Shear Strength Evaluation of Silt-Clay Soil Under Uni-Axial Compression

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Abstract. Effect of different moisture content and applied pressure to soil shear strength parameters are evaluated. Silt-Clay soil from Ngemplak, Kalikotes, Klaten Regency becomes the subject of the experiment. The research was conducted using a simulation in the laboratory to determine the relationship between water content and soil pressure. The expected values are the pressure that arises and the shear strength of the soil when using four water constructions of 20%, 25%, 30%, and 35%. For each variation of moisture content, three different pressure in the form of uni-axial compression that considered based on the different energy given by equipment used to do compaction will affect the soil density. The applied pressure used is 1.5 kN, 2.5 kN, and 3.5 kN. The result showed that moisture content having a great impact on soil shear strength parameter. The cohesion of soil decreases due to an increase in water content. The friction angle works in linear conditions with moisture content but decreases at the value of 35% water content. The best-fitted distribution for the relationship between soil shear strength and moisture content is polynomial order two. Follow the equation for 1.5 kN applied pressure is:

\[ y = -0.0036x^2 + 0.2236x - 2.4898 \]

for 2.5 kN applied pressure the equation is:

\[ y = -0.0025x^2 + 0.1545x - 1.3383 \]

and for 3.5 kN applied pressure the equation is:

\[ y = -0.0022x^2 + 0.1357x - 1.0344 \]

1. Introduction
In a construction project, the soil is one of the vital aspects that need special attention. The soil quality affects the strength of the building above it. In the Unified classification system, the soil is classified as coarse-grained soil (sand and gravel) if less than 50% passed sieve number 200 and classified as fine-grained soil (silt/clay) if more than 50% passed sieve number 200 [13].

Not only has to function as a support for building foundations, but the soil is also used as embankment material as commonly used in construction projects for dams, dikes, and roads. However, the quality of soil often not in accordance with the quality that has been planned, so some efforts need to be made to improve the quality of the soil as construction materials. One of the efforts made to improve the soil quality is compaction. Soil compaction is a mechanical method to increase the density of soil grains caused by removing air void through the soil pore [14]. By providing dynamics loads to the compaction process, soil granules move closer to each other so that the air void on it can be reduced. The soil density is affected by the type of soil and compaction energy given to the soil. The soil compaction objectives include increasing the shear strength of soil, reducing the soil compressibility, reducing permeability of soil, reducing changes in volume due to changes in moisture content, etc.
The one that has a significant effect on compaction is moisture content. Water in the compaction process can have a low and high impact on soil density, especially on fine-grained soil. Fine-Grained soils tend to have low permeability, so it is challenging to compact if the soil is in a very saturated condition. But, if consolidated in the right ways, the shear strength of soil can be increased significantly. Shear strength is the resistance force carried out by soil grains against friction or pull [15]. Based on that understanding, if a load is applied above the soil, it will be held by soil cohesion, which depends on the soil types and density, and by friction between soil grains. This research is trying to evaluate the effect of uniaxial compression on the shear strength of soil, the type of testing conducted is DST (Direct Shear Test). And for sampling, the variation of soil moisture content and pressure are used.

2. Research Method
Data sampling was collected by conducting laboratory experiments using some variation of soil moisture content and pressure in the compaction process. Several researchers have discussed the strength of water absorption to soil [1–9] to obtain soil types’ strength and stability for specific applications. Calculation of water absorption capacity against soil pressure cannot be separated from the effect of the stability. Some of the following stability researchers [10–12] have submitted stability algorithms for specific applications. And of course, if the observations are made in a computer simulation, a sharp display is required. The following researchers have [19–26] discussed algorithms for reducing the dimensions and brightness of images even on a small scale. The land’s appearance can be compared to the background view of the human body affected by the pandemic during this New Era. In case the soil density is in different conditions, and the shear strength parameter of soil will vary. Soil sample used as the subject of the experiment taken from Ngemplak, Kalikotes, Klaten Regency in a disturbed condition. The research stages include initial moisture content test of soil in dry air condition, sampling, and loading test, then conducting a direct shear test to evaluate the soil shear strength parameters. Before experimenting, the literature study was done simultaneously with preparing soil samples and required tools.

The soil sample was made using a mold with a diameter $\pm 15.5$ cm and high $\pm 18$ cm. The model has four moisture content variations: 20%, 25%, 30%, and 35%. Then, compact the soil using a loading testing machine modified with the screw jack, based on the method [16]. The applied pressure used in this experiment is 1.5 kN, 2.5 kN, and 3.5 kN. Each variation moisture content was given three different applied pressure. The total number of samples got from the loading stage is 12 samples.

The third stage is conducting a direct shear test for each soil sample taken three different models to be tested using direct shear test apparatus. Testing was done using three average loads. The test result then processed using the Microsoft Excel program to get the soil shear strength parameter value. The conclusion of the experiment is concluded based on the data obtained from the test. The vertical loading test setting presented in Figure 1 and Figure 2, direct shear test apparatus illustrated in Figure 3 and flowchart of the experiment can be shown in Figure 4.

3. Result and Discussion
3.1. Moisture Content Test Result
Because this research will use some variation of moisture content, it is needed to calculate the value of adding water to reach the planned moisture content. Firstly, it is required to know the importance of initial water content. From the test, the average value of soil moisture content in the air-dried condition is 10.5%.
3.2. Physical Properties of Soil
The type of soil classification that is often used is based on AASHTO and USCS. Based on the research that has been done by [17], the number of soil that passing sieve number 200 is 66%, the value of LL is 49.14%, PL 38.75%, PI 10.39%, SL 23.2%, and soil specific gravity is 2.598. Based on USCS, by reading the plasticity chart, the soil included in ML-OL having means the soil is silty soil with low-plasticity (ML) or organic silt or clay with low-plasticity (OL). From the value of LL=49.14% and PI=10.39%, soil can be classified as silt-clay soil with moderate to deficient general rating of subgrade. Gradation of soil particle can be seen in figure 5:

3.3. Relation Between Moisture Content (%) and Cohesion ($c$)
The soil cohesion will be decreased due to the increase of moisture content. This statement deals with the previous experiment done by [18]. In fine-grained soil, the effective soil area is higher so that the variation of moisture content will affect the plasticity of the soil. Fine-grained soil particles have a negative electrical charge. To offset the charge, particles attract positive charge ions (cations) from salts present in pore water. Water molecules are dipolar molecules. That is, hydrogen atoms are not arranged symmetry around oxygen atoms. Suppose the number of water molecules is larger than soil particles. In that case, water molecules that do not bind to soil particles will attach to the water molecules themselves with different poles. In this case, when water and soil are stuck, then given some pressure, it will help the soil particle move near each other, it means that the binding between same particle or commonly referred as cohesion are rise, but when the value of water is higher, it will block the soil particle to move closer each other. For more precise result can be seen in figure 6:

3.4. Relation Between Moisture Content (%) and Friction Angle ($\phi$)
The soil with higher moisture content will be denser so that the friction angle also increases when the soil moisture content is also increased. But, in the particular value of moisture content, the friction angle ($\phi$) is decreased. It can happen because the soil density also decreases due to the soil sample’s condition already in a saturated state. The soil cannot be compacted effectively. Water has a function as a lubricant in the compaction process. If the amount of water is excessive, it will make the soil surface wet, the slippery of soil becomes higher, so the friction between soil particles reduces. The result can be shown in figure 7:

3.5. Effect of Pressure on Soil Shear Strength Parameter
Besides being influenced by water content, soil density is also influenced by the effort given to the soil to solidify. On the same amount of moisture content, it can be seen that the value of
cohesion in the soil decreases with increasing pressure given to the soil, while the value of the friction angle on the soil increases.

High pressure will help soil particles move closer to each other. At the same level of moisture content, friction between soil particles increases because of soil particles trying to fill the void with the help of high pressure. The soil cohesion decreases because the binding between soil and water becomes low when the soil itself already filled the void on it: figure 8 and figure 9 shown the relation between the effect of pressure on soil shear strength parameter.

3.6. Effect of Moisture Content and Pressure on Soil Shear Strength
The value of soil shear strength will be increased by conducting this experiment due to increased water content. But, in the certain moisture content, the value of soil shear strength is decreased.
It can happen because the value of soil cohesion already decreases. In the same moisture content level with different pressure, the value of soil shear strength increases continuously. The regression models using polynomial order two can be shown in figure 10. From the regression model, got the equation that can be shown in Table 1 below: $D$ is Dependent Variable, $I$ is Independent Variable, $A$ is Applied Pressure (kN), $SS =$ Shear Strength, $MC =$ Moisture Content.

Regression analysis is used to know the relationship between dependent and independent variables. A dependent variable is a variable that is influenced by an independent variable.
Table 1: Relation between dependent and independent variables

| $D$ | $I$ | Predictive Models | $R$  | $A$  |
|-----|-----|--------------------|------|------|
| SS  | MC  | $y = -0.0036x^2 + 0.2236x - 2.4898$ | 1    | 1.5  |
| SS  | MC  | $y = -0.0025x^2 + 0.1545x - 1.3383$ | 0.9526 | 2.5  |
| SS  | MC  | $y = -0.0022x^2 + 0.1357x - 1.0344$ | 0.922  | 3.5  |
Figure 6: Relation Between Moisture Content (%) and Cohesion (c)

Figure 7: Relation Between Moisture Content (%) and Friction Angle ($\phi$)

Figure 8: Relation Between Pressure (kN) and Friction Angle ($\phi$)

Figure 9: Relation Between Pressure (kN) and Cohesion (c)
Figure 10: Regression Models of Soil Shear Strength (Kg/cm²) and Moisture Content (%).

An Independent variable is a variable that caused a change in the dependent variable. In this analysis, the dependent variable is the shear strength of soil, and its value will be affected by the soil moisture content that acts as the independent variable. R is influenced by the weight of independent and dependent variables. The value of R ranged from -1 to +1. The relationship is perfect when the coefficient of R equal to +1 or -1 and considered to be unrelated between the two variables tested when R’s coefficient values are equal to 0 or close to 0. From the research result, the relationship between dependent and independent variables is considered a perfect relationship because R is close to 1. It means that the value of moisture content has a big impact on the shear strength of the soil.

4. Conclusion
The research has some conclusions as follows: Moisture content having a big impact on soil shear strength parameter. By increasing the soil moisture content, the cohesion of soil become decrease, and the value of friction angle increase then decrease in certain moisture content The pressure given to the soil as some effort to compact the soil gives different impacts to the soil shear strength parameter. By increasing the pressure, the value of soil cohesion is decreases in the same level of moisture content. And the value of friction angle rises due to the increase of pressure. Shear strength value of soil influenced by the value of soil cohesion and friction angle. Best fitted distribution for the relationship between soil shear strength ad moisture content is polynomial order two. Follow the equation for 1.5 kN applied pressure is \( y = -0.0036x^2 + 0.2236x - 2.4898 \), for 2.5 kN applied pressure the equation is \( y = -0.0025x^2 + 0.1545x - 1.3383 \), and for 3.0 kN applied pressure the equation is \( y = -0.0022x^2 + 0.1357x - 1.0344 \).

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