Analysis of shear strength of the expansive soil stabilized with kaolin at various soaking times

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Abstract. Expansive clay soils are high shrinkage soils that have low bearing capacity. So an effort is needed to reduce the nature of its swelling. One effort that can be done is the method of soil stabilization, where the soil is mixed with materials that can reduce soil swelling and increase the shear strength of the soil. One of the materials that can be used is kaolin powder. Kaolin is a stabilizing agent found in nature so it is easy to obtain. The purpose of this research is to analyse the decrease of expansive soil swelling and the value of its unconfined compression strength at various soaking times. The test was carried out by mixing 9% kaolin powder against dry soil weight. The stabilized soils were then compacted as samples to be soaked with time variations of 0 days, 3 days, 7 days, 10 days, and 14 days. The results of the test after soaking 14 days is a decrease of the stabilized soil swelling value up to 67.78%. The unconfined compression strength is increase up to 77.28% compared to its natural condition.

1. Introduction
Soil research is needed to ensure the stability of the building because the strength of the structure will be directly affected by the ability of the local subgrade and foundation to accept and continue the working load. Each location has different characteristics and types of soil, as well as its bearing capacity. The problem is soil with low bearing capacity. Expansive clay soils are extensively distributed worldwide, and are a source of great damage to infrastructure and buildings [1]. One type of soil with low bearing capacity is expansive clay, expansive clay is a soil with high shrinkage properties. Expansive soil is one of the most devastation type of soil damaging roads, building, and pipe line each year [2]. To overcome the problem of expansive soil, efforts are made in the form of soil improvement or stabilization. Soil stabilization is an action or effort made to improve soil properties so that it meets the required conditions. One of the soil stabilization can be done by mixing kaolin with expansive soil [3].

Kaolin is a natural material in the form of rock. Kaolin is composed of clay material, the main mineral of kaolin is kaolinite which consists of one sheet of tetrahedic silica and one sheet of aluminium octahedra, the two sheets are bonded together. The kaolinite particles may be more than a hundred piles so they are difficult to separate, so the mineral is stable and water is difficult to enter between the plates to produce expansion or shrinkage. Kaolin contains silica, aluminium oxide, iron oxide more than 70%. This content is included in a material called the pozzolan material. This material produces a pozzolanic reaction with the soil where this reaction is a reaction between silica and free calcium hydroxide with the soil, so that the reaction that occurs can increase soil strength.
Research on soil stabilization with kaolin has been done before [4] regarding residual soil stabilization using kaolin and lime, the results of this study show that the addition of kaolin and lime 10% can increase the CBR value of the soil after planting for 14 days. Another study [5] was about the comparative analysis of shear strength in Depok red soil by mixing kaolin with variations of 5%, 8%, and 10%. In this study, it was found that the addition of 8% kaolin was the optimum level and increased the cohesion value of red soil, where the higher the soil cohesion value, the more bearing capacity it had. In this study, 9% of the dry weight of the soil was used. This percentage refers to previous studies. The study aims to determine the effect of soaking time on soil swelling and UCT value.

2. Methods

In this study, the disturbed soil test specimen was taken from the Meikarta Cibatu Project, Cikarang Selatan, Bekasi. The mixed material used is kaolin, Mesh 325, in powder form. Various criteria adopted to recognize the presence of expanding lattice type clay minerals in a natural soil can be broadly classified into two categories namely, mineralogical identification and inferential testing methods [6].

2.1. Testing the physical and mechanical properties of soil

2.1.1. Atterberg limit. Tests carried out to identify expansive soils are carried out by testing the correlation of index properties without carrying out mineralogical identification. Atterberg testing which consists of: Liquid Limit Test [7], Plastic Limit Test [8] and Test of Shrinkage Limits [9].

2.1.2. Soil density testing. This test aims to determine the Specific Gravity (Gs) value or weight of a soil, namely the ratio between the soil grain weight and the water content weight at the same temperature (temperature) and volume. Testing the physical properties of the soil with the Specific Gravity test [10].

2.1.3. Compaction test. The purpose of this test is to obtain the optimum water content, in which the soil moisture content has a maximum dry density. The optimum water content obtained will later be used as water content for making soil samples with kaolin mixture for development tests. The soil is mixed with different moisture content. Soil compaction testing [11] (Table 1).

| Sample type | Soaking time |
|-------------|--------------|
| 1           | 0 days       |
| 2           | 3 days       |
| 3           | 7 days       |
| 4           | 10 days      |
| 5           | 14 days      |

2.2. Testing of soil development (swelling)

The purpose of soil development (swelling) testing is to determine the potential for expansive clay soil to expand. This test is carried out using a paralon pipe and a consolidation tool dial. The soil with the kaolin mixture that has been compacted is put into a paralon pipe with a diameter of 12 cm and a height of 16 cm, then the soil is cured for 7 days and closed tightly using a plastic bag. After brooding, the top of the ground is covered with parchment paper and cover notes, where the cover notes are given a hole in the middle with a diameter of 3 cm, the underground part is also covered with parchment paper. After that, the consolidation tool dial is installed. Then the soil sample was immersed based on the variation of the soaking time.
2.3. *Unconfined Compression Test (UCT)*
This test aims to determine the free compressive strength of cohesive soil, which is an approach of undrained soil shear strength. The soil used is a soil sample that has been tested for swelling, based on the duration of soaking. From the unconfined compression test, the value of free compressive strength ($q_u$) will be obtained to determine the undrained shear strength of the soil. Testing the value of free compressive strength (Unconfined Compression Test) on soil with a mixture of kaolin [12].

3. Results and discussions

3.1. *Test result of physical properties of soil with Atterberg limits and density (Gs)*
From the data analysis of Atterberg boundaries and soil and kaolin density tests, the results are in Table 2.

| Soil Conditions | Liquid Limit (LL) (%) | Plastic Limit (PL) (%) | Plasticity Index (PI) (%) | Shrinkage Limit (SL) (%) | Specific Gravity of Kolin (gr/cm³) |
|-----------------|-----------------------|------------------------|--------------------------|--------------------------|---------------------------------|
| Clay            | 60,34                 | 20,48                  | 39,85                    | 7                        | 2,628                           |

Based on the results of the Atterberg limits test that has been obtained, it can be seen that the soil used is clay which has a high liquid limit value ($LL > 50$) and is fine grained soil with high plasticity values. From the results of the liquid limit test and the plasticity index obtained from the Atterberg limits test, the soil can be classified using the USCS system plasticity diagram. Based on the plasticity diagram, it is obtained that the type of soil used is included in the CH type soil group. According to the soil classification table of the USCS system, CH soil is clay where the soil is an inorganic clay with high plasticity.

3.2. *Identification result based on soil physical properties testing*
The results of the physical properties tests on the soil used in this study are used as a guide to identify the soil and the degree of development of the clay soil, so it can be seen that the soil under study is a type of expansive soil. From the results of testing the Atterberg limits that have been obtained, the value of the plasticity index (PI) of the tested clay soil is 39.85%.

| PI (%) | Property         | Type of soil | Cohesion     |
|--------|------------------|--------------|--------------|
| 0      | Non Plastic      | Sand         | Non-Cohesive |
| <7     | Low Plasticity   | Silt         | Partially Cohesive |
| 7 – 17 | Moderate Plasticity | Silty Clay | Partially Cohesive |
| >17    | High Plasticity  | Silty Clay   | Cohesive     |

Table 4. Identification of expansive soils based on the relationship between the plasticity index and the potential to expand in clay soils [13].

| Plasticity Index (%) | Potential Expanding |
|----------------------|---------------------|
| 0 – 15               | Low                 |
| 10 – 35              | Medium              |
| 20 – 55              | High                |
| >35                  | Very High           |
Based on Table 3 and Table 4 it is concluded that the tested clay has the potential to expand critically, namely the soil expands and shrinks rapidly.

3.3. Compaction testing results
Based on the graph of water content, it can be seen that the optimum water content from the compaction test results on the soil is 24.9%. This optimum water content is used for the large amount of water that will be mixed into the soil for development tests (swelling) and the free compressive strength of the soil with the kaolin mixture.

3.4. Development potential test results (swelling)
The compaction process for the development test sample and free compressive strength using the optimum water content that has been obtained from soil compaction is 24.9%.

| Percentage of Kaolin | Development Potential (swelling) (%) |
|---------------------|--------------------------------------|
| 0 %                 | 0 (day) 3 (days) 7 (days) 10 (days) 14 (days) |
| 0 %                 | 0 5.12 6.51 6.53 6.54 |
| 9 %                 | 0 1.62 2.08 2.09 2.094 |

Based on the graph in Table 5, it can be seen that soil with a mixture of 9% kaolin can suppress soil development (swelling). The difference in development that occurs after 14 days of soaking is 4.446%, where the soil mixture with 9% kaolin can suppress the swelling of 67.98% compared to the soil without kaolin mixture. From this figure it can also be seen that the increase in swelling that occurs during immersion with a mixture of 9% kaolin is more constant than without the mixture which we can see that the increase that occurs in the original soil is quite drastic. Therefore, mixing expansive soil with 9% kaolin can optimize the reduction in the development (swelling) of expansive clay. These are hydraulic materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials [14].

The percentage of development that occurs with expansive clay mixed with 9% kaolin seen from soaking for 14 days is shown in Table 6.

| Kaolin Levels | Great Development (swelling) (%) |
|---------------|----------------------------------|
| 9%            | 0 day 3 days 7 days 10 days 14 days |
|               | 0 77.65 99.33 99.80 100 |

3.5. Unconfined compression test results

| Soaking time (day) | Development Test Soil (swelling) | Remoulded soil | Cu (kg/cm²) | St |
|--------------------|----------------------------------|----------------|-------------|----|
| 0                  | 3.61 1.805 3.01 1.505            | 1.199          |
| 3                  | 2.83 1.415 1.92 0.96             | 1.47           |
| 7                  | 1.69 0.845 1.05 0.525            | 1.61           |
| 10                 | 1.13 0.565 0.80 0.4              | 1.41           |
| 14                 | 0.82 0.41 0.60 0.3              | 1.36           |
Based on table 7, it can be seen that the longer the immersion given to the soil with the kaolin mixture, the lower the value of its Unconfined Compression Test value ($q_u$). From Table 7 can also be seen that the sensitivity value of the soil with the kaolin mixture is <2, so the soil with the kaolin mixture is considered insensitive soil. Based on table above also can be seen that the soil sensitivity value does not change too much.

### 3.6. Land development relationship with unconfined compression test value ($q_u$)

![Graph of the relationship between the percentage of swelling and value of unconfined compression test.](image)

**Figure 1.** Graph of the relationship between the percentage of swelling and value of unconfined compression test.

Based on Figure 1, it can be seen that the higher the percentage of development, the lower the value of the free compressive strength of the soil. Clay soil with a mixture of kaolin which was carried out by the UCT test with a large percentage of development of 77.36% decreased in value from the optimum value of 3.61 kg/cm$^2$ to 2.83 kg/cm$^2$ which had a difference of 0.78 kg/cm$^2$ so that the percentage difference in value was 21.60% of the optimum value. The decrease in value occurs continuously when there is land development of 99.33%, which shows the difference in value of 1.92 kg/cm$^2$ from the optimum value so that the percentage difference in value is 53.18% from the optimum value. Decrease in the value of unconfined compression test ($q_u$) soil continues to occur until the soil expands 100% where the difference is 2.79 kg/cm$^2$ from the optimum, so that the percentage decline in value is 77.28% from the optimum value.

From these data it can be concluded that as the size of the expansion of the soil sample with the kaolin mixture increases, the value of the soil bearing capacity decreases based on the value of the free compressive strength of the soil and the shear strength of the soil.

### 4. Conclusion

Based on the tests that have been carried out in the laboratory and data analysis, the following conclusions can be drawn:

- The soil sample tested in this study had a plasticity index (PI) value of 39.85%. With the value of PI that has been obtained, the soil used is expansive clay with high plasticity. From the plasticity index value, it can also be seen that the soil is classified as clay soil with high potential and development rate, where the plasticity index is greater than 35%.
- From the results of swelling testing, it can also be seen that the swelling that occurs in soil with a mixture of 9% kaolin is quite stable or constant compared to that of without a mixture where the increase is very drastic. So it can be concluded that mixing of 9% kaolin can optimize the reduction of expansive soil swelling.
- Based on the results of the unconfined compression test $q_u$, the value of free compressive strength decreases with the duration of soaking the soil. The highest decrease occurred after
soaking for 14 days. The decrease in $q_u$ value is 77.28% of its optimum free compressive strength.

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