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Study of pile friction capacity in soft clay soil based on laboratory scale model.

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Abstract. Banjarmasin City is an area with a type of soil with a low bearing capacity known as peat soil or soft clay. Wooden pile foundation which is the most frequently used choice in buildings in this city, relies on the principle of attachment or friction to support the structure. Following the discussion, this method has significant Differential Settlement risks. In the case of pile foundation, changes in shear strength of soil have an impact on bearing capacity of pile, such as modifications in soil water content. The first scenario during this study included wetting the object for 1 day and draining it for 2, 4, and 8 days. The second phase was wetting the test object for 3 days and drying it for 2, 4, and 8 days. Additionally, the third scenario was immersing the object for 5 days and draining it for 2, 4, and 8 days and also forming an object with the original water content. A loading test and an unconfined compression test were later conducted.Based on the total analysis results, increasing internal water content generally reduced friction bearing capacity (Qs) of pile. Increasing water content caused soil cohesion to decrease, changing the distance between particles and reducing shear strength of soil. Moreover, shear strength capacity of soil was weakened due to an increase in water content, enlarging the pores, and also reducing soil density.

Keywords. soft clay, friction capacity, pile foundation, soil water content.

1. Introduction

Buildings in Banjarmasin City are structures that generally rely on wooden pile foundation as the main solution to overcome soft clay soil conditions with low bearing capacity. This type of soil has limited load-bearing capacity and is susceptible to high compression, often causing structural collapse (bearing capacity failure). Meanwhile, more stable hard soil can only be found at depths of 30 to 50 m, allowing the available foundation options to be limited. Wooden pile foundation relies on the principle of friction to support the structure. This method has a significant risk of differential settlement, which is an uneven difference in foundation settlement and can cause cracks in the tilt of buildings.

Differential settlement has a serious impact on strength and durability of buildings. An example is the case of the collapse of a three-story shophouse in Gambut District, Banjar Regency, in 2022, which was caused by differential settlement. Following the discussion, cracks in the structure have been visible since 2021. Further investigations showed the cause of the cracks was an inappropriate foundation design and implementation that ignored technical standards. In Banjar Regency, around 100 multi-story buildings were reported to be in a tilted condition in the same year, and in Banjarmasin City, 11 houses experienced foundation subsidence during 2023.

Factors causing differential settlement include foundation design that does not follow SNI (Indonesian National Standard) 8460 of 2017 standard, lack of technical analysis, and the absence of soil investigation before construction. In addition, changes in building function, uneven additional loads, and the influence of loads from surrounding buildings also worsen the situation. This condition shows the type of foundation used is often unable to accommodate the differences in settlement that occur, leading to settlement values exceeding the required tolerance.

Previous analysis of clay soil in Semarang City showed that water content greatly affected bearing capacity of soil. When water content increases, bearing capacity of soil decreases drastically, and friction bearing capacity (Qs) of pile does not return to its original condition despite water content decreasing. This situation shows that changes in water content directly affect shear strength of soil, affecting the stability of the foundation. An increase or decrease in water content by 20% can significantly reduce shear strength of soil, thereby increasing the risk of structural collapse.

Further studies show that changes in water content affect soil shear parameters such as friction angle (φ) and cohesion (c). High water content tends to decrease these values, while low water content increases the values. In clay soil, changes in cohesion greatly affect Qs of pile. Changes in soil water content can cause Qs of pile to decrease in soil types such as in Banjarmasin City, which is dominated by soft clay, increasing the risk of foundation structure failure.

A study related to soil conditions in Banjarmasin City, using soft clay soil samples and substitution of Galam wood pile material, is expected to provide a more detailed Qs image of pile. Therefore, this study aims to determine how much Qs the pile has in holding the load above it, as well as to understand the effect of water content on soil shear strength and foundation stability with laboratory scale method.

Concerning this issue, several questions are formulated, namely how water content affects bearing capacity of pile friction foundations on soft clay soil. Other questions include how soil shear strength has effect after increasing water content, and what factors cause differential settlement in multi-story buildings in Banjarmasin City. This study aims to analyze the effect of water content concerning the formulated questions mentioned earlier.

2. Method

This study was conducted on Unlam Street, North Banjarmasin District, with soft clay soil samples obtained from a depth of 1 m. The experimental method was carefully arranged, starting from the preparation of tools such as handboring, PVC pipes, plastic wrap, and 16 mm diameter gelam wood. Moreover, the samples were wrapped in plastic to maintain individual condition before being tested in Soil Mechanics Laboratory, Faculty of Engineering, Lambung Mangkurat University. The test included soil characteristics such as water content, specific gravity, liquid/plastic/shrinkage limit, unconfined compressive strength test, and hydrometer analysis. Variations in wetting time (1, 3, 5 days) and drying (2, 4, 8 days) were conducted on 108 test objects. Additionally, gelam wood pile model (configuration 1, 2, 4 piles) was tested in a 3" diameter PVC pipe with a distance of 2D. The loading test was modified to measure pile friction and settlement capacity. The data was processed into tables/graphs for evaluation and to produce accurate conclusions.

3. Results and Discussion

3.1. Result

Table 1. Comparison of Qs and water content values for test object category 1 day immersion

1 Day Immersion				
1 Pile	w	41.80%	39.22%	32.11%
	Qs	0.70	0.80	1.26
2 Piles	w	43.22%	38.17%	33.13%
	Qs	1.04	0.64	1.99
4 Piles	w	43.59%	39.40%	34.03%
	Qs	4.15	2.43	3.29
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4 Piles	w	43.59%	39.40%	34.03%
	Qs	4.15	2.43	3.29

Table 2. Average values of water content and Qs of test specimens after 1 day of immersion

average w	42.87%	38.93%	33.09%
average Qs	1.96	1.29	2.18

Table 1 showed that, when considering the number of piles, number 4 had Qs than the smaller piles. The outcome occurred because the largest number of piles had a larger accumulation of the circumference area and surface of the shaft. Therefore, the accumulated value of Qs was also greater. [1] Tamara & Fahriani (2017) stated that a higher efficiency value of pile group showed better condition, as it led to the greater group bearing capacity in the group configuration.

Table 3. Comparison of Qs and water content values for test specimens after 3 days of immersion

3 Days Immersion				
1 Pile	w	43.22%	36.31%	30.62%
	Qs	1.04	0.64	3.29
2 Piles	w	41.55%	35.85%	31.06%
	Qs	0.84	1.16	1.46
4 Piles	w	43.29%	36.30%	33.31%
	Qs	1.88	2.99	4.50

Table 4. Average values of water content and Qs of test specimens after 3 days of immersion

average w	42.69%	36.15%	31.66%
average Qs	1.25	1.59	3.08

Table 3 showed the relationship between water content and Qs for variations in the number of piles with 3 days of immersion and then drying for 2, 4, and 8 days. Generally, the increase in water content less than 35.85 to 36.30% signified that Qs increment was moderate. When the decrease in water content exceeded this range, Qs value increased significantly. Piles with 4 had greater Qs than those having fewer piles. However, water content level for pile was higher at 33.31% compared to the test object with 1 pile, which had water content level of 30.62 and 31.06%, respectively. The outcome occurred because the highest number of piles had a larger accumulation of circumference and surface area of shaft, leading to the accumulation value of Qs becoming even greater.

Table 5. Comparison of Qs and water content values for test specimens after 5 days of immersion

		5 Days Immersion		
1 Pile	w	44.05%	37.11%	33.40%
	Qs	0.50	1.04	1.66
2 Piles	w	44.55%	37.43%	33.97%
	Qs	1.83	2.19	2.85
4 Piles	w	44.61%	38.13%	34.17%
	Qs	2.39	4.02	5.26

Table 6. Average values of water content and Qs of test specimens after 5 days of immersion

average w	44.40%	37.56%	33.84%
average Qs	1.57	2.42	3.25

Table 5 showed the relationship between water content and Qs for variations in the number of piles with 5 days of immersion, which was then dried for 2, 4, and 8 days. When water content exceeded the range of 33.40% to 44.61%, Qs consistently increased. Moreover, the behavior of increasing Qs occurred in all variations in the number of test piles.

Table 5 showed that piles with a total of 4 had greater Qs compared to those having fewer piles. The outcome occurred because the largest number of piles had a larger accumulated value of the circumference and surface area of pile shaft. Therefore, the accumulated value of Qs during the process became higher.

Table 7. Comparison of Qs and water content values for test object category 1 pile

1 Pile				
1 Day Immersion	w	41.80%	39.22%	32.11%
	Qs	0.70	0.80	1.26
3 Days Immersion	w	43.22%	36.31%	30.62%
	Qs	1.04	0,64	3.29
5 Days Immersion	w	44.05%	37.11%	33.40%
	Qs	0.50	1.04	1.66

Table 8. Average water content and Qs of 1 pile test specimen

average w	43.02%	37.55%	32.04%
average Qs	0.74	0.82	2.07

During the process, Qs value obtained was affected by the number of piles embedded. Figure 4 showed a comparison graph categorizing the number of piles, implying the significant difference in bearing capacity observed for each test object under various immersion time. Based on Table 8, the immersion for 1, 3, and 5 days as well as 2, 4, and 8 days of drying in 1 pile test specimen showed an increase in carrying capacity of friction when water content decreased. However, there was an increase in power Support significant friction when water content was less than 36.31 to 39.22%.

Table 9. Comparison of Qs and water content values for 2 piles test specimen category

2 Piles				
1 Day Immersion	w	43.22%	38.17%	33.13%
	Qs	1.04	0.64	1.99
3 Days Immersion	w	41.55%	35.85%	31.06%
	Qs	0.84	1.16	1.46
5 Days Immersion	w	44.55%	37.43%	33.97%
	Qs	1.83	2.19	2,85

Table 10. Average values of water content and Qs of 2 pile test specimens

average w	43.11%	37.15%	32.72%
average Qs	1.24	1.33	2.10

According to Table 10, the immersion for 1, 3, and 5 days as well as 2, 4, and 8 days of drying in 2 piles of test specimen showed the number of immersion days. During the analysis, the test for 5 days signified linear lines where water content in soil became higher, Qs reduced.

Table 11. Comparison of Qs and water content values for 4 piles test specimen category

4 Piles				
1 Day Immersion	w	43.59%	39.40%	34.03%
	Qs	4.15	2.43	3.29
3 Days Immersion	w	43.29%	36.30%	33.31%
	Qs	1.88	2.99	4.50
5 Days Immersion	w	44.61%	38.13%	34.17%
	Qs	2.39	4.02	5.26

Table 12. Average values of water content and Qs of 4 piles test specimens

average w	43.83%	37.94%	33.84%
average Qs	2.81	3.15	4.35

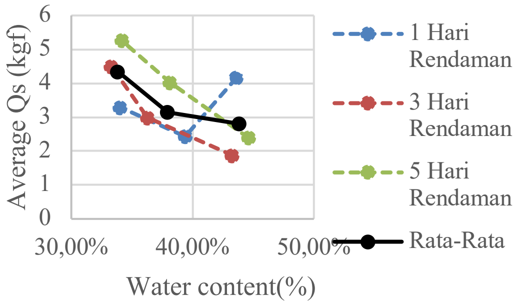

Figure 1. Bearing capacity curve for variations in immersion for 1, 3, and 5 days, as well as 2, 4, and 8 days of drying on 4 piles of test specimens.

Figure 1 showed immersion for the days mentioned earlier when drying in 2 pile test specimens. During the test, the immersion for 5 days showed a linear line where water content in soil became higher, Qs reduced.

3.2. Discussion

Based on the results and analysis described earlier, the outcome showed that as the increase in water content in soil became higher, Qs of pile foundation decreased. When viewed from the existing field conditions, specifically in the conditions of the many slanted buildings in Banjarmasin City and Banjar Regency that occurred after the flood in 2021 until early 2022, the condition correlated with the results of the study. The flood conditions increased water level leading to enlargement of soil pores, thereby reducing the density of soil. This condition also caused the weakening of bonds between soil particles, which affected soil friction.

According to the evaluation of foundation failure in multi-story buildings conducted by [2] Marzuki & Alpiannor (2016), the failure was showed by the presence of non-uniform settlement (differential settlement). This process occurred due to low foundation bearing capacity, strip configuration patterns, and several piles that affected the distribution of forces on piles as well as the presence of eccentricity. Irregularity in the foundation led to additional moments acting on the foundation. This greatly affected the distribution of loads acting on piles. The additional moments caused the load received by pile to exceed bearing capacity of a single pile limit. In addition, the non-uniform or uneven load distribution in the structure was borne by friction pile foundation that had experienced degradation due to increased water content, causing potential differential settlement.

4. Conclusion

In conclusion, increased water content in general decreased carrying capacity of pile friction. The lowest water content value of 32.51% was obtained at the condition of 1 pile test that was immersed for 1 day and then dried for 8 days, leading to friction carrying capacity of 1.25 kgf. The highest water content value of 44.75% was obtained at the condition of 2 piles test objects immersed for 5 days and dried for 2 days, causing friction carrying capacity of 1.83 kgf.

Shear strength capacity of soil was weakened due to the increase in water content, thereby enlarging pores and reducing soil density. The increase in water content caused soil cohesion to decrease, changing the distance between particles and reducing soil shear strength. Moreover, major factor that caused differential settlement during the study was the increase in water content in soil around friction pile foundation, as Qs decreased.

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