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The Influence of Water Content Variations on Friction Capacity of Piles in Expansive Soil

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Abstract

Seasonal change in tropical climate countries like Indonesia causes variations in soil moisture content. On expansive soil, this condition influences the soil moisture content in the upper few meters, which is generally termed as the active zone. The water content variation induces the changes in physical and mechanical characteristics of the soil and these changes have an impact to the friction capacity of piles. The main objectives of this research are to investigate the influence of water content variations on friction capacity of concrete and steel piles. A series of laboratory experiments were conducted considering the water content variations and pile material. A pile model made of concrete and steel was penetrated to soil sample which was placed in a cylindrical tube. This tube has a diameter about 15 times the diameter of the pile model. The pile model was loaded to failure to investigate the friction capacity. Based on the results from laboratory testing, it can be concluded that the change of water content have a great impact to friction capacity of piles. Friction capacity of concrete and steel piles has decreased up to eight and nine times from drying condition to wetting condition. The results also showed that pile material influenced the friction capacity which steel pile had higher friction capacity than concrete pile.

Keywords: *Pile foundation, Friction capacity, Water content*

1. Introduction

Seasonal change in tropical climate countries like Indonesia causes variations in soil moisture content. On expansive soil, this seasonal cycle influences the soil moisture content in the upper few meters, which is generally termed as the active zone. Soil water evaporation during the dry season decreases soil moisture content. In wet season, when it rains, water infiltration into the soil increases the water content. This water content variation induces changes in physical and mechanical characteristics of the soil, especially for expansive soil [1-5]. The change of water content due to seasonal cycles would cause shrinking and swelling in expansive soil. The differential movement caused by shrinkage or swell of expansive soils can increase the probability of damage to the foundation and superstructure.

In the case of pile foundation, the change of water content due to drying and wetting cycles leads to changes in the friction capacity of piles. In this research, a series laboratory experiments were conducted considering the water content variations and pile material to investigate the friction capacity of piles under drying and wetting cycle.

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2. Literature Review

The change in water content greatly affects the strength of expansive soils used in structural foundations. Expansive soils are bound together by electrochemical bonds between individual particles, as soil cohesion. Water content significantly modifies the soil cohesion. As water content increases, soil cohesion decreases. This is because increasing the water content can change the distance between particles, decreasing the strength of the inter-particle bonds. The decrease in bond strength results in a decrease in cohesion and a loss of shear strength.

In previous study, it was shown that soil cohesion in dry season reaches four times higher than in wet season. For example, in the dry season, cohesion was 149 kN/m^2, while in wet season, cohesion decreased up to 37 kN/m^2 [1, 6].

In clayey soil, load capacity of pile was strongly determined by the friction between pile and soil. The friction capacity (Q_f) was determined using the equation as shown in Eq. 1 [7].

$$Q_f = \alpha \; c_u \; A_s \tag{1}$$

Where α is adhesion factor, c_u is undrained shear strength, and A_s is the contact area between pile and soil.

There are several charts showing the relationship between undrained shear strength and adhesion factor, which were suggested by some researcher to determine adhesion factor. Some of them are shown in Figure 1 [8].

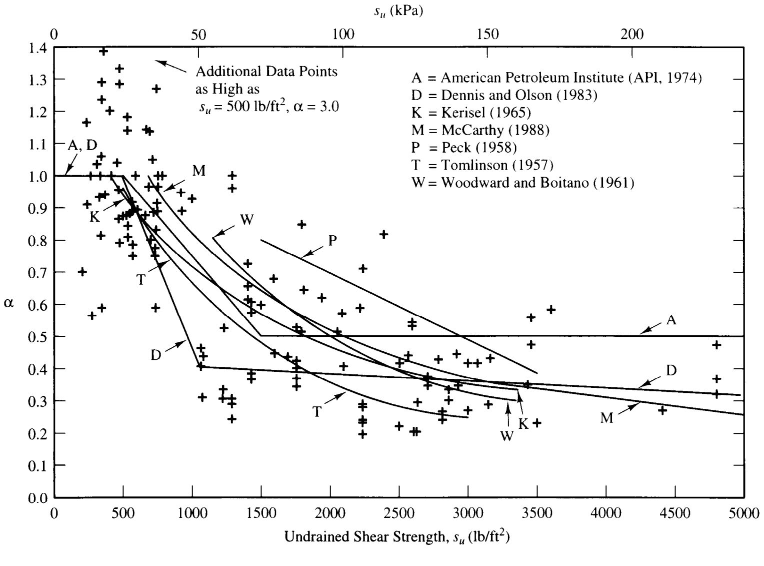


Figure 1. Adhesion Factor [8]

3. Characteristics of Soil Sample

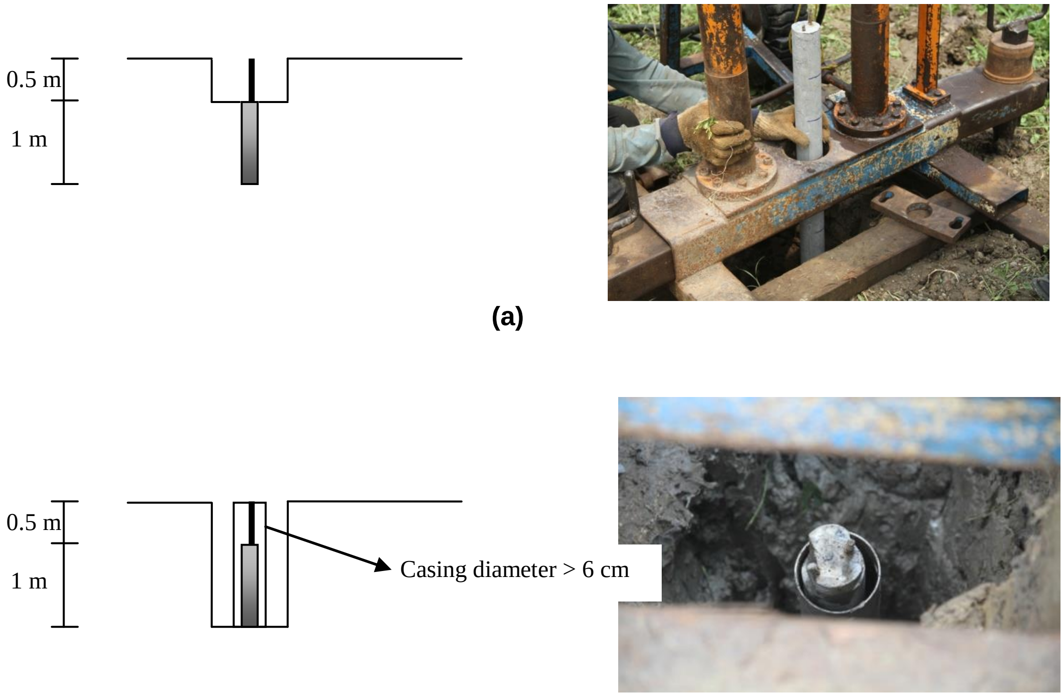
In this research, field and laboratory experimental was conducted using soil sample taken from Citraland, West Surabaya, Indonesia. The initial characteristics of soil sample such as: water content, specific gravity, liquid limit, plastic limit, soil particle, and soil classification is shown in Table 1.

Table 1. Initial Characteristics of Soil Sample

Water content (%)	Specific gravity	Liquid limit (%)	Plastic limit (%)	Soil particles			Undrained shear strength, c_u (kg/cm^2)	Soil classification (USCS)
				gravel (%)	*sand* (%)	*fines* (%)		
44.5	**2.65**	**109**	**30**	**0**	**0.11**	**99.9**	**0.26**	**CH**

4. Research Methodology and Experimental Procedure

The experimental research was conducted to investigate the friction capacity of piles under drying wetting cycles. The friction capacities of piles were determined by the field and laboratory tests. In the field, test pile model with a diameter of 5.7 cm and a length of 1 m was inserted to the soil. The schematic of the field test is presented in Figure 2. The first step, the model pile was inserted to the soil to investigate the total capacity of piles (Figure 2a). Afterward, pile covered with casing was inserted to the soil to investigate the end bearing load only (Figure 2b). Thus, the friction load of piles could be determined by subtracting its end bearing load from its total capacity. In the field, Cone Penetration Test (CPT) was also conducted to investigate the effect of pile material in friction capacity of piles. CPT piles could represent steel pile material, thus the friction capacity of steel pile could be determined. This field experiment was done to obtain the validity of laboratory experiment.



(a)

(b)

Figure 2. Field Experiment (a) Total Pile Load (b) End Bearing

Undisturbed soil sample was taken by pipe tube with a diameter of 15.24 cm (6”) and a length of 15 cm as shown in Figure 3. Soil sample was taken at a depth of 1 m.

The weight of undisturbed soil sample was also measured to ensure the uniformity of soil sample in all tubes. Afterward, undisturbed soil sample was wrapped in plastic to maintain its water content same as in its field condition.

Figure 3. Soil Sampling

For laboratory experimental, concrete and steel model piles were made with a diameter of 1 cm and a length of 30 cm. As shown in Figure 4, a test pile was inserted to the soil sample tube to investigate its friction capacity. The soil sample tube was made by PVC with 15.24 cm (6”) in diameter considering the boundary effect of 15 times pile diameter [9-10].

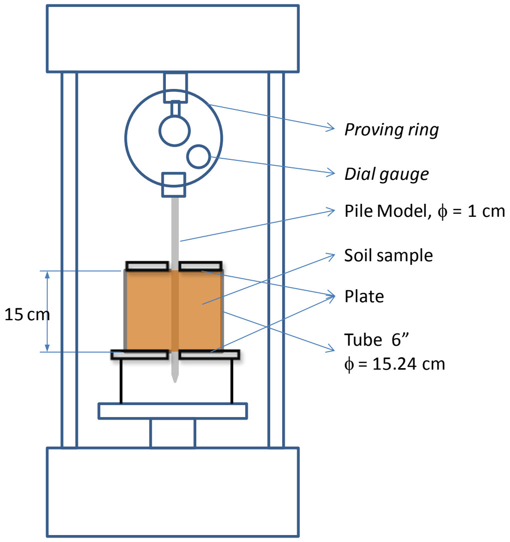


Figure 4. Laboratory Model Pile

The soil sample in the tube was tested considering water content variation based on the field condition. Based on the secondary data from Soil Test Company in Surabaya, the variation of soil moisture content at West Surabaya due to seasonal change throughout the year range from 25% to 55 % (Figure 5). The water content variation in this research is showed in Table 2.

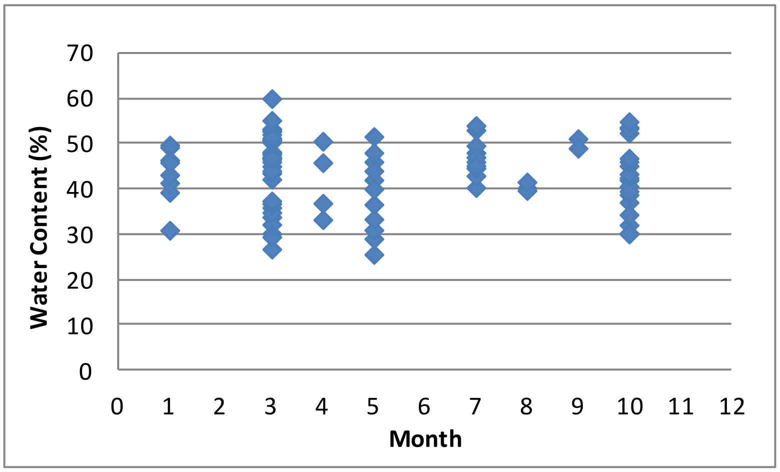


Figure 5. Variation of Water Content at West Surabaya in a Year

Table 2. Drying and Wetting Condition

	Wetting 15 %	Wetting 10 %	Wetting 5 %	Initial	Drying 10 %	Drying 20 %	Drying 30 %	Drying 40 %	Drying 50 %
Water Content (%)	51.18	48.95	46.73	44.5	40.05	35.06	31.15	26.7	22.25

Note: Drying x% → $W_{c\ (x)} = W_{c\ (initial)} - x\%\ W_{c\ (initial)}$
Wetting y% → $W_{c\ (y)} = W_{c\ (initial)} + y\%\ W_{c\ (initial)}$

5. Result and Discussion

The results of this research were obtained by doing several field and laboratory experiments. Laboratory loading test was conducted to represent the loading test at the field. Friction capacity of concrete piles at the laboratory and field were 0.154 kg/cm^2 and 0.192 kg/cm^2, respectively. Friction capacity of steel piles at the laboratory and field is 0.245 kg/cm^2 and 0.267 kg/cm^2, respectively. It can be concluded that the accuracy of concrete and steel model pile is 80 % and 92 %, respectively.

5.1. Drying – Wetting

The relationship between friction load and displacement of model piles is shown in Figure 6 and Figure 7. In general, frictions load increased with the decreasing water content. Drying and wetting cycles greatly affected the friction capacity of piles. The difference of friction capacity in the range between wetting 15 % to drying 50 % was 8.7 times for concrete pile and 9.3 times for steel pile. At more dry condition, when soil becomes unsaturated, suction phenomena might be occurred. Soil suck any material within, hence the increasing of friction load. On steel pile model (Figure 7), the friction load continued to increase with the increasing displacement until it reaches its peak point and then decreased. While on concrete model pile, the increasing of friction load is not as steep as on a steel model pile and it has no peak point (Figure 6).

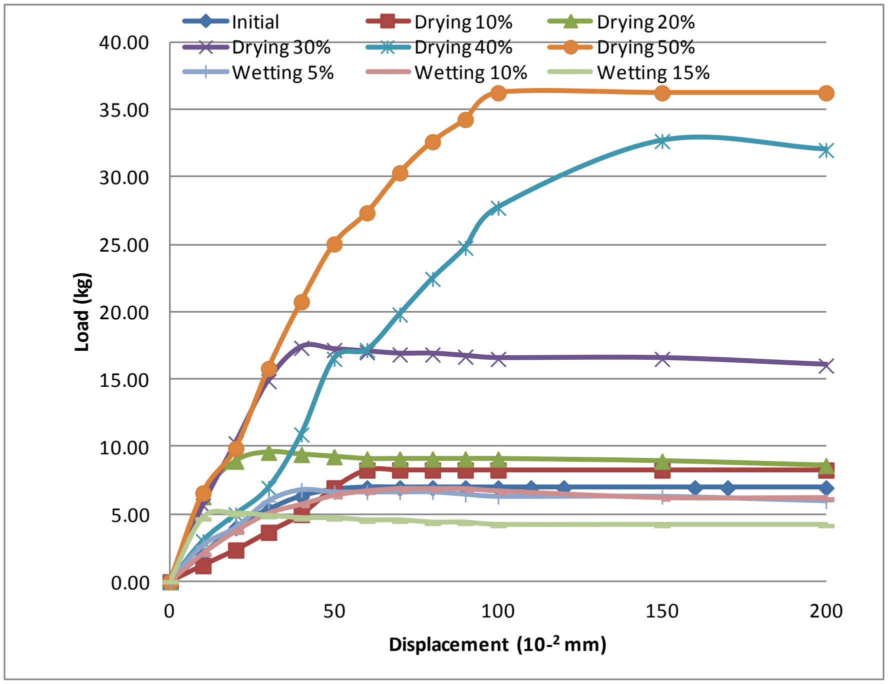


Figure 6. Load - Displacement Curve of Concrete Pile Model

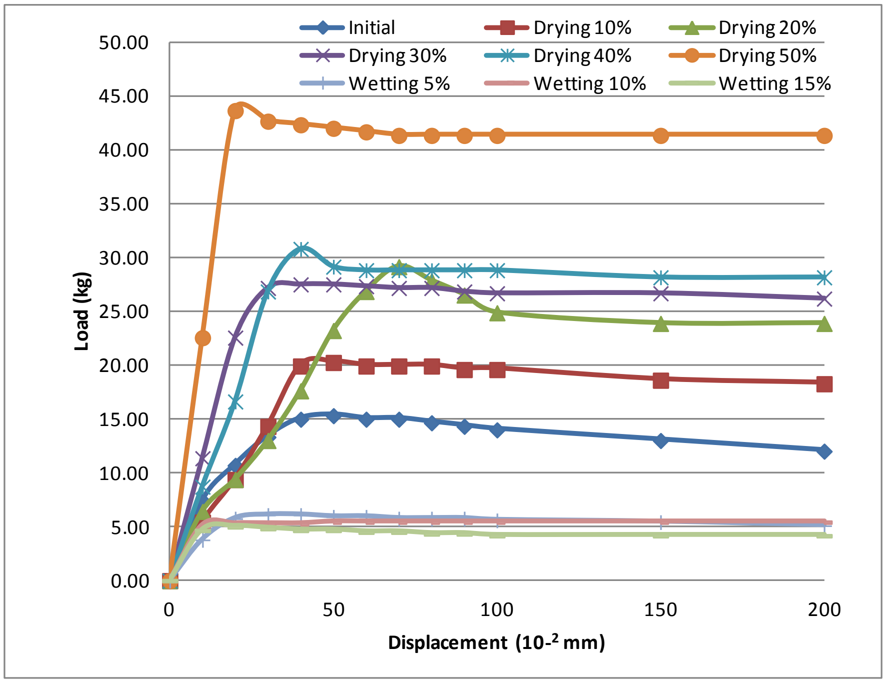


Figure 7. Load - Displacement Curve of Steel Pile Model

5.2. Pile Material

From these tests, it could be concluded that when pile inserted to the expansive soil, the steel pile has higher friction capacity compare with the concrete pile, especially at drying 20 % condition (Table 3 and Figure 8). This phenomenon is thought that suction between soil and steel material stronger than suction between soil and concrete material. It might happen because the surface of concrete more porous than steel material, hence soil suck steel material stronger than concrete material.

At initial condition up to drying 30 %, the difference between steel and concrete piles friction load is considerably high. The friction load differences increased with the increasing drying condition until drying 30% was reached. However, as drying condition reached up to drying 40 % and 50 %, the friction load differences between steel and concrete pile getting smaller. Likewise, as water content increased, from wetting 5 % up to wetting 15 %, friction load of steel and concrete piles were almost the same.

Table 3. Friction Load Differences between Concrete and Steel Pile

Condition	Friction Load for Concrete (kg)	Friction Load for Steel (kg)	Difference (kg)
Initial	6.98	12.04	5.07
Drying 10%	8.30	18.31	10.02
Drying 20%	8.62	23.92	15.30
Drying 30%	16.05	26.23	10.18
Drying 40%	32.05	28.21	3.84
Drying 50%	36.30	41.41	5.11
Wetting 5%	5.98	5.11	0.87
Wetting 10%	6.15	5.44	0.71
Wetting 15%	4.17	4.45	0.28

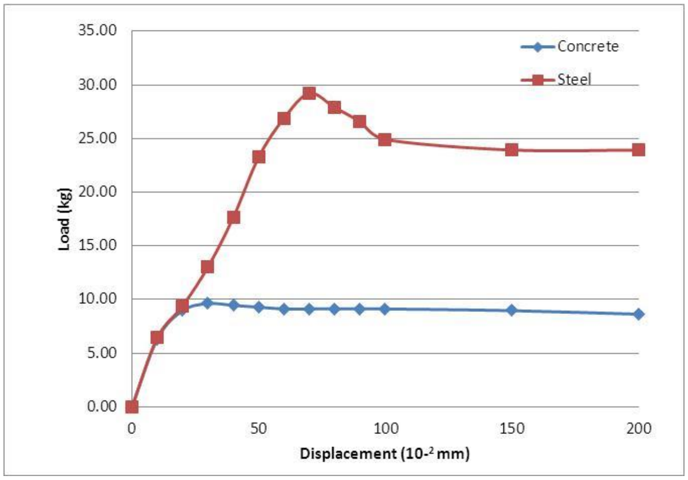


Figure 8. Load - Displacement Curve of Pile Model at Drying 20 %

6. Concluding Remarks

A series of experiments were conducted to investigate the effect of water content variation and pile material on friction capacity. The following is a summary of the conclusion from this investigation:

1. The laboratory loading test could represent the field loading test, it has a 80% accuracy rate for concrete pile and 92 % for steel pile.

2. Drying and wetting greatly affected the friction capacity of pile foundation. Friction load increased with the decreasing water content. The difference of friction capacity in the range between wetting 15 % to drying 50 % was about eight to nine times.
3. In steel pile model, the friction load continued to increase with the increasing displacement until it reaches its peak point and then decreased. While on concrete model pile, the increasing of friction load is not as steep as on a steel model pile and it has no peak point.
4. On expansive soil, steel pile has higher friction capacity compare with concrete piles. However, in wetting condition and very dry condition (drying 40 % and 50 %), friction load of steel and concrete piles were almost the same.

Furthermore, another type of clay, for example non-expansive soil is necessary to be observed so this research could represent the problem at the field more widely. The behavior of friction capacity changes might be different for non-expansive soil.

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