Unconfined compressive strength and California Bearing Ratio test on clay stabilization using silica sand

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Abstract. Clay is a soil with certain particles which has plastic properties when it is mixed with water, so that clay needs to be stabilized before it is ready to be used. In this study, the stabilizing agent used was silica sand, which is a mineral commonly found and has a hexagonal crystal structure (SiO₂). The purpose of this study was to determine the effect of adding silica sand to the properties index, Unconfined Compressive Strength (UCT), and California Bearing Ratio (CBR) value of clay soil. The result showed that according to AASHTO this soil was classified as A-7-6 (9) and according to USCS it was classified as CL (Clay - Low Plasticity). The original soil sample has a moisture content of 34.43%; specific weight of 2.65%; liquid limit of 47.33%; plastic limit of 17.45%; and plasticity index of 29.88%. The values of unsoaked design CBR and UCT for the original soil were 6.29% and 1.42 kg/cm². Among all the variations, the mixture of 30% silica sand reached the optimum value of soaked California Bearing Ratio which is 14.86%, meanwhile, the mixture of 12% silica sand reached the optimum value of free compressive strength in Unconfined Compression Test which was 2.90 kg/cm².

1. Introduction

Soil is a mixture of grains that have different sizes. This grouping system is relatively simple because it is only based on the soil grain size distribution that divides the soil into several groups, namely sand with a grain diameter of 2.0-0.05 mm, silt with a grain diameter of 0.005-0.002 mm, and clay with a smaller grain diameter of 0.02 mm [1][2][3][4].

The size of the soil grains is usually represented in a graph, which is a grading curve or a partial size distribution curve. Soil that has a nearly vertical grain size distribution curve (all particles with almost the same size) is called uniformly graded. If the curve stretches over a rather large area, the soil is said to be well-graded.

Clay has several general properties such as hydration, activity, flocculation and dispersion as well as the influence of liquid [2]. Soil activities differ depending on the mineralogy of the clay itself. For kaolinite the activity values were 0.4-0.5, illite 0.5-1.0 and montmorillonite 1.0-7.0. If the activity value (A) is greater than 1.25, then the soil is classified as active and expansive [2][5].

Clay soil is a type of soil that is often subjected to a stabilization process. This is due to the soft, plastic, and cohesive nature of the clay soil when it is wet which is causing large volume changes due to the influence of water and also causing the soil to expand and shrink in a relatively short period of time. Soil stabilization is the process of mixing soil with certain materials to improve the technical properties of the soil. Soil stabilization is also an attempt to change or improve the technical properties of the soil so that it will meet certain technical requirements. If the soil in the field is very loose or very easily stressed or has an unstable consistency index, high permeability, or has other undesirable properties that make it becomes unsuitable in a construction project, then the soil needs to be stabilized [2][6][7].
2. Research Methods

This research used experimental methods and was carried out at the Laboratory of Soil Mechanics, Department of Civil Engineering, Universitas Sumatera Utara. The soil samples used were soil with and without stabilizing agent. The stabilizing agent used in this research was silica sand which will be mixed in various variations.

2.1. Test Performed

Tests conducted in the laboratory were the physical properties of soil and soil mechanical test. Soil mechanical tests consist of standard compaction test, CBR, and UCT. The samples needed for Atterberg limit test are 12 samples, for compaction test are 55 samples, for CBR are 32 samples and for UCT are 10 samples with 3 days of curing time.

2.1.1. Standard Compaction Test

Compaction is the process of removing air from the pores of the soil mechanically (crushed/pounded). In compaction process, the density achieved depends on the amount of water trapped in the soil [8]. The purpose of this test is to obtain the optimum moisture content and maximum dry unit weight.

2.1.2. California Bearing Ratio (CBR)

California Bearing Ratio (CBR) test is the value of soil strength in percent units which becomes one of the parameters in planning a construction. There are two types of CBR measurements, they are CBR value for penetration pressure at 0.254 cm (0.1") against the standard penetration of 70.37 kg/cm² (1000 psi) where the CBR% = (Load 0.1" / (3 x 1000)) x 100 and CBR value for penetration pressure at penetration at 0.508 cm (0.2") against standard penetration of 105.56 kg/cm² (1500 psi) with CBR% = (Load 0.2" / (3 x 1500)) x 100 [9][10][11].

The laboratory tests were carried out in two ways:

- Soaked Design CBR
  Soaked Design CBR was carried out for 1 day to make a water-saturated soil. Implementation of this method was more difficult and required a relatively large amount of time and money.

- Unsoaked Design CBR
  Unsoaked design CBR was carried out immediately after the soil has been compacted for testing. This method usually results in a CBR value that is greater than the soaked design CBR. This test is carried out to determine the value of the free compressive strength of disturbed, remolded, and compacted soil samples.

2.1.3. Unconfined Compression Test (UCT)

Unconfined compression test aims to determine the free compressive strength of soil samples that have cohesion, either undisturbed, remolded, or compacted soil. In this test, the free compressive strength is determined as the maximum load achieved per cross-sectional area or load per cross-sectional area at 15% axial strain [12].

3. Test Result

From the research that has been carried out with the mixtures of silica sand of 3%, 6%, 9%, 12%, 15%, 18%, 21%, 24%, 27%, 30%, the results are as follows:

3.1. Index properties of soil and stabilizer

| Table 1. Index properties of soil and silica sand |
|---|---|---|
| No | Testing | Soil | Silica sand |
| 1 | Water Content | 34.43% | - |
| 2 | Specific Gravity | 2.65 | 2.55 |
| 3 | Liquid Limit | 47.33% | Non plastic |
| 4 | Plastic Limit | 17.45% | Non plastic |
| 5 | Plasticity Index | 29.88% | Non plastic |
| 6 | Sieve Analysis passing | 48.81% | 18.06% |
| No. 200 | | | |
From the data in Table 1, according to AASTHO classification system, the sample is included in the soil type A-7-6 and according to USCS classification system, the sample is included in the CL group, namely inorganic clays with low to moderate plasticity [1] [2].

The liquidity index value of the soil without any stabilizing agents is:

\[
LI = \frac{W_{L-PL}}{PL} = \frac{34.43\% - 17.45\%}{29.88\%} = 0.56\% \ (0 \leq LI \leq 1) \text{ indicates that the soil is in a plastic area.}
\]

The group index for soil without any stabilizing agents is:

\[
GI = (48.81 - 35) [0.2 + 0.005 (47.33 - 40)] + 0.01 (48.81 - 15) (29.88 - 10) = 8.97 \approx 9.
\]

3.2. Testing the physical properties of the soil using stabilizing agents

The results of the physical properties test include specific gravity, Atterberg limit, and sieve analysis test. The results of the specific gravity test and sieve analysis can be seen in Table 1; and the results of the Atterberg test for each variation are shown in Table 2.

| No | Samples                  | Liquid Limit (LL) | Plastic Limit (PL) | Plastic Index (PI) |
|----|--------------------------|-------------------|--------------------|--------------------|
| 1  | Soil without silica sand | 47.33             | 17.45              | 29.88              |
| 2  | Soil + 3% silica sand    | 45.72             | 17.24              | 28.48              |
| 3  | Soil + 6% silica sand    | 43.56             | 17.89              | 25.67              |
| 4  | Soil + 9% silica sand    | 41.32             | 18.34              | 22.98              |
| 5  | Soil + 12% silica sand   | 39.44             | 19.21              | 20.23              |
| 6  | Soil + 15% silica sand   | 37.39             | 20.11              | 17.28              |
| 7  | Soil + 18% silica sand   | 35.61             | 20.59              | 15.02              |
| 8  | Soil + 21% silica sand   | 33.29             | 20.95              | 12.34              |
| 9  | Soil + 24% silica sand   | 30.90             | 21.15              | 9.75               |
| 10 | Soil + 27% silica sand   | 28.19             | 21.39              | 6.80               |
| 11 | Soil + 30% silica sand   | 25.73             | 20.89              | 4.84               |

3.3. Compaction test for soil without silica sand

The results of the Standard Proctor compaction test on the soil without any stabilizing agents show that the optimum water content is 21.12% and the maximum dry unit weight is 1.34 g/cm³.

3.4. Compaction test for soil with silica sand

From the soil compaction test that has been carried out on the original soil, the dry unit weight of the original soil is 1.34 gr/cm³. In Figure 1, it can be seen that the dry content weight value has decreased after adding silica sand starting from the addition of 3% to 30% silica sand, while this soil has the most optimal dry content weight in addition of 12% silica sand which was 1.63 gr/cm³. The dry unit weight kept decreasing when more silica sand content was added.
Figure 1. Variation of maximum dry unit weight ($\gamma_{d\text{ max}}$) with Silica Sand Content

Figure 2. Variation of optimum water content ($w_{\text{opt}}$) with Silica Sand Content

3.5. CBR Test
This test was carried out in a soaked condition because the conditions experienced in the field are water-saturated and the soil experiences maximum swelling. Soaked design CBR is used to obtain the original CBR value in the field when the water is saturated and the soil experiences maximum swelling.
Figure 3. Variation of CBR value with Silica Sand Content

Figure 3. shows the effect of adding a mixture of silica sand on the CBR value. In this experiment, the CBR value increased with each addition of silica sand, in the 30% mixture variation, the CBR value was 14.86%, it happened because the addition of silica sand material affected the water content contained in the soil, where the silica sand material will bind the soil particles and soil fragments that are bound together in one unit.

3.6. Unconfined Compression Test (UCT)

The free compressive strength test was conducted on each variation of the silica sand mixture. Table 4.7 shows the value of soil compressive strength ($q_u$) obtained in each variation of the mixture and Table 4.8 shows the comparison of soil compressive strength ($q_u$) value between the original and remolded soil.

Figure 4. Variation of compressive strength value with silica sand content
Figure 5. Graph of the relationship between soil compressive strength ($q_u$) and strain on original and remolded soil samples

Figure 4 shows that in the results of the free compressive strength test, the compressive strength ($q_u$) of original soil is 1.42 kg/cm² and the compressive strength of the remolded soil ($q_u$) is 0.70 kg/cm². Then the addition of 3% silica sand mixture has made 1.73% increase in value, and kept increasing up to a mixture of silica sand by 12%. The maximum compressive strength value was 2.91 kg/cm², it was obtained in the 12% mixture of silica sand and it can be seen that the free compressive strength value of the original soil is smaller than all samples mixed with silica sand. This is due to the cementation process caused by the reaction of the silica sand mixture in the soil sample. The cementation process forms a substance that can bind the soil grains so that the value of the free compressive strength of the soil becomes better.

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