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The shear strength alteration on clay soil considering the plasticity index and the percentage of fine aggregates in tropical climate regions

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The shear strength alteration on clay soil considering the plasticity index and the percentage of fine aggregates in tropical climate regions

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Abstract. Seasonal changes in tropical regions could cause variations of soil water content, especially in clay soil. Furthermore, there is a significance difference in shear strength between wet and dry clay soil which depends on the plasticity index and the percentage of fine aggregates. Laboratory experiments were conducted to investigate the effect of the plasticity index and the percentage of fine aggregates in clay soil on soil shear strength changes due to water content variation. Soil samples were obtained from five locations in Surabaya City, Indonesia. The soil characteristics were tested in a laboratory to obtain the initial water content, Atterberg limits, specific gravity, and soil size distribution. The next stage was drying the soil samples. Each one was stored at room temperature to reach the determined soil weight. The shear strength of the soil in initial and drying conditions was determined by an unconfined compression test. The results indicated that the lower the moisture contents of soil, the greater the shear strength of soil, and vice versa. Soil shear strength changes up to 52 times within the range of 36% to 72% of moisture content The results also show that the value of shear strength variation depends on the plasticity index and the percentage of fine aggregate.

1. Introduction

Seasonal changes in tropical regions like Indonesia can cause variations in soil water content. In clay soils, these conditions affect the shear strength in the active zone, where groundwater fluctuations occur. During the rainy season, there is an increase in groundwater level, whereas it decreases in the dry season. Variation in water content in active zone will cause changes in soil characteristics and this change affects the shear strength of clay-bound soil [1-4].

The behavior of clay soil due to variations in water content should be considered so that the foundation can be designed properly and does not cause any damage to the building's structure. One important thing to note is the penetration of water into the soil, which can increase the soil's water content and reduce soil shear strength significantly [5-8]. In this research, a series of laboratory experiments were conducted to understand the impact of variations in water content on the shear strength of clay. In addition, this study also investigated the effect of plasticity index values and the percent of fine aggregate on shear strength changes in clay soils due to seasonal groundwater fluctuations.

2. Water content variation on clay

Clay is a soil with particles that are smaller than 0.002 mm. Clay particles are very fine and flat in shape. Moreover, clay is very hard in a solid state but when the water content increases, it has a plastic state. At higher water content, clay is sticky and very soft [9-10].

Clay with a groundwater level is generally in a saturated condition in which all soil voids are filled with water. However, in soil layers where groundwater fluctuations occur, variations in water levels can occur. The soil layer in the active zone can be in unsaturated conditions and its physical and mechanical characteristics can change. Groundwater fluctuations occur in the active zone is as shown in figure 1.

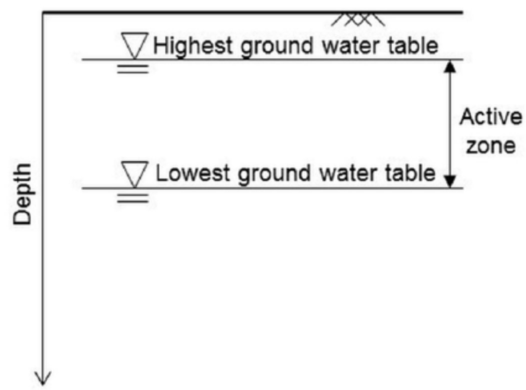

Figure 1. Active zone.

Changes in water content in the active zone greatly affect the shear strength of clay and thus its ability to support the foundation above. Water content has a significant effect on changes in soil cohesion. When water content increases, soil cohesion decreases. An increase in water content can change the distance between soil particles, which is followed by a decrease of bond strength between soil particles. Decreasing bond strength results in a decrease in cohesion and the loss of shear strength in clay-bound soil. In a previous study, it was shown that soil cohesion in the dry season reached four times higher than soil cohesion in the rainy season. For example, cohesion was 149 kN/m^2 in the dry season, while in the rainy season, cohesion decreased to 37 kN/m^2 [1].

3. Research methodology

This research begins by determining the area of soil sampling in the Surabaya City area. Soil samples were obtained from five separate locations in East and South Surabaya. Soil samples were taken undisturbed using a Shelby tube with a diameter of 7 cm at the depth of the active zone, which is about one meter from the ground surface. The soil sample in the tube was then immediately covered with wax or plastic at the top and bottom to prevent changes in moisture content. The soil sample was then carried to the laboratory for soil testing. The next research stage was to conduct laboratory testing of soil samples taken from the field.

Laboratory testing was conducted to determine the physical and mechanical characteristics of the soil. Some physical characteristics tests were done to identify soil samples, which were taken from the field. Several laboratory tests were conducted to determine the soil's physical characteristics such as water content, consistency index (liquid limit and plastic limit) and specific weight. In addition the soil was tested to determine its mechanical characteristics in order to obtain the value of the soil's shear strength parameters. In this study, the mechanical parameter of the soil was represented by undrained

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shear strength. The undrained shear strength value was obtained from the results of the unconfined compression test.

Physical and mechanical characteristics tests were carried out on two variations of soil moisture conditions. The first condition was the initial condition, represented by the undisturbed soil sample taken from the field. The second condition was the drying condition in which the soil samples underwent a drying process with a moisture content of about 10%, 20%, 30%, 40% and 50% of the initial moisture content. The drying processes were not conducted inside an oven, but by placing soil samples in free air. This was done to avoid damage to the arrangement of the particles of each soil sample, until it reaches the desired moisture content. Water content variations carried out in the laboratory were used to simulate soil conditions in the field at the depth of the active zone. Determination of variation moisture content was adjusted to the actual moisture content variations that occur in the field throughout the year. The water content variation interval that occurs throughout the year was obtained from secondary data in the form of soil testing results at the Soil Mechanics Laboratory, Petra Christian University.

4. Result and analysis

Physical characteristics testing of the soil was carried out on all soil samples taken from the five locations in Surabaya. The results of these tests are shown in table 1.

Table 1. Initial Soil Characteristics.

No	Location	Water Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Fine Aggregates (%)
1	Makarya	72,46	2,61	103,44	22,56	80,88	82,41
2	Siwalankerto	61,09	2,63	104,15	43,10	61,06	91,92
3	Kertomenanggal	92,28	2,64	99,04	41,23	57,81	93,92
4	Krian	74,17	2,66	93,51	40,81	52,71	96,42
5	Keputih	111,85	2,58	117,32	28,37	88,95	76,52

As a basis for determining the water content variation that occurs throughout the year, secondary data was collected from the Soil Mechanics Laboratory, Petra Christian University. Secondary data was soil moisture content data taken from several locations in East and South Surabaya throughout the year. The water content data used in this study was determined at a depth of about 1 to 2 meters below ground level. The variation in water content obtained throughout the year is shown in figure 2, where the value of water content ranges from 36% to 72%.

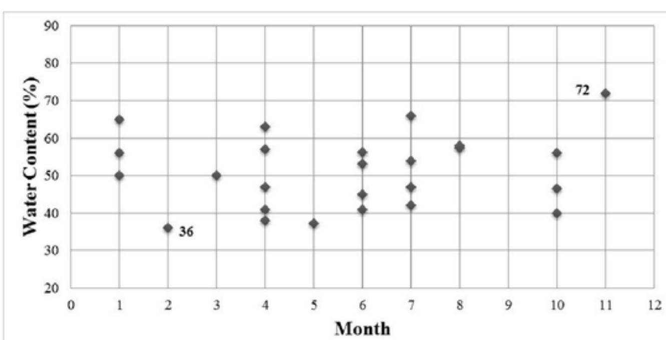

Figure 2. Water content variation in several locations in East and South Surabaya during a year.

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Based on the water content variations that occur in the field, similar variations were applied to the soil samples taken from the field. The variation in water content was carried out in the form of a reduction in soil moisture content of 10%, 20%, 30%, 40% and 50% of the initial moisture content. The variation in water content on unconfined compressive strength of the soil in the five locations can be seen in figure 3 to figure 7. The results of the variation in water content shows that there was a significant change in unconfined compressive strength of the soil. The results showed that the shear strength increases with a decrease of soil water content. As the water content of the soil sample reduce there was an exponential increase in the soil's unconfined compressive strength, especially when the soil water content approached the plastic limit value. This phenomenon is caused by the soil changing from the plastic phase to the semi-solid phase.

From the variations in water content carried out on the soil samples, the equations relationship between changes in water content and unconfined compressive strength were obtained. These equations are expressed in a graph with a value R^2 greater than 0.95 (figure 3 to figure 7).

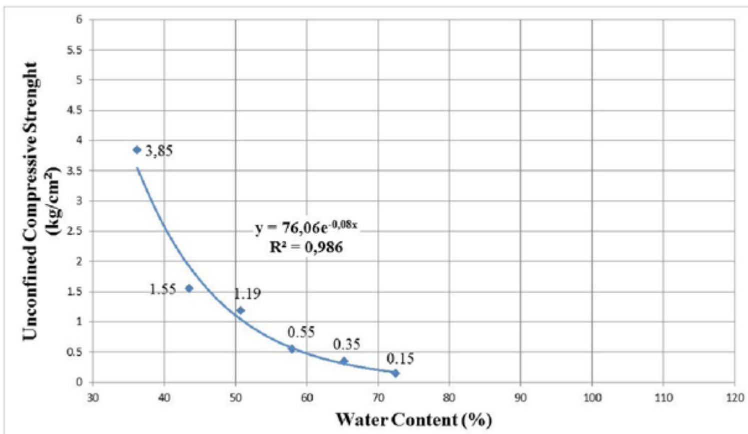

Figure 3. Changes in unconfined compressive strength due to water content variation at Makarya.

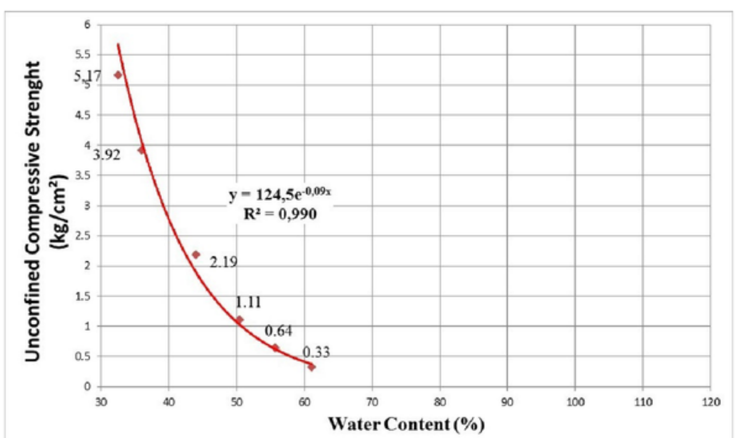

Figure 4. Changes in unconfined compressive strength due to water content variation at Siwalankerto.

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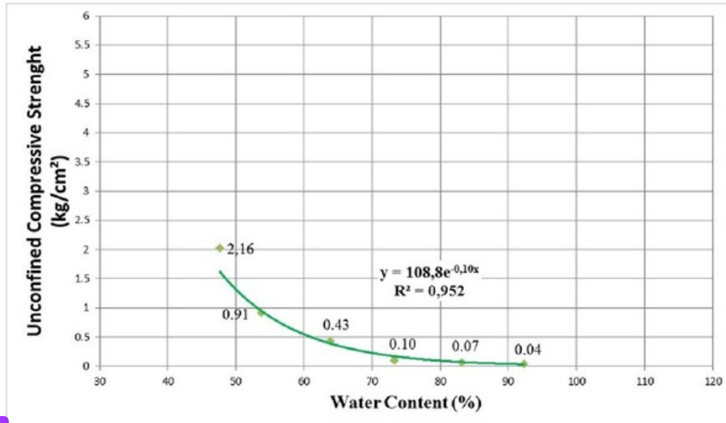

Figure 5. Changes in unconfined compressive strength due to water content variation at Kertomenanggal.

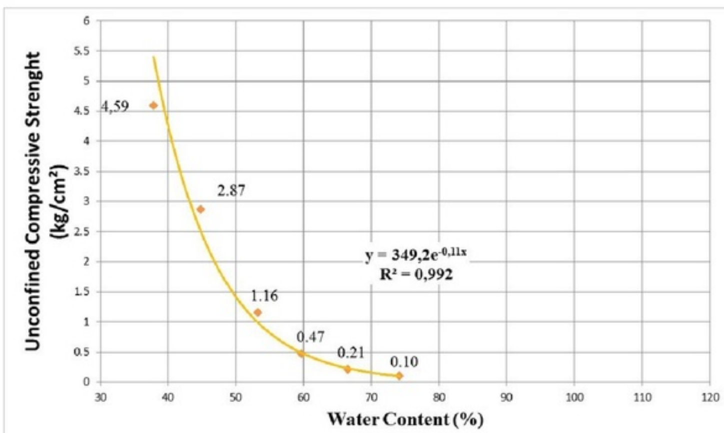

Figure 6. Changes in unconfined compressive strength due to water content variation at Krian.

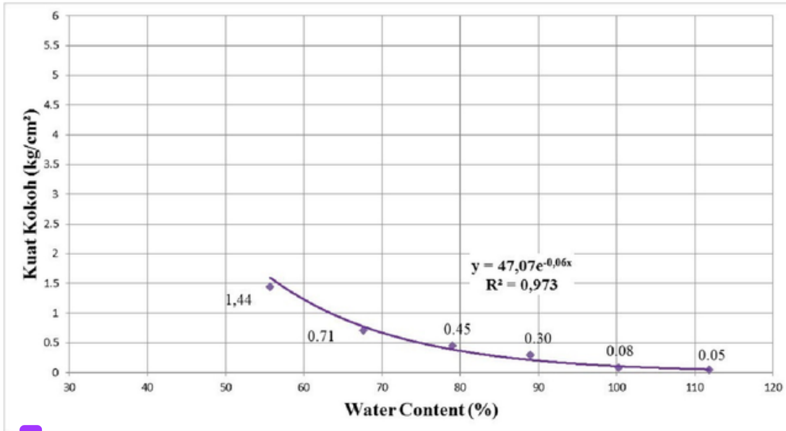

Figure 7. Changes in unconfined compressive strength due to water content variation at Keputih.

The equations from figure 3 to figure 7 could be applied to make strong predictions of soil at a certain water content value. Based on the range of water content variations obtained throughout the year as shown in figure 2, where the value of water content ranges from 36% to 72%, unconfined compressive strength in each location as the water content changed from 36% to 72% could be predicted as shown in table 2.

Table 2. Changes in unconfined compressive strength (UCS) based on water content variation in several locations at East and South Surabaya along during a year.

Location	Plasticity Index	Fines Aggregate (%)	Initial UCS (kg/cm²)	UCS at Water Content 72 % (kg/cm²)	UCS at Water Content 36 % (kg/cm²)	Changes in UCS (times)
Makarya	81	82,41	0.15	0.17	3.57	21.33
Siwalankerto	61	91,92	0.33	0.19	4.88	25.53
Kertomenanggal	58	93,92	0.04	0.08	2.97	36.60
Krian	53	96,42	0.10	0.13	6.66	52.46
Keputih	89	76,52	0.05	0.63	5.43	8.67

In five locations of soil sampling, each location has a separate plasticity index value, which influences the magnitude of changes of unconfined compressive strength in the soil. Figure 8 shows that along with a decrease in the plasticity index value, the soil's unconfined compressive strength will be greater. This is caused by a change of water content in the soil with a smaller the plasticity index value; soil phase conditions become possible to immediately change from plastic condition to semi-solid conditions and vice versa. Soil with a small index of plasticity shows a short range between the liquid limit and the plastic limit so that unconfined compressive strength changes significantly when changes in water content occur in the soil.

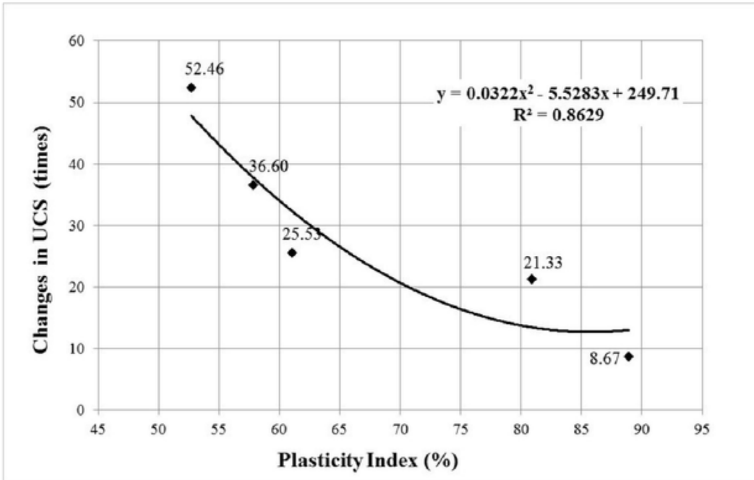

Figure 8. Relationship between plasticity index and changes in UCS.

In addition, each location at the five soil-sampling locations has a variation percentage of fine grains. The percentage value of fine grain can affect the magnitude of the unconfined compressive strength change that occurs in the soil. Figure 9 explains that along with the increase in the percentage of fine grains, the unconfined compressive strength change will increase. In the range of changes in water content of 36%, clay soils with a percentage value of fine grains of less than 80% had a change in unconfined compressive strength of up to eight times. Clay with a percentage value of fine grains of more than 95% undergoes a change of unconfined compressive strength in the soil of up to 50 times.

The higher the percentage value of fine grains, the higher the clay content of the soil. This was due to the fact that the clay was formed from soil particles that could absorb water. Clay behavior was very susceptible to addition or reduction in water content. Some clay was very sensitive to interference, so there would be a change in the value of shear strength due to the disruption of the original structure of the soil.

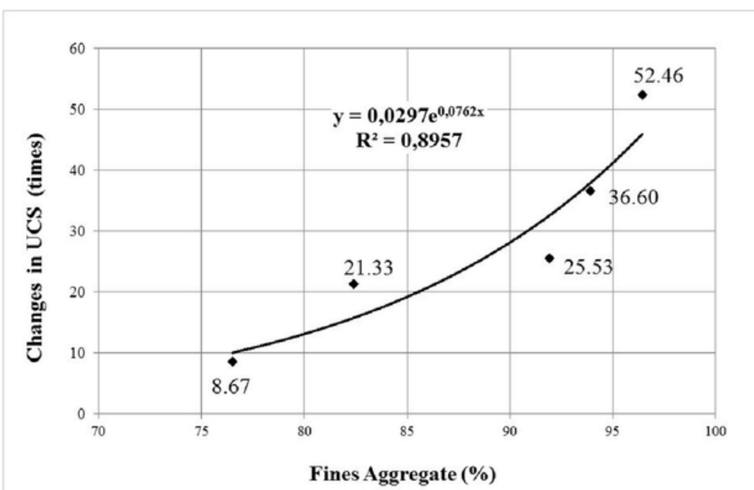

Figure 9. Relationship between fine aggregates and changes in UCS.

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Figure 10 and figure 11 show the relationship between the percentage of fine aggregates and specific gravity and the plasticity index. The increase of specific gravity caused by increases in fine aggregates was due to the specific surface of soil particle increasing so that the soil weight also increased compared to the unit weight of water. Otherwise, increasing the percentage of fine aggregates was followed by a decrease of the plasticity index. Generally, increasing the percentage of fine aggregates was followed by an increase in the plasticity index [11] but in this study, the decrease of plasticity index was due to the soil consisting of a higher percentage of silt particles compare with clay particles. The silt contents were almost half of the percentage of the fine aggregates.

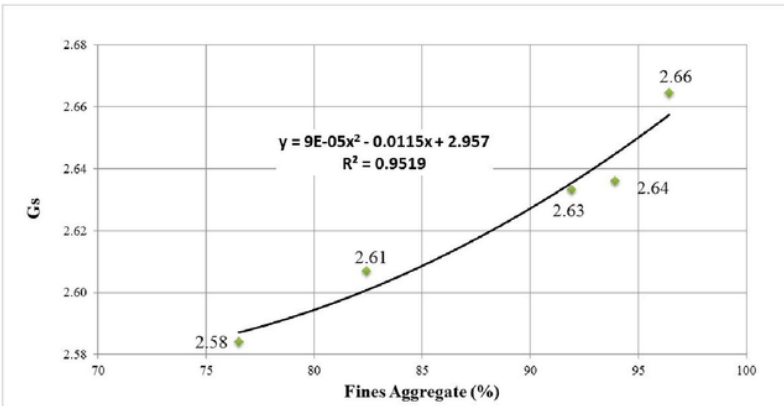

Figure 10. Fine aggregates and specific gravity relationship at five locations.

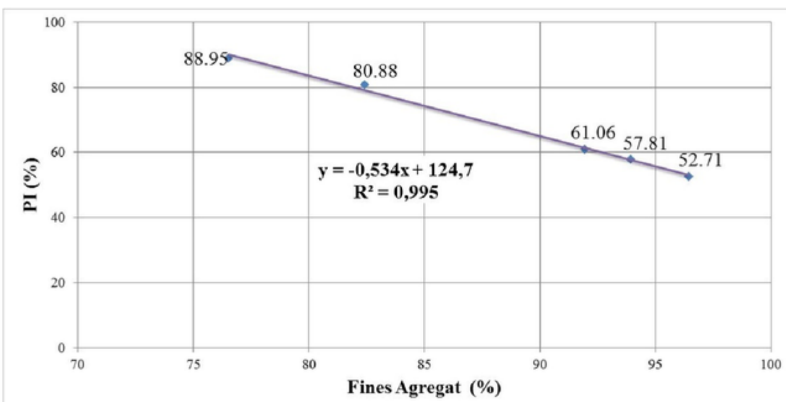

Figure 11. Relationship between fine aggregates and plasticity index.

5. Conclusion

Based on the series experiments, data analysis and interpretation of several graphics above, the conclusions of this research are:

1. When the soil water content approaches the plastic limit, there was a significant increase in unconfined compressive strength. From this study, the relationship between unconfined compressive strength and water content was expressed in the form of equations with R^2 greater than 0.95.

2. In the same range of water content changes, which was approximately 36%, in clay soils with a plasticity index of about 90, unconfined compressive strength changes about eight times. Whereas in clay with a plasticity index value of around 50, unconfined compressive strength changes in the soil reached 50 times The relationship between the plasticity index (PI) and the unconfined compressive strength change of soil (Δqu) in this study could be expressed in the equation $\Delta qu = 0.0322PI^2 - 5.528PI + 249.71$ with the value $R^2 = 0.86$.
3. In the same range of water content changes, which was equal to 36%, clay soils with a percentage value of fine grains less than 80% underwent unconfined compressive strength changes in the soil eight times. When clay had a percentage value of fine grains of more than 95%, changes in unconfined compressive strength reached fifty times. The relationship between the percentage of fine grains and the changes of unconfined compressive strength of soil (Δqu) in this study can be expressed in the equation $y = 0.0297e^{0.0762x}$ with the value $R^2 = 0.9$, where:
   - x = percentage of fine grains
   - y = unconfined compressive strength change (Δqu)

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