Material Science and Engineering Technology VIII

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Material Science and Engineering Technology VIII

Selected peer-reviewed papers from
8th International Conference on Material Science and Engineering Technology (ICMSET 2019)

Edited by
Prof. Ramesh K. Agarwal

9 783035 716061

ISBN: 978-3-0357-1606-1

Materials Science Forum Vol. 998

Electronically available at **www.scientific.net**

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Materials Science Forum

ISSN 0255-5476

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ISSN print 0255-5476 ISSN web 1662-9752

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The Effect of Heat Induction on Shear Strength of Soft Soil in Radial Zone

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Keywords: Soft clay, radial zone, heat induction, shear strength, temperature.

Abstract. The main problem in infrastructure development at the soft clay was its bearing capacity therefore it needs to be improved. In this research, the improvement method was carried out by modeling in small scale of preloading and heat induction combination. Location of soft clay sampling was in Takalar, Indonesia. The purpose of this study was to investigate the change of the shear strength of soft soil corresponding with heat induction at the radial zone. The shear strength was obtained by vane shear test and compressive strength from unconfined compressive test (UCT). The heat applied ranging from 100^o C, 200^o C, 300^o C, and 400^o C with static preloading load 0.20 kg/cm^2. The strengths of the soil in radial zones have been tested at R0, R1, and R2. At lowest temperature 100° at R0 the compressive strength was 0.203 kg/cm², at highest temperature 400° at R0 the compressive strength 0.467 kg/cm², there was a significant increasing of compressive strength value with the change of temperature. At the highest temperature 400^0 the shear strength from vane shear tests resulting at R0 0.240 kg/cm^2, R1 of 0.128 kg/cm^2, R2 of 0.077 kg/cm^2. At the lowest temperature of 100^o C shows R0 at 0.116 kg/cm^2, R1 at 0.070 kg/cm^2, R3 of 0.046 kg/cm^2. The results show a tendency of declining strength value as the soil farther away from center of heat induction. The experimental result from this model produces strength that can be used as a parameter of the foundation model on soft soil.

Introduction

In Indonesia about 10 % or 20 million hectares land areas was covered by soft clays, so it became necessary to deal with its soil improvement. The available improvement methods were preloading, prefabricated vertical drain (PVD), electro-osmosis, vacuum consolidation, electro-heating. In this research, the improvement method was carried out by modeling in small scale of combination of preloading and heat induction.

Preloading can accelerate the proccess of consolidation and settlement on soft clay. In this case, the static load was applied to give uniform condition for all soil tested. Heat was inducted by stick copper with the help of electric power. When clayey soil inducted by the heat, according to Francois [1] it will have several disturbances, such as significant deformation, increase in pore water pressure, etc. Also, one important aspect upon heating in soil was explained by Sridharan and Venkatappa Rao [2], Morgenstern and Balasubramonian [3], and Mitchell [4] that temperature changes have significant effect on the physico-chemical forces between the clay particles which control the mechanical behavior of the saturated fine-grained soil (soft clays). Therefore, it is evident that changes in the temperature may alter the shear strength behavior and induce volumetric strain.

Testing Program

Location of Soft Clay Samples. The soft clay for this research were obtained from Takalar, Indonesia. The location is shown in Fig. 1 below. The test was carried out in Hasanuddin University's geotechnical and environmental research laboratory.

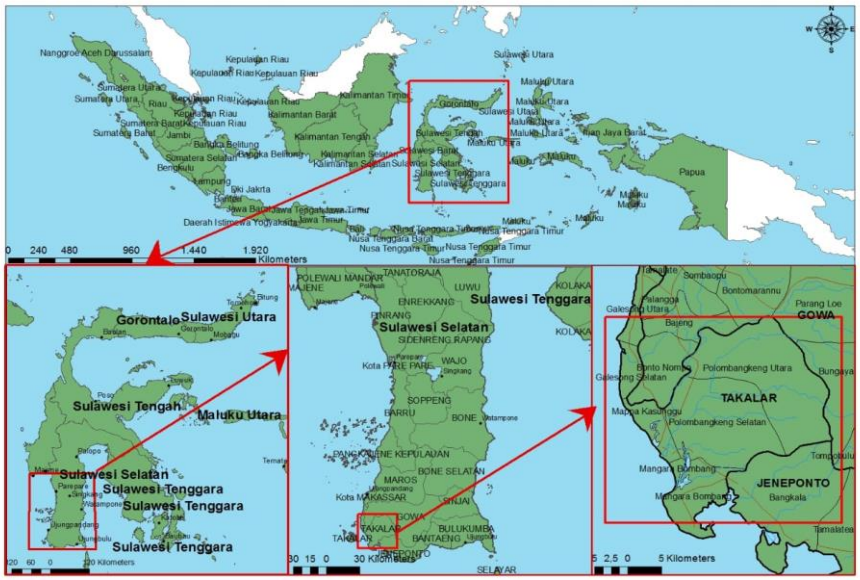

Fig. 1 Soft clay location

Preloading. The soil was transferred from the sampling site to the laboratory for further testing. The first preparation was reconstitution of the soil for resembling the natural condition of the sampling site. Then preloading was carried out with load 0.20 kg/cm^2, it was illutrated in Figure 2.

Unconfined Compressive Test (UCT). Unconfined compressive strength tests of cohesive soils can be performed on intact, remolded or reconstituted soil specimens but in this case the reconstuted specimens were tested. The compressive strength of soil caan be calculated by equation below:

$$\sigma_c = \frac{P}{A} \quad (1)$$

Where, σ_c = The compressive stress (kg/cm²)
P = Given applied load (kg/cm²)
A = Corresponding average cross-sectional area (cm²)

The peak or the maximum value of σ_c report as q_u (kg/cm²) where described as the unconfined compressive strength of the soil.

Vane Shear Test. The vane shear test is a method of measuring the undrained shear strength of a cohesive soil. The equipment consists of a straight rod with four vanes on one end, arranged in a cruciform pattern, and a combined handle/torque gauge. The vane shear test can be done both in the laboratory and field. The laboratory vane shear tests were carried out with undisturbed and undrained condition to resemble the field conditions. The expression to calculate the shear strength using equation by Merrifield [5] below:

$$Su = \frac{T}{\pi(\frac{HD^2}{2}+\frac{D^3}{6})} \quad (2)$$

Where, Su = The shear strength (kg/cm^2)
T = Torque (kg-cm)
D = Diameter of vane (cm)
H = Height of vane (cm)

Heat Induction Test Model on Soft Soil. The research conducted in test tub, the preloading and heat induction model shown in Figure 2 with the dimensions of 50 x 70 x 150 cm of soil tested, in the figure it showed a post-reconstitution conditions.

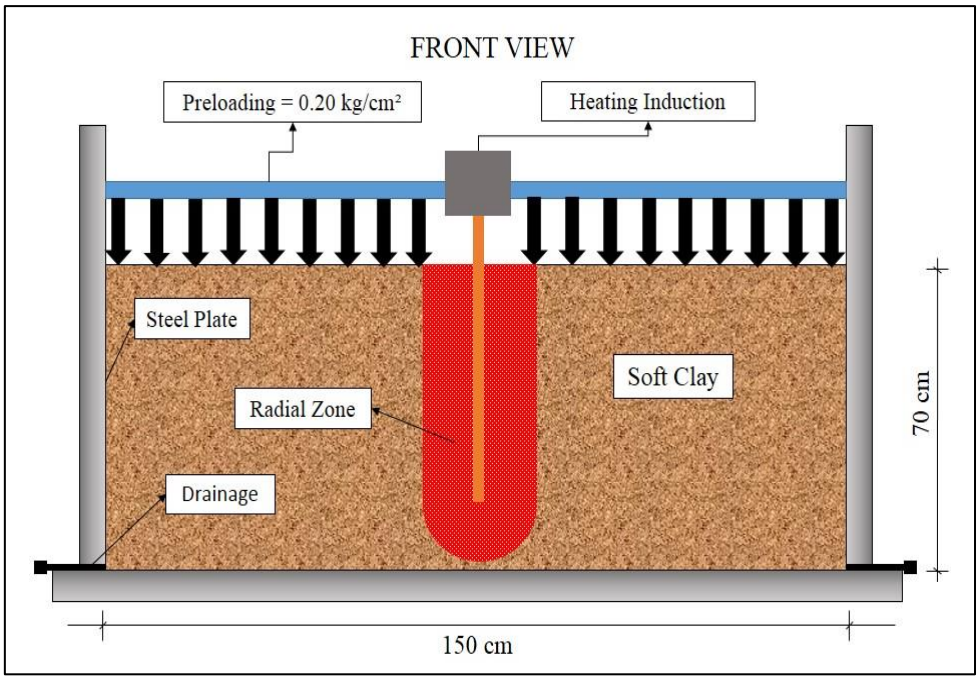

Fig. 2 The preloading and heat induction

Thermal induction was inducted with 40 cm length metal rod with temperature regulator up to 400^0 C. The soft clay tested for vane shear was carried out in the radial zone R0, R1, R2. The R0 located in center of soil heat induction, R1 located 20 cm away from the center, and R2 located 40cm away from center of heat induction. The layout of radial zone and position for R0,R1 and R2 shown in Fig. 3.

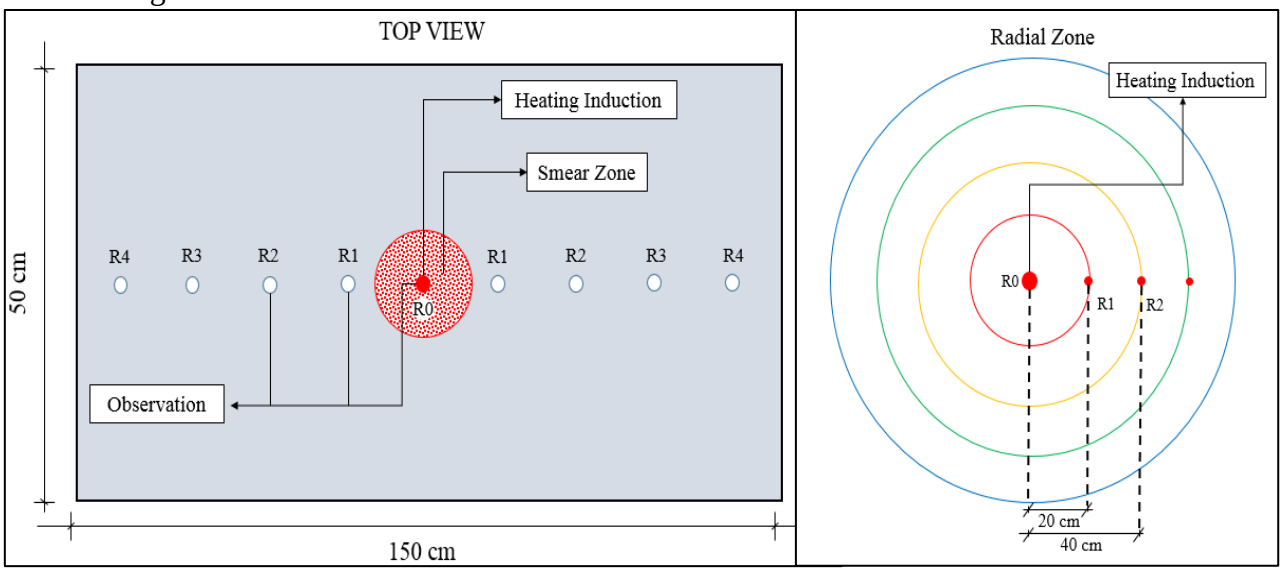

Fig. 3 The layout of radial zone and position for R0, R1 and R2

Result and Discussion

Characteristics of Soft Soils and Their Classification. The results showed that the type of soil based on Unified Soil Classification System (USCS) was CH and based on the American Association of State Highway and Transportation Officials (AASHTO) was A-7-5. The summary of index properties of soil tested was shown in Table 1.

Table 1 Soil properties index test results

Parameter	Value	Testing Method
1. Volumetric Parameter		
- Specific Gravity	2.71	ASTM D-162
- Water Content (%)	73.55	ASTM D-2216-98
- Density (kg/cm^3)	1.66	
2. Grain size distribution		ASTM C-136-06
- Clay (%)	50.42	
- Silt (%)	41.37	
- Sand (%)	8.21	
- Gravel (%)	0.00	
3. Atterberg Limit		
- Liquid Limit (%)	69.90	ASTM D-423-66
- Plastic Limit (%)	33.30	ASTM D-424-74
- Plasticity Index (%)	36.60	ASTM D-4318

The Strength with Unconfined Compressive Test (UCT). The UCT result after the soil inducted by heat at temperature 100°, 200°, 300°, 400° at R0, R1, and R2 is shown in Table 2.

Table 2 The result of UCT with various temperature

Temperature (°C)	UCT (kg/cm²)		
	R0	R1	R2
100	0.203	0.129	0.093
200	0.247	0.154	0.107
300	0.375	0.222	0.134
400	0.467	0.250	0.155

The compressive strength of a soil under static loading (0.20 kg/cm^2) decreases with an increasing of distance from the center of soil heating induction. This conclusion is drawn from the laboratory experiments also shown in the Fig. 4. At lowest temperature 100° at R0 the compressive strength was 0.203 kg/cm², at highest temperature 400° at R0 the compressive strength was 0.467 kg/cm², there was a significant increasing of compressive strength value with the change of temperature. Whereas, at R1, the highest temperature the compressive strength 0.250 kg/cm² and the lowest temperature 0.129 kg/cm². However, at R2 (the farthest soil from soil heat induction) seemingly did not have significant effect to the compressive strength, because the change value of compressive strength not very large. It suspected that the temperature effect only effective (in term of increasing the strength of soil) only at R0 and R1. In general, the farther the soil from the center of heat induction, the less shear strength obtained.

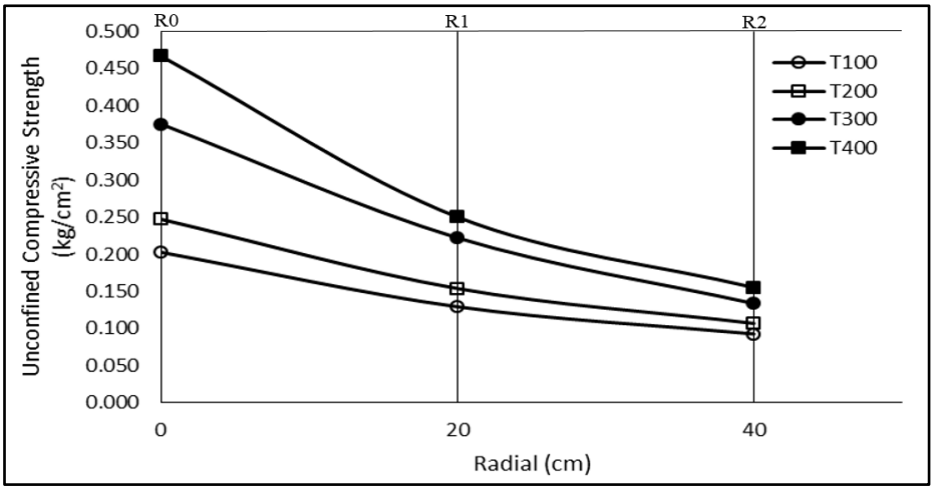

Fig. 4 Radial-unconfined compressive strength relation at different temperature (heat induction)

Shear Strength Measurement with Vane Shear Test. The vane shear test result after the soil inducted by heat at temperature 100°, 200°, 300°, 400° at R0, R1, and R2 is shown in Table 3.

Table 3 The result of vane shear test with various temperature

Temperature (°C)	Shear Strength (kg/cm²)		
	R0	R1	R2
100	0.116	0.070	0.046
200	0.155	0.085	0.054
300	0.186	0.101	0.062
400	0.240	0.128	0.077

.

From vane shear test the shear strength plotted with radial of soil tested R0, R1, R2 which had 20 cm distance for each point is shown in Figure 5 below. The result shows that the farther the soil from the center of heat induction, the less shear strength obtained.

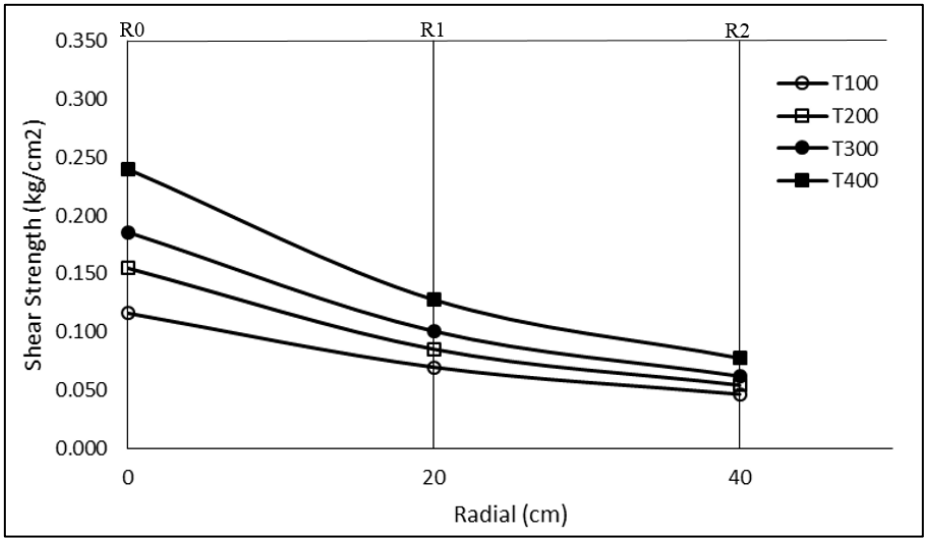

Fig. 5 Radial-shear strength relation at different temperature (heat induction)

The result of vane shear test shows similar behavior from UCT result. It was suspected that the difference between value of both testing because the principle of their testing procedure, the vane shear test, shearing the soil with horizontal shearing while UCT applied load in vertical axis. It shows an obvious effect upon heating, it is suspected that the temperature hardening the bond of clay particle due to water evaporation but only effective in radial zone R0 and R1.

Conclusions

From the results of the research, it could be concluded that:

1. The soil used in the study was classified as clay type or CH by USCS which has chracteristics that the change in water content will affect the value of the shear strength.
2. At the highest temperature 400^0 the shear strength from vane-shear tests resulting at R0 0.240 kg/cm^2, R1 of 0.128 kg/cm^2, R3 of 0.077 kg/cm^2. At the lowest temperature of 100^oC shows R0 at 0.116 kg/cm^2, R1 at 0.070 kg/cm^2, R2 of 0.046 kg/cm^2.
3. It shows an obvious effect upon heating, it is suspected that the temperature hardening the bond of clay particle due to water evaporation but only effective in radial zone R0 and R1.

Acknowledgment

Author would like to express gratitude and thank to LPDP (Indonesia Endowment Fund for Education) for all kind of support so that this research could be carried out to date, and also would like to to thank to all colleague at Geothecnical Laboratory of Hasanuddin University who had been involved to this research until the completion.

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