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Behaviour of Friction Resistance of Pile Groups on Clay Soil During Loading Tests: Case Study in Semarang and Temanggung, Central Java, Indonesia

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Abstract - Shear strength parameters influence the bearing capacity of pile foundations, *i.e.* internal friction angle (ϕ) and cohesion (c). Soil parameters are affected by water content, which can be altered by climate change. Clay soils have high swelling and shrinking potential, caused by changes in water content, and this can affect the failure of foundations. Analysis of the influence of moisture content on the friction resistance of piles needs to be carried out, especially in clay soils. This research uses laboratory experiments to model four piles, with diameters of 16 mm. The pile group models are modeled in soil samples taken from three different locations, i.e. Tembalang, Pengaron, and Pingit, in Central Java. The samples were treated (soaking and drying) for one, three, and seven days. The USCS categorization of the soil samples were OH (organic clay with medium plasticity) and CH (inorganic clay with high plasticity). Friction resistance in piles within soaking conditions, decrease in proportion to an increase in moisture content. On the other hand, friction resistance increases under drying conditions. However, the friction resistance of the soil that had been treated (by soaking and drying) was not equal to the initial conditions.

Keywords: friction resistance, deep foundation, pile group, clay soil, moisture content

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Introduction

Clay soil has high swelling and shrinkage potential because of soaking and drying during the rainy and dry seasons. These conditions can lead to the failure of building structures constructed on them, such as the failure of foundations. Swelling of the clays that occur in the Pingit Temanggung area of Indonesia, has resulted in the uplift of some house foundations, thus damaging the structures above. Meanwhile, shrinkable clay in the Penggaron area has affected the settlement of foundations, thus affecting building construction.

Foundation failure also occurred during the construction of pillar number 28 of the Cenger Bridge 2, with a diameter of 1.85 m and length of 10 m. The results of the Pile Driving Analyzer (PDA) test on pillar number 28 (carried out before the rains) gave a total bearing capacity of 1,537.8 tons, a friction resistance of 1,525.7 tons, and point bearing capacity of 12.1 tons. Meanwhile, the PDA test after the rains gave decreased values:

a total bearing capacity of 998 tons, consisting of friction resistance of 915 tons, and point bearing capacity of 82.4 tons.

Damage occurred to a bridge pillar at the Cisomang Purwakarta toll road in West Java, Indonesia and this was caused by soil movement due to changes in the structure of the clay shale. The foundation of the bridge moved as much as 1.2 cm, which caused the pier head on the 40 m tall bridge pillar to move 52 cm.

Mylonakis and Gazetas (1998) stated that soil layers affected the settlement of pile groups and interactions between piles caused additional stresses. The method they used was Winkler-type models for pile-soil and pile-soil-pile interaction analysis. A research into the shear strength reduction at the soil/structure interface was also carried out by Tiwari *et al.* (2010) using variations in soil/concrete, soil/wood, and soil/steel. The skin resistance of the soil/structure interface depends on the surface material of the structure and the soil material.

The Artificial Neural Network (ANN) model was carried out by Hanna *et al.* (2004) to predict the efficiency of pile groups in granular soil under axial loads. The ANN model considers how the planar geometry of the group, the effect of pile installation, pile length, soil conditions, and type of loading affects group efficiency. This model can provide a higher level of accuracy than the corresponding conventional models and yielded the highest coefficient of determination (R^2= 0.72) and lowest error (MAE= 0.157 and RMSE= 0.23). Conventional models yielded a much lower coefficient of determination (R^2= 0.0001 to 0.081) and much higher errors (MAR= 0.42 to 0.49 and RMSE= 0.23 to 0.62).

Numerical analyses of pile friction behaviour in soils have been studied. For example, Ghazavi *et al.* (2014) conducted a study on vertical and inclined piles in a group, to study the interaction between piles and soil. The simple closed solution method was used to characterize the inclined and vertical piles. Numerical analysis was also performed using FLAC3D. Parametric studies have been carried out to determine the parameters that contribute to the pile-soil-pile interactions. The results of these analyses showed that the presence of neighbouring piles is important, resulting in less ground movement at the source pile head. Chen and Hsu (2017) presented a model of batter pile behaviour under lateral soil movement, using numerical simulations of the three-dimensional Fast Lagrangian Analysis in the Continua (FLAC3D) programme. The piles, which were located at the edge, caused increases in the bending moment in the middle of the vertical group. The maximum bending moment in the pile group was smaller than that of the vertical pile group in sandy soil, but the bending moment reached 5 to 8 times that in clay soil. Indarto (2011) conducted a study related to the friction resistance of piled foundations in soils. The results showed that an increase in the moisture content of 56.19% caused a decrease in the friction resistance of the pile of 90.22%. However, the results of calculations using numerical modeling indicated that, if the depth of soaking increases, the friction resistance of the pile decreases. Kim *et al.* (2018) also developed a pile with negative skin friction (PileNSF) programme to predict the bearing capacity of a pile embedded in a consolidated soil. This one-dimensional analytical model was based on the nonlinear load transfer method and Mikasa's general one-dimensional consolidation theory. The results showed that excess pore pressure decreases and, as the surcharge load increases, the drag load and down drag on the pile increases. Kong *et al.* (2013) conducted negative skin friction (NSF) analysis of a pile group embedded in a consolidating soil. Practical comparative engineering analysis was used to verify the level of accuracy and reliability of the mathematical models. The mathematical models (considering nonlinear, consolidated soil, and group effects) can reflect the practical negative skin friction of pile groups effectively and accurately.

In addition, there have been a few experimental laboratory studies of pile friction behaviour in soil foundations. Tjandra *et al*. (2013) studied the effects of water content variation on the adhesion factor in pile foundations. A laboratory experiment with a pile model made of concrete was placed in a cylindrical tube with a diameter of 15 times the diameter of the pile model. The friction resistance and undrained shear strength decreased by up to eight times, from dry to wet conditions. The adhesion factor increased with increasing undrained shear strength. The undrained shear strength value increased with decreasing moisture content.

Research on the behaviour and friction resistance in a pile group has been carried out by evaluating the behaviour of the pile and, also, the negative skin influence on the pile group. Some simulations, using the programming model, have been carried out to determine the friction resistance of the pile groups, but research experiments have been scarce. Analysis of the influence of moisture content on the resistance friction of the pile, especially on clay soil, needs to be carried out to determine the behaviour of the interaction between the soil and the pile. Therefore, in this study, a laboratory-scale experiment was conducted to determine the behaviour and changes on friction resistance in a pile group due to the influence of soil moisture content in three different types of clay.

Materials and Method

In this study, soil samples were taken from Penggaron and Tembalang, in Semarang City, and one from Pingit in Temanggung, Central Java Province (Figure 1). Those samples comprise black clay in Penggaron at 7°1’1.9”S/110° 29’36.5”E, red clay from Tembalang at 7°3’10”S/110°26’3E, and yellow clay from Pingit at 7°31’86”S/110° 32’33”E.

This research was conducted through laboratory experiments by modeling four 16 mm diameter piles, penetrated inside a mold fabricated from a 3 inch diameter PVC pipe. The modeled piles were made of concrete, using molded PVC with a diameter of 16 mm (Figures 2 and 3).

The unconfined compression test was used for proving the ring penetrometer test on the pile model. Before testing, the height of the test equipment was adjusted to the samples. As well as the underside of the samples, there had to be

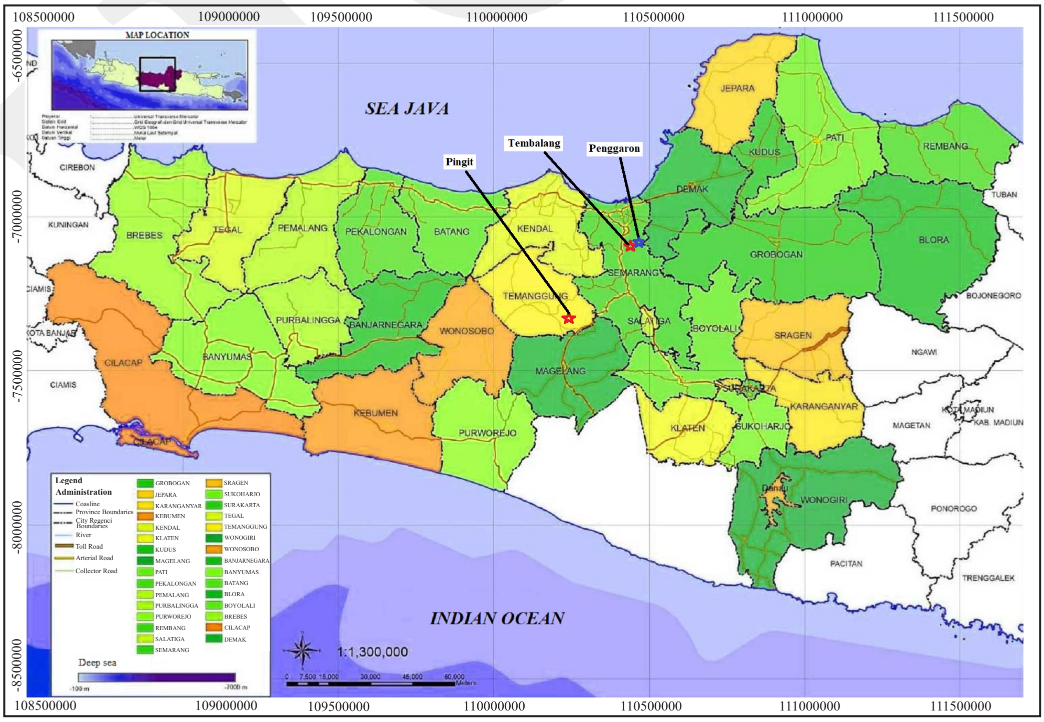

Figure 1. Locations of soil sampling.

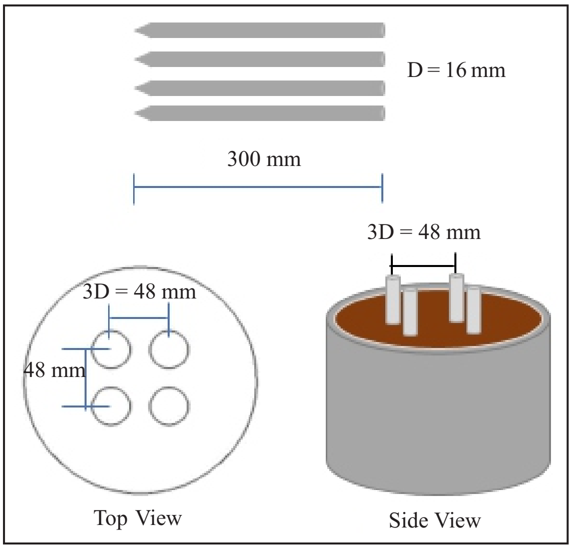

Figure 2. Illustration of penetration pile model.

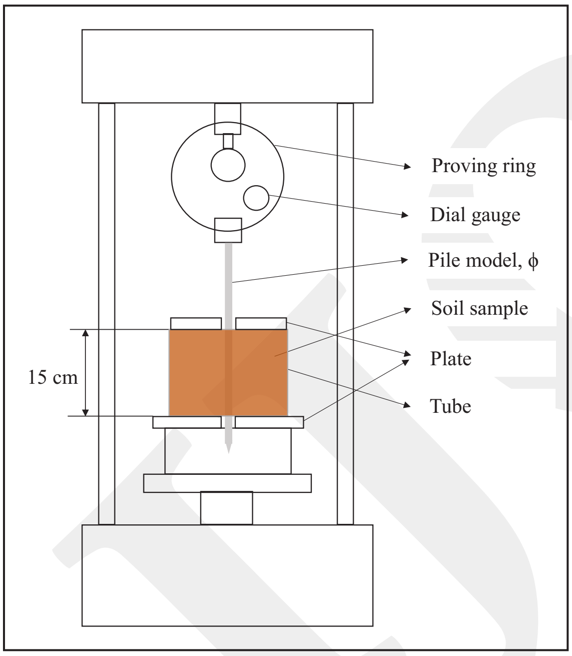

Figure 3. Schematic proving ring penetrometer.

a space so that, when testing, the pile remained undisturbed. The schematic of the ring penetrometer test is shown in Figure 3.

The samples were subjected to different treatments. In the first treatment, the specimens were soaked for one day. The second samples were soaked for three days and the third samples were soaked for seven days. After soaking in each scenario, the test specimen was drained for 1, 3, and 7 days, with the aim of creating different moisture contents in each sample. In addition, a sample was formed with moisture content close to the initial field conditions. The research plan scenarios are presented in Table 1.

Results

The soil properties, moisture contents, and Atterberg limits for all clay samples (from Tembalang, Penggaron, and Pingit) are given in Tables 2 and 3. The grain size distribution curve is shown in Figure 4.

Based on Figure 4, the grain size distribution in the soils from Tembalang and Penggaron is poorly graded, whereas the narrower grain size distribution from the soil from Pingit is more homogeneous. Table 2 shows the specific gravity of Tembalang, Pingit, and Penggaron soils, including organic clay soils. The void ratio of Pingit soil has the highest value among the three soil samples. Based on the grain size distribution curves (and using the Unified Soil Classification System/USCS classification), Tembalang soil is categorized as OH (organic clay with medium plasticity), while

Table 1. Research Scenarios

Sample Locations	Scenario	Initial condition	Treatment					
			Soaking (Day)			Drying (Day)		
			1	3	7	1	3	7
Tembalang	1.1	√	√			√	√	√
	1.2	√		√		√	√	√
	1.3	√			√	√	√	√
Penggaron	2.1	√	√			√	√	√
	2.2	√		√		√	√	√
	2.3	√			√	√	√	√
Pingit	3.1	√	√			√	√	√
	3.2	√		√		√	√	√
	3.3	√			√	√	√	√

Table 2. Soil Property Results

Parameter, symbols	Unit	Tembalang Clay	Penggaron Clay	Pingit Clay
Specific Gravity, *Gs*		2.59	2.60	2.65
Dry Density	g/cm³	1.28	1.35	0.9
Void Ratio, *e*		1.03	0.92	1.93
Porosity, *n*		0.51	0.48	0.66
Degree of Saturation, *Sr*	%	97.72	100.00	85.00

Table 3. Results of Moisture Contents and Atterberg Limits

No	Sample location	Moisture Content (%)	Atterberg limits (%)		
			LL	*PL*	*PI*
1	Tembalang	38.71	56.20	42.44	13.76
2	Penggaron	35.45	73.20	30.21	42.99
3	Pingit	61.98	77.00	45.44	31.56

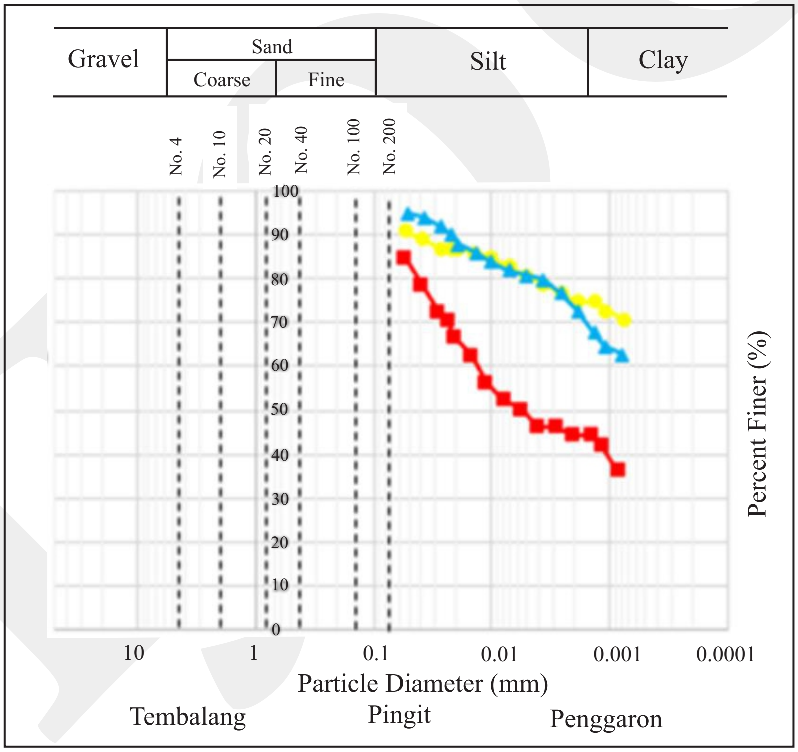

Figure 4. Grain size distribution curves for soil samples.

the Pingit and Penggaron soils are in the CH category (inorganic clay with high plasticity).

Based on the results of the unconfined compression test (Figure 5), the maximum unconfined compression strength of Tembalang clay q_u= 2,327 kg/cm^2. The clay is classified as being very stiff. Penggaron clay has a maximum unconfined compression strength q_u= 1,046 kg/cm^2, which belongs to the stiff category, while the Pingit clay has q_u= 0.761 kg/cm^2, which belongs to the medium category, based on ASTM D2166-66 standards (2016).

Undisturbed soil samples were used in the direct shear test. The test results (Figure 6) show

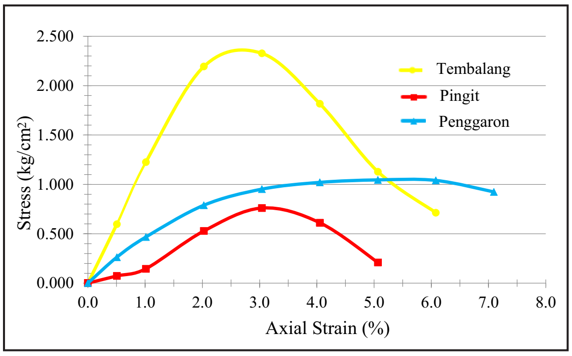

Figure 5. Results of Unconfined Compression Tests.

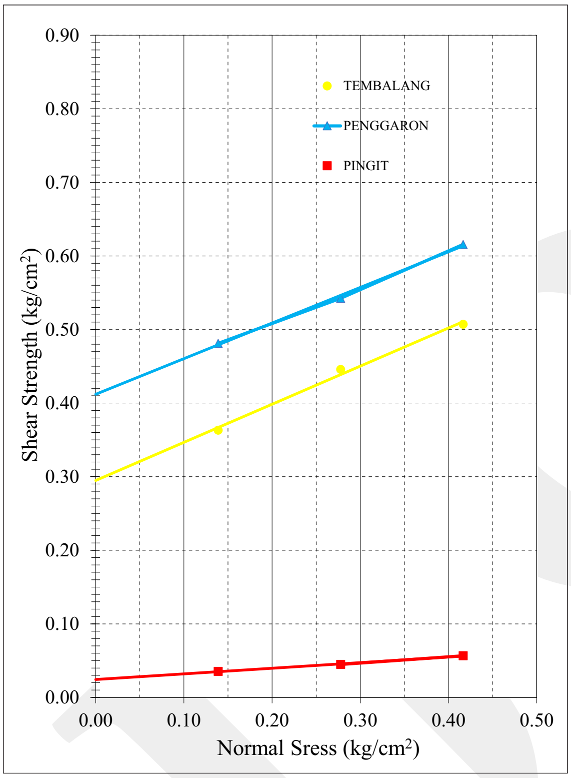

Figure 6. Results of Direct Shear Strength Tests.

that the Tembalang clay has a soil cohesion value c= 0.298 kg/cm^2 with an internal friction angle φ= 27.31º. Penggaron clay soil has c= 0.415 kg/cm^2 and φ= 25.81º, whereas Pingit clay has c= 0.0275 kg/cm^2 with φ= 4.37º. From the test results, it can be seen that the values of the internal friction angle of Tembalang and Penggaron soils are quite similar. In contrast, the internal friction angle of Pingit soil is the lowest. Likewise, the cohesion value of Pingit soil is smaller, compared to Tembalang and Penggaron soils. The higher moisture content in the soil caused decreasing values of cohesion c and internal friction angle φ.

Figure 7 shows the testing results of the bearing capacity of the initial soil condition, during soaking, and after the drying process. The bearing capacity of the soils at Tembalang, Pingit, and Penggaron (under initial moisture conditions) are 2.66, 1.81, and 2.49 kN, respectively. After soaking, the bearing capacity of the soil in all samples decreased significantly from the initial conditions. The soil bearing capacity of Scenario 1, after soaking the Tembalang, Pingit, and Penggarong samples, decreased by 39.60%, 42.03%, and 48.51%, respectively, from the initial conditions. The soil bearing capacity for Scenario 2 at Tembalang, Pingit, and Penggarong decreased by 44.29%, 56.45%, and 58.32%, respectively. The most significant decrease occurred in Scenario 3, where the bearing capacity of Tembalang, Pingit, and Penggaron soils decreased by 74.81%, 65.17%, and 79.98%, respectively. This was due to decreasing soil shear parameters, which affects the bearing capacity of the soil.

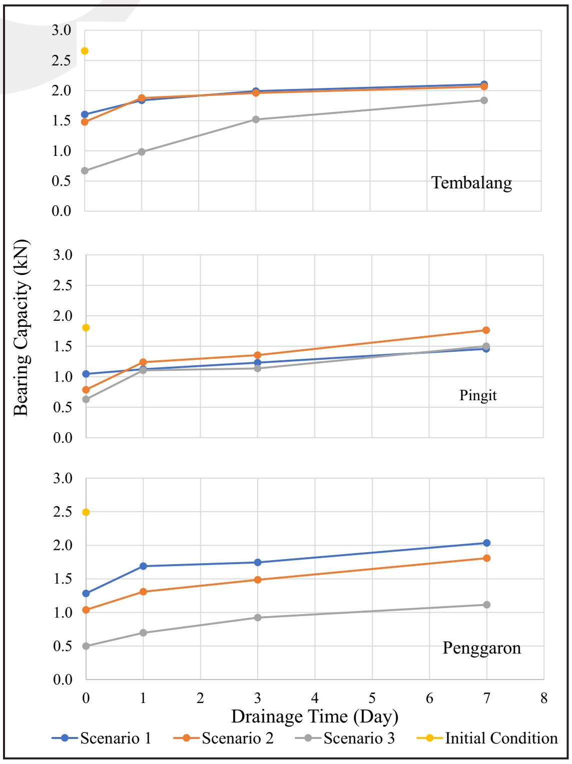

Figure 7. Relationship between Bearing Capacity and Drainage Time. (a) Tembalang (b) Pingit (c) Penggaron.

Compared with the initial condition, the value of soil bearing capacity for all of the scenarios increased after 1, 3, and 7 days of soil drainage. For seven-day drainage, the bearing capacity value of Scenario 1 for Tembalang, Pingit, and Penggaron soils increased up to 2.10, 1.46, and 2.03 kN, respectively. For Scenario 2, the soil bearing capacity of Tembalang, Pingit, and Penggaron soils increased up to 2.07, 1.76, and 1.81 kN, respectively. In contrast, the bearing capacity of Scenario 3 for Tembalang, Pingit, and Penggaron soils was 1.84, 1.50, and 1.11 kN, respectively and the increase in the soil bearing capacity for Scenario 3 was not significant compared with Scenarios 1 and 2. This was due to the fact that the Pingit soil has a greater void ratio compared with the Tembalang and Penggaron soils. This result also showed that, after seven-day drainage time, the value of soil bearing capacity did not reach the initial condition value (see Figure 7).

Figure 8 shows the relationship between moisture content and drainage time in the Tembalang, Pingit, and Penggaron soils. The soaking time for 1, 3, and 7 days caused increasing soil moisture contents in Scenario 1, 2, and 3, respectively. The initial soil moisture condition for Tembalang and Penggarong was 26%, while the moisture content of the Pingit soil was 60%. In Scenario 3, the soil moisture content of Tembalang and Penggarong soils increased to 50%, while the moisture content of the Pingit soil reached almost 80%.

In Scenario 1, after seven-day drainage, the soil moisture content of Tembalang and Penggaron soils was 24%, while the soil moisture content of Pingit was 61.19%. For Scenario 2, the soil moisture content of Tembalang, Pingit, and Penggaron were 25%, 56%, and 31%, respectively. In Scenario 3, the value of the soil moisture content at Tembalang, Pingit, and Penggaron were 24.31%, 53.27%, and 26.72 %, respectively. This result shows that the drying process for seven-day drainage caused decreased moisture contents for all soil samples and could reduce it to less than the initial condition.

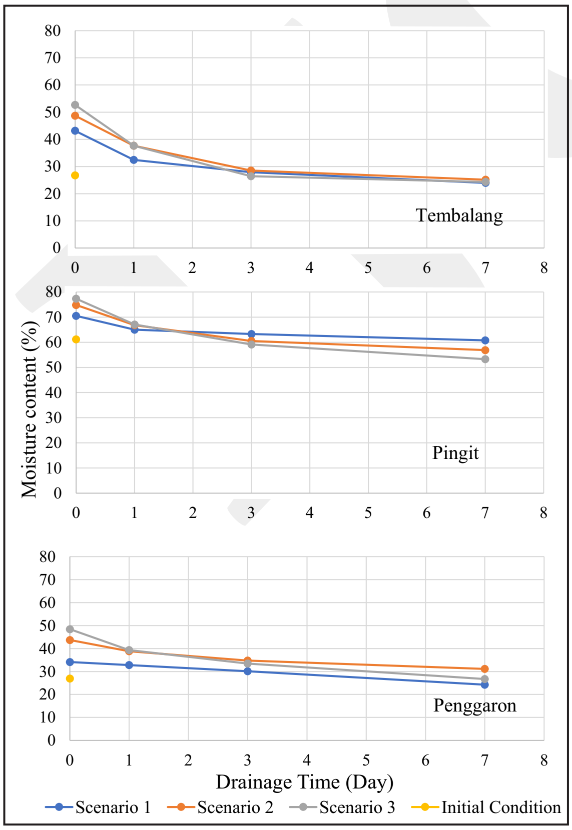

Figure 8. Relationship between moisture content and drainage time. (a) Tembalang, (b) Penggaron, (c) Pingit.

Discussion

Figure 9 shows the relationship between bearing capacity and soil moisture content for Tembalang, Penggaron, and Pingit soils. The initial conditions of friction resistance and soil moisture content were 2.66 kN and 26.72%, respectively for Tembalang soil, 1.81 kN, and 61.19%, respectively for Pingit soil and 2.49 kN and 26.90%, respectively for Penggaron soil. On Figures 9 and 10, it can be seen that the relationship between friction resistance and moisture content are quite similar for Tembalang and Penggaron soils. This is due to the fact that the soil from the two locations has similar shear strength parameters and moisture contents. The friction resistance pattern of Pingit soil tends to be smaller, compared to Tembalang and Penggaron soils, and this is due to the high moisture content at Pingit, which affects the soil shear strength parameters and reduces the friction resistance of the soil. These results show that the higher the soil moisture content, the smaller the soil friction resistance and, by con-

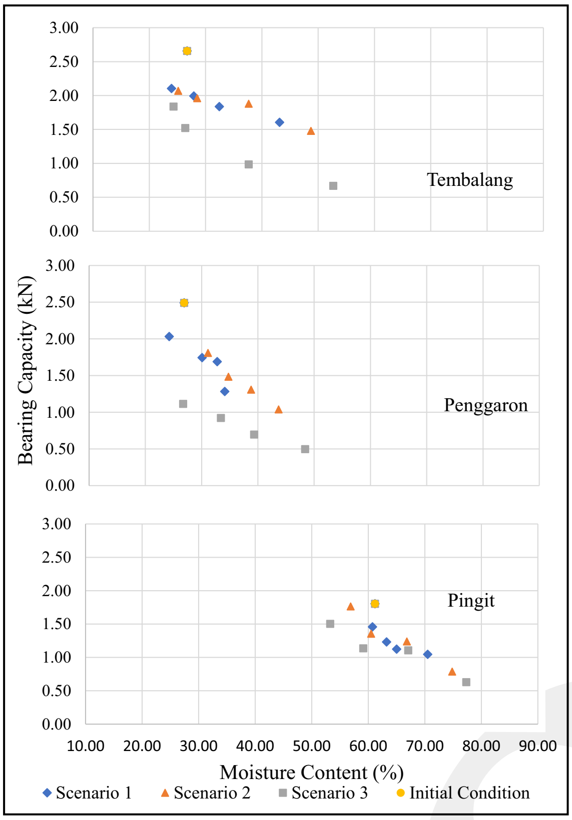

Figure 9. Relationship between Bearing Capacity and Moisture Content. (a) Tembalang (b) Penggaron (c) Pingit.

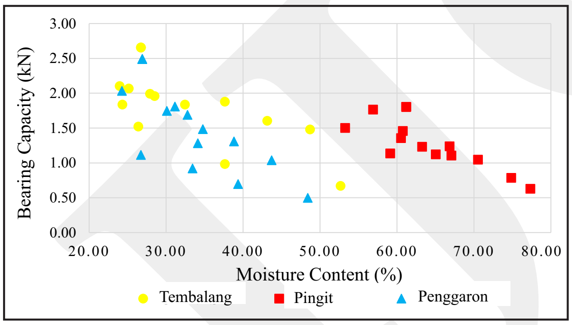

Figure 10. Relationship between Bearing Capacity and Moisture Content

trast, the smaller the moisture content, the greater the friction resistance. Homogeneous grain size distribution affects the friction resistance between the pile and the soil. This study has shown that the soil friction resistance value after draining for seven days, does not reach initial conditions. This is because the characteristics of the soil material is iso-elastic. Changing soil shear strength parameters, especially the value of soil cohesion, has a significant effect on friction resistance.

Conclusion

From this study, it can be concluded that changing the soil moisture content of clay soil has a significant effect on the friction resistance. Increasing soil moisture content, due to soaking, caused a decrease in friction resistance, while soil drainage caused an increase in the friction resistance. However, the value of friction resistance in soil samples that have been treated by soaking, followed by seven-day drainage, did not reach its initial conditions. This is due to the iso-elastic characteristics of the soil material. Changing soil shear strength parameters, especially the value of soil cohesion, has a significant effect on the friction resistance of piles.

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