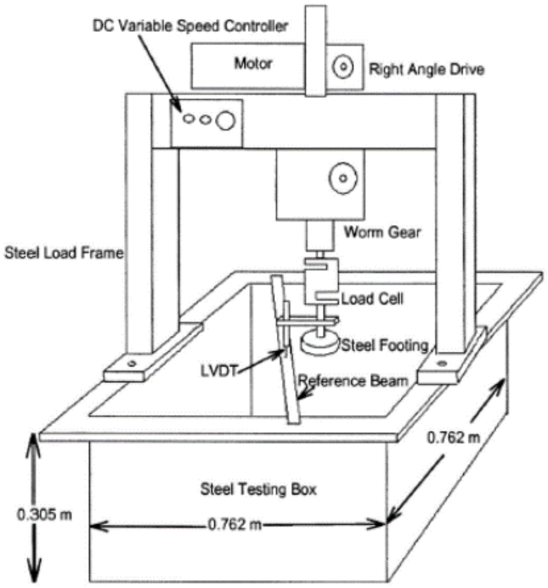

Fig. 7 Test equipment diagram, foundation size model used for testing [9]

2. METHODOLOGY

As described in the prior section regarding the research objective and scope, three reinforced concrete square foundation sizes: 1.0x1.0x0.25, 1.2x1.2x0.25, and 1.5x1.5x0.25 m shown in Fig. 8 were placed on Khon Kaen loess at a depth of 1.0 m. Moreover, a reinforced concrete foundation, sized 1.0x1.0 m, was observed for bearing capacity at depths of 0.5, 1.0, and 1.5 m. Four LVDTs were installed at the foundation corner to measure the settlement. The 50-ton hydraulic jack was set up at the center of the footing, and the applied load was read via load column, as illustrated in Fig. 9. Thirty piles were used as the counter load, as shown in Fig. 10.

This study investigated the foundation's behavior in dry and wet conditions. The load increment in this study was 20 kPa, and the load was maintained for 60 min. The maximum applied load was 200 kPa. After loading, the settlement was recorded at 1, 2, 4, 8, 15, 30, and 60 min each cycle of the load [10]. The failure was defined as a total settlement of 25 mm [11]. Although the foundation reached the failure, a pressure of 200 kPa was still applied. After loading to 200 kPa, the foundation was soaked for three hours as presented in Fig 11. The settlements of the soaked foundation were observed at 0, 60, 90, 120, 150, and 180 min with constant 200 kPa pressure. Moreover, the moisture content near the footing was determined at the beginning of testing, before soaking, and at the end of testing.

Fig. 8 Isolated footing.

Fig. 9 The installation of instrument.

Fig. 10 Reaction beam and load pile transfer.

Fig. 11 Soak condition

Undisturbed samples were used to determine the soil-water characteristic curve (SWCC) by pressure plate. The collapse potential and collapse index of Khon Kaen loess was investigated by double oedometer test. Khon Kaen loess's structure and mineral composite were examined with the scanning electron microscope (SEM) and energy dispersive X-ray spectrometer (EDX).

Before the trench for testing was excavated, the hand auger and standard penetration tests were performed to investigate the soil profile.

3. EXPERIMENT RESULTS

The basic properties of Khon Kaen loess are shown in Table 2. According to the hydrometer and sieve analysis, Khon Kaen loess was classified as SM [12]. Besides, Khon Kaen is defined as severely collapsible soil according to [13], as shown in Table 2 and Fig 12.

Table 2 Basic Properties of Khon Kaen loess

Properties	
Liquid limit (LL), %	16
Plastic limit (PL), %	13.4
Plasticity index (PI), %	2.6
Specific gravity (G_s)	2.66
Void ratio (e)	0.8–0.7
Dry density (γ_d), kPa	15.65
Sand (%)	60.00
Silt (%)	19.90
Clay (%)	21.60
USCS classification	SM
Collapse index (%)	27.37
Degree of collapse	Severe

The boring log in Fig 13 showed that Khon Kaen loess was 4.5 m thick with laterite underneath. SPT-N values were high because this test was performed in the summer. Also, the groundwater was not present.

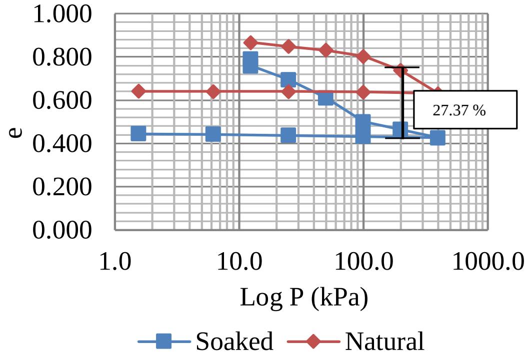

Fig. 12 Double oedometer test

According to SEM's result, as shown in Fig. 14, the structure of Khon Kaen loess is loose, with various sizes of the void. Moreover, Fe was found in Khon Kaen loess, as shown in Table 3 and Fig. 15

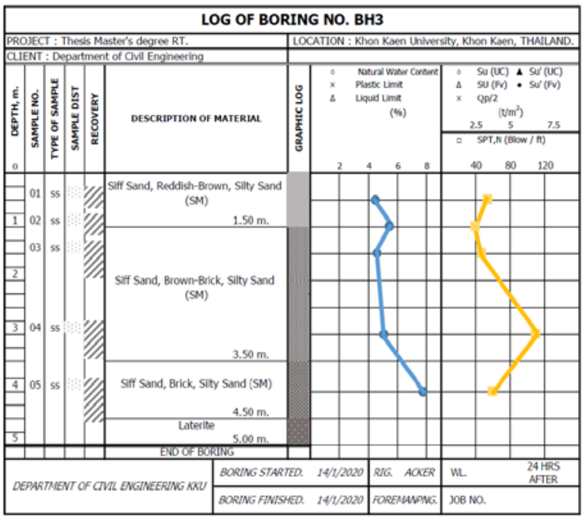

Fig. 13 Boring log

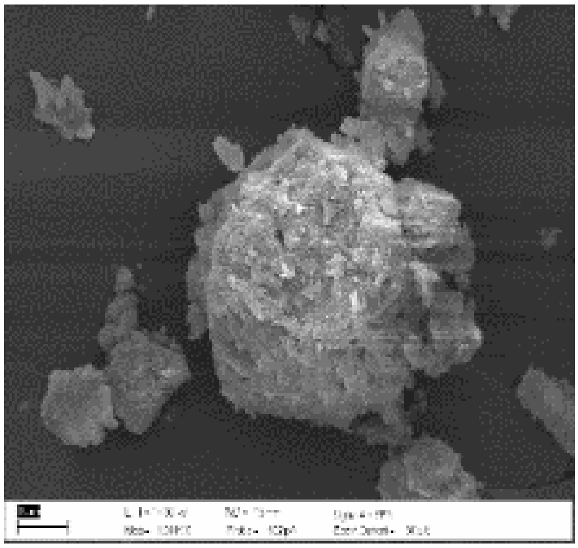

Fig. 14a Structure of Khon Kaen loess by SEM Test

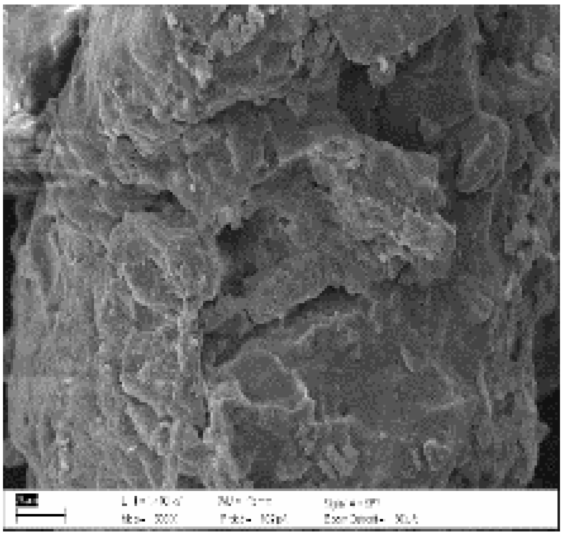

Fig. 14b Structure of Khon Kaen loess by SEM

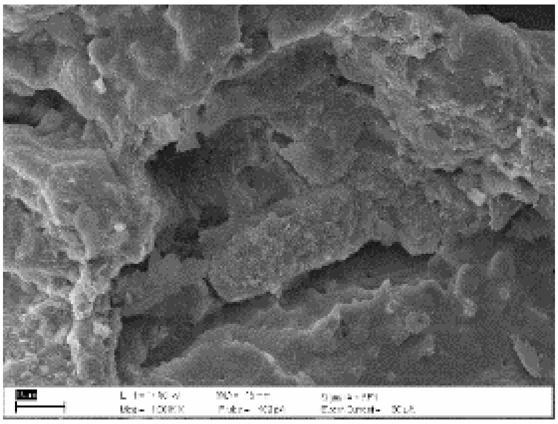

Fig. 14c Structure of Khon Kaen loess by SEM

Table 3 Mineral in Khon Kaen loess

Mineral	Weight (%)	Atomic (%)
O	24.73	57.61
Al	7.71	10.64
Si	15.61	20.71
Fe	2.54	1.69

3.1 Soil Water Characteristic Curve

The soil water characteristic curve (SWCC) [14] of Khon Kaen loess (see Fig. 16) showed that the air entry value is 4.8 kPa according to. Moreover, the saturation regime was classified as a matric suction range of 0–4.8 kPa, or a degree of saturation higher than 80. The transition regime is defined as a matric suction range of 4.8–14.0 kPa, or a saturation degree between 47% to 81%. Finally, Khon Kaen loess with a matric suction higher than 14 kPa, or degree of saturation less than 45%, was in the residual regime.

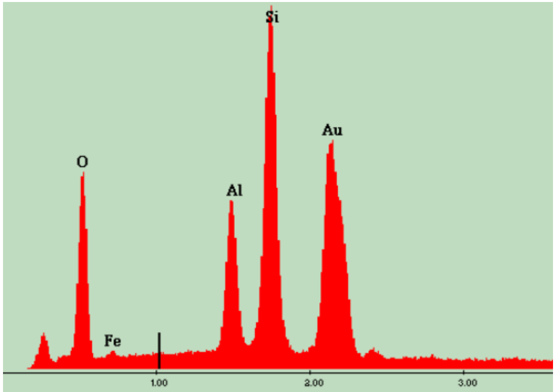

Fig. 15 Result of EDX method

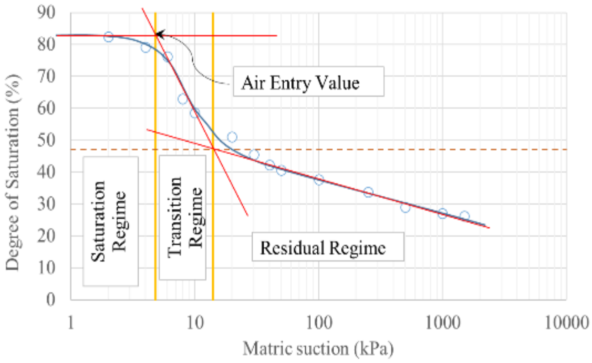

Fig. 16 SWCC of Khon Kaen loess

3.2 Field Result

The test results of the field's foundation were shown in Table 4. The tests were performed in three sizes and three depths in wet and dry conditions. The degree of saturation was calculated from the moisture content obtained from the initial, before soak, and the final. The final degree of saturation of some test (after soaking for 3 hours) are higher than 100% because the soil sampling near a footing, which is in the mud condition. Moreover, the foundation size 1.0x1.0 at depth 0.5 and 1.5 m did not failed after soaking for 3 hours. However, the settlement of these foundations increase 3 times. The condition of Khon Kaen loess, wet or dry, was defined in SWCC in Fig. 16, based on the initial degree of saturation. Khon Kaen loess on the transition regime was defined as wet, and Khon Kaen loess on the residual regime was defined as dry.

The rate of the settlement was observed regarding loading and soaking. The settlement rate in the soaked condition was observed within three hours. As presented in Table 4, the settlement rate during loading on wet soil is higher than on dry soil. However, the soaking settlement rate under the wet condition is slower than under the dry condition. The foundation settlement on wet Khon Kaen loess is more remarkable than on its dry state.

Table 4 Results of foundation testing in the field

Depth (m)	Foundation (m^2)	Condition	Pressure at 200 kPa			Soak		
			$\%S_r$	Settlement (mm)	Rate of Settlement (mm/min)	$\%S_r$	Settlement (mm)	Rate of Settlement (mm/min)
1.00	1.0 x 1.0	Dry	38.70	7.0*	0.012	97.25	21.7*	0.123
1.00	1.2 x 1.2	Dry	6.93	61.4	0.102	79.48	93.6	0.179
1.00	1.5 x 1.5	Dry	50.50	32.6	0.054	82.14	48.3	0.087
0.50	1.0 x 1.0	Dry	6.60	2.4*	0.004	120.20	7.0*	0.026
1.50	1.0 x 1.0	Dry	20.40	9.1*	0.015	103.60	62.0	0.294
1.00	1.0 x 1.0	Wet	58.00	54.8	0.091		No Soak	
1.00	1.2 x 1.2	Wet	69.94	109.0	0.182	123.99	121.7	0.071
1.00	1.5 x 1.5	Wet	85.09	131.7	0.220	108.62	151.2	0.108
0.50	1.0 x 1.0	Wet	53.30	413.9	0.690		No Soak	
1.50	1.0 x 1.0	Wet	42.70	73.3	0.122	85.6	102.4	0.162

* Not Failure @ 25 mm

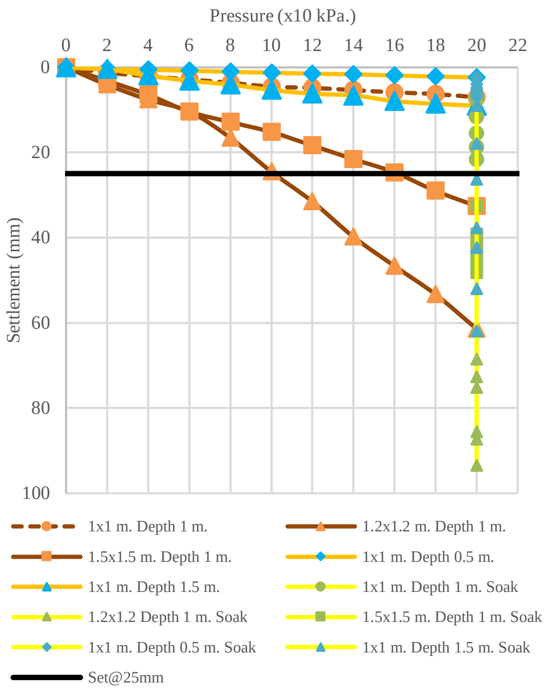

Fig. 17 Pressure–settlement curve; dry condition

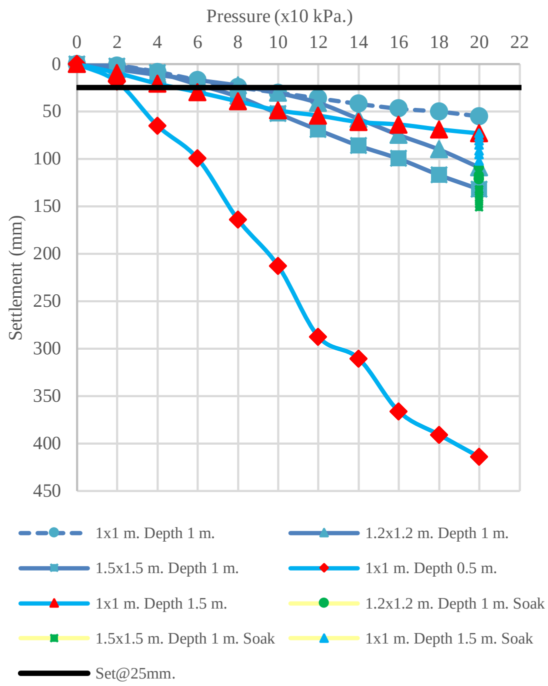

Fig. 19 Pressure–settlement curve; wet condition

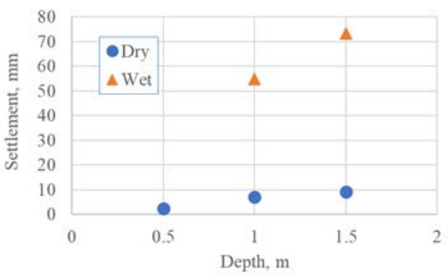

Fig. 18 The relationship between foundation depth and settlement

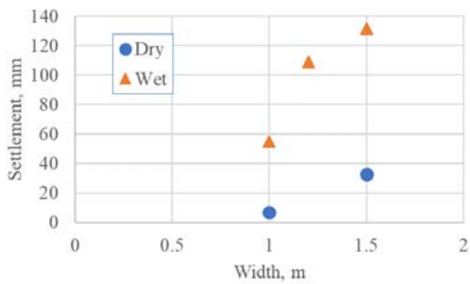

Fig. 20 The relationship between foundation width and settlement

The relationships between pressures and foundation settlements on dry and wet Khon Kaen loess are presented in Fig. 17 and 19, respectively. Figure 17 shows that the foundation size of 1.0x1.0 m at dry condition did not fail because the failure is defined as a 25 mm settlement. Therefore the maximum applied pressure of foundation size 1.0x1.0 m is 200 kPa. The 1.2x1.2m and 1.5x1.5m foundation sizes failed at 100 and 160 kPa, respectively. On the other hand, all foundations on wet Khon Kaen loess failed at different pressures, as presented in Fig. 19.

The settlement of a foundation on dry and wet Khon Kaen loess depends on the foundation's depth and width as presented in Fig. 18 and 20, respectively. According to Table 4, the result of foundation 1.0x1.0 m size at depth 0.5 m under wet condition and 1.2x12 at depth 1.0 m under dry condition are uncommon. Since the result of these foundations was omit. Massive and deep foundations tend to have higher settlement rates than smaller and shallow foundations. The settlement rate increased sharply with the size and depth of foundation on wet Khon Kaen loess. Meanwhile, the settlement rate slowly increased according to the size and depth of the foundation on wet Khon Kaen loess.

The initial degree of saturation was plotted with the settlement at 200 kPa pressure, as shown in Fig. 21, presenting a good relationship exponentially. The different settlement rates between wet and dry soils were plotted versus the applied pressure, as shown in Fig. 22. It seems that the settlement rate of foundations varied with the depth or width of the foundation. The relationships between the different degrees of saturation and settlement rates, as illustrated in Fig. 23, also show a good agreement exponentially.

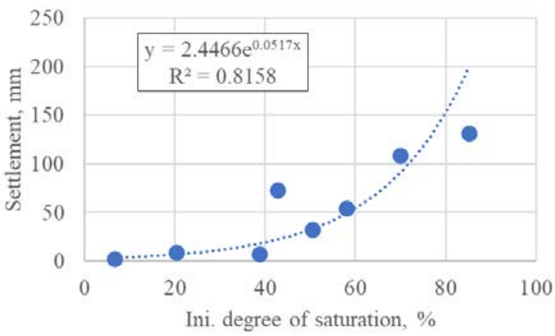

Fig. 21 The relationship between initial degree of saturation and settlement

4. DISCUSSION

The test result showed that Khon Kaen loess is loose sand with various void sizes.

The binders between sand particles were silt, clay, and Fe mineral. These binders were washed out when wet, which caused collapsing. In this research, three different sizes and depths of the foundation were studied in a transition regime and residual regime.

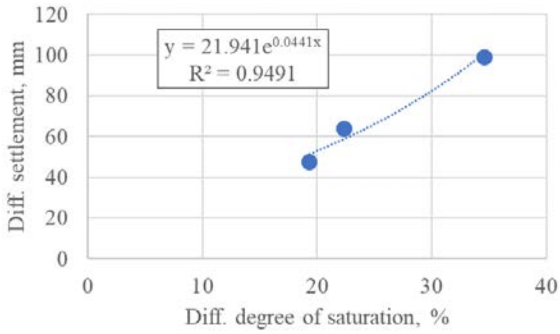

Fig. 22 The relationship between differential degree of saturation and differential settlement

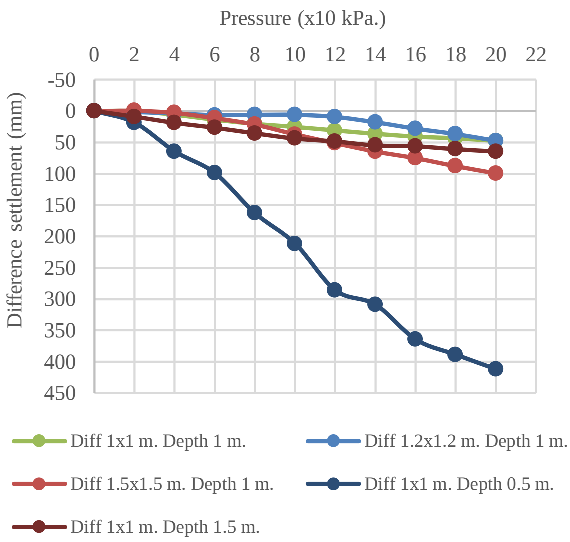

Fig. 23 Difference Settlement Foundation Testing

The field test showed that the foundation settlement on wet or transition regime soil was higher than that of the foundation on dry or residual regime soil by 4 to 8 times. Under a soaked condition for three hours, the foundation's settlement increased by about 0.1 to 0.4 times for wet soil. Moreover, the foundation's settlement on wet soil increased by 0.5 to 6.0 times, depending on the foundation's size and depth.

Fig. 24 shows the differential settlement between, before, and after soaking for 3 hours was slightly and dramatically increased with the foundation's depth on wet and dry soil, respectively. However, the differential settlement was decreased with the foundation's width, as illustrated in Fig. 25.

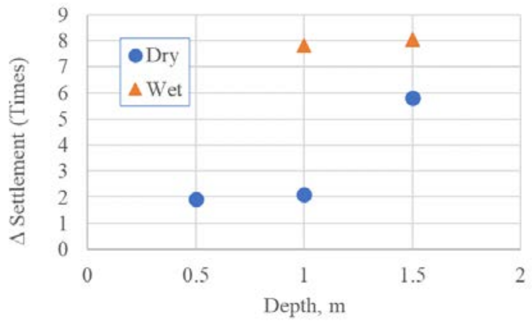

Fig. 24 The relationship between foundation depth and differential settlement after soaking

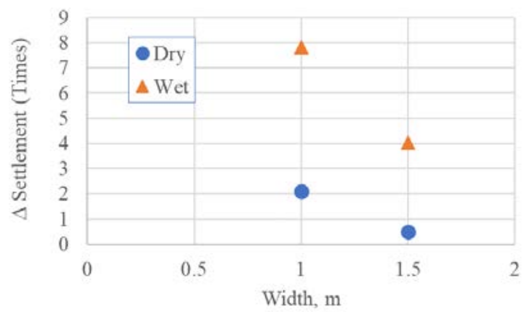

Fig. 25 The relationship between foundation width and differential settlement after soaking

5. CONCLUSIONS

This research studied subsidence behavior from the field testing of real foundations, specifying different sizes and depths. This research found that massive and deep foundations tend to have higher settlements than small and shallow foundations. Moreover, there is a good relationship between the initial degree of saturation and the foundation's settlement. Therefore, it can be concluded that the foundation settlement on collapsing soil depends on size, depth of foundation, and the saturation degree of the soil. Wet soil achieves a higher settlement than dry soil. Additionally, foundation settlement increased in the soaked condition. However, this research was investigated in the field, where parameters cannot be controlled, such as the degree of saturation and the soil profile variable. Further research is needed.

6. ACKNOWLEDGMENTS

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