Expansive Clay Soil Stabilization Using White Soil Material and Sulfuric Acid Solution (H$_2$SO$_4$) For Subgrade in Godong Area - Grobogan District

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Abstract. Expansive clay is classified as an unstable soil. Soil stabilization of expansive clay can be achieved by means of replacement, chemical, and physical methods. This research studies the stabilization of expansive clay using chemical methods, by combining white soil from NTT with H$_2$SO$_4$. This study was conducted to determine the effect of adding white soil and H$_2$SO$_4$ to soil physical and mechanical properties and to improve expansive clay. The method used physical and mechanical testing, namely: property test, CBR, UCS, and Oedometer with variations in composition with an addition of 3%, 4%, and 5% white soil from the weight of expansive clay and 5% H$_2$SO$_4$ from OMC water content at 0, 7, 14, and 28 days of aging, then compared to untreated expansive clay. The results showed that physically stabilized clay became inactive, although its plasticity and expansion rate decreased. Mechanically, there was an increase in the compressive and shear strength of 43.82%, and unsoaked CBR density of 83.25% and soaked CBR of 7.4%, which is directly proportional to the aged soil. Swell potential and swell pressure decreased by 90.71% and 65.71% respectively. The optimum composition is the composition with an addition of 3% white soil and 5% H$_2$SO$_4$ at 28 days of aging.

1. Introduction

The tropical climate causes high rainfall and a long dry shift in Indonesia so that land most areas of the country tends to have large shrinkage. This type of soil experiences significant volume changes along with changes in water content [1]. One way to design the nature of the soil to meet certain technical requirements is the soil stabilization method. Technically, soil stabilization can be achieved by mechanical, physical and chemical stabilization [2].

An example of expansive soil stabilization by means of chemical admixtures is the stabilization of soil with lime, which is widely used in road projects. For optimum results, the ratio of lime used is usually between 3% - 7%. Thomson found that with an addition of lime levels between 5% - 7%, it would produce greater strength than 3% lime [3]. In another study, the results obtained by stabilizing the soil with cement were almost the same as soil stabilization with lime [4].

White soil from Kupang city, East Nusa Tenggara has the potential to be a good soil stabilization material. The dominant chemical elements in this soil are 52% Magnesium Calcium Carbonate and 48% Magnesium Phosphate [5]. This chemical content in white soil can function as a chemical stabilization material, while the compound used as stabilization agent is sulfuric acid (H$_2$SO$_4$). Clay soil stabilization using H$_2$SO$_4$ on sub grade in Godong-Purwodadi at 50 Km mark, Grobogan showed an increase in physical and mechanical properties, while swelling pressure and swelling potential did not show a
significant increase [6]. Expansive soil stabilization by adding limestone to embankment work provides a significant CBR value [7].

Expansive clay is one type of fine-grained colloidal soil formed from expansive minerals, namely: montmorillonite, illite, kaolinite, halloysite, chlorite, vermiculite, and attapulgite [8]. These colloidal soils have a high potential for shrinkage, in accordance to changes in water content. If the clay mineral content increases, the surface area, liquid limit, and plasticity index will increase, so the potential of the shrinkage will increase as well [9]. Test of expansive clay properties ex. Godong, Grobogan found 49.1% PI, with the following mechanical properties: $q_u = 4.61 - 6.87$ kg/cm$^2$, $C_u = 2.31 - 3.44$ kg/cm$^2$, $CBR$ Unsoaked = 7.10–11.40%, $CBR$ Soaked = 1.21–4.32%, Dry Nett ($\gamma_d$) = 1.34–1.41gr/cm$^3$, Disturbed Swell Potential = 13.96%, Disturbed Swell Pressure = 700 kPa, Undisturbed Swell Potential = 15.03%, Undisturbed Swell Pressure = 900 kPa [10].

Identification of expansive clay by indirect method is an empirical relationship on experience and identification of Atterberg Limit, clay content, initial moisture content, dry volume weight, and shrinkage limit [11]. Atterberg limit of soil is the main parameter in indirectly identifying expansive soils [12]. This test refers to ASTM D4318–000 standards [13]. The Plasticity Index (PI) is the difference between the Liquid Limit (LL) and the Plastic Limit (PL) expressed by equation 1. The correlation between PI value with the type and swelling soil is shown by table 1 and table 2.

$$PI = LL - PL$$

| PI | Properties | Soil Type | Cohesion       |
|----|------------|-----------|----------------|
| 0  | Non-Plastic| Sand      | Non-Cohesive   |
| <7 | Low Plasticity | Silt      | Partially Cohesive |
| 7-17 | Medium Plasticity | Silt Clay | Cohesive |
| >17 | High Plasticity | Clay      | Cohesive |

Table 1. PI value and type of soil [14].

The Activity Method is intended to indirectly identify expansive clay [16]. The parameter of activity can be seen in equation 2.

$$Activity (A)_{remold} = \frac{PI}{C-10}$$

Legends: $PI = Plasticity Index$, $C =$ the percentage of clay escaping the filter 0.002 mm. Because the dividing coefficient in equation 2 only applies to remolded conditions, equation 3 is used for unremolded soil conditions.

$$Activity (A)_{dunreemold} = \frac{PI}{C-n}$$

Legends: $n =$ valued at 5. The land categories of the equation are A <0.75 (inactive), 0.75 <A <1.25 (normal), A> 1.25 (active).

Unconfined Compression Test (UCS) is the amount of axial load per unit area when the specimen has collapsed or when the axial strain reaches 20%. Experiments of free compressive strength in the laboratory were carried out on remolded soil samples. The axial stress on the ground can be calculated by equation 4.
A \sigma = q_u = \frac{P}{A} \tag{4}

Legend: $\sigma = q_u =$ Axial strain, $P =$ load, $A =$ unit area. Soil shear strength can be calculated by equation 5.

\[ C_u = \frac{\sigma_1 + \sigma_3}{2} = \frac{\sigma_1}{2} = q_u \tag{5} \]

Legend: $C_u =$ undrained shear strength, $C_{ut} =$ undrained shear strength, $\sigma_3 = 0$, $C_u =$ undrained shear strength, $\sigma_3 = 0$, $q_u =$ unconfined compressive strength. $q_u$ as unconfined soil strength.

CBR is widely used for highway planning as recommended by Nelson and Miller [17]. Test of expansion of expansive clay is performed using CBR tools with ASTM D 1883-99 standards [18]. The expansion that occurs is expressed in percent, which is the ratio between the amount of expansion of the soil divided by the initial height of the expansive clay soil multiplied by 100%, expressed in the formula in equation 6.

\[ CBR = \frac{PT}{PS} \times 100\% \tag{6} \]

Legend: $CBR =$ California Bearing Ratio, $PT =$ load-on-trial, $PS =$ standard load.

Expansion potential as a percentage of the development of lateral samples soaked (saturated) with pressure is \(<6.9 \text{ kPa}\), while for compacted soils it can reach maximum density at its optimum water content [19]. Clay which contains many montmorillonite minerals has the potential to expand and is generally tested using the Loaded Swell Test method with the ASTM-D-4546-90 method B [20]. This test can be calculated using equation 7 as follows:

\[ SP_t = \frac{\Delta h}{h_0} \times 100 = \left(\frac{e_{v,0} - e_o}{1 + e_o}\right) \times 100 = \left(\frac{\gamma_d}{\gamma_{d,0}} - 1\right) \times 100 \tag{7} \]

Legends: $SP_t =$ Swell Potential ($\%$), $e_{v,0} =$ Void ratio after expansion is stabilized at vertical pressure $\sigma_{v,0}$, $\gamma_{d,0}$ = dry density at void ratio $e_{v,0}$.

2. Methods

This study is carried out by experiments. Primary data was collected from making expansive test specimens of white soil stabilized clay at 3%, 4%, and 5% of the weight of untreated expansive dry soil and stabilizer material in the form of 5% $\text{H}_2\text{SO}_4$. Test specimens were aged for 0, 7, 14, and 28 days to determine the change in stabilized soil, after which tests were conducted which included the test of Index Properties (Atterberg in accordance with the ASTM D4318 standard (2000), hydrometer and grain size in accordance with the ASTM D 422 standard (1963)), UCS test from Proctor samples in accordance with the ASTM D2166 standard (2016), swell potential and swell pressure in accordance with the ASTM D4546 standard (1996), and CBR in accordance with the ASTM D 1883 (2014). The analysis is conducted by comparing between existing expansive clay and expansive clay after stabilization.

3. Results and Discussions

The mixture composition is defined as follows: Composition 1, expansive clay + 3% white soil + 5% $\text{H}_2\text{SO}_4$ + Water. Composition 2, expansive clay + 4% white soil + 5% $\text{H}_2\text{SO}_4$ + Water. Composition 3, expansive clay + 5% white soil + 5% $\text{H}_2\text{SO}_4$ + Water.
3.1. Physical Properties of Expansive Stabilized Soils

Based on the PI values of stabilized clay at Figure 1(a) it shows that there is no activity of expansive clay. This is indicated by the PI value smaller than 0.75, while the untreated expansive clay shows activity (Figure 1(b)). The type of soil after stabilization is still classified as clay type with high plasticity and is cohesive, this is indicated by the PI value greater than 17 [15], although the PI value of stabilized soil is still smaller than the PI value of the untreated soil (Figure 2(a)). Viewed from the rate of expansion based on the PI value, the stabilized expansive clay is still very high with a PI value greater than 30. Nevertheless, the stabilized PI values of expansive clay soils are still smaller than those of the untreated expansive clay (Figure 2(b)).

![Figure 1](image1.png)

**Figure 1.** PI Value of expansive clay (a), expansive clay activity based on PI values (b) before and after stabilization.

![Figure 2](image2.png)

**Figure 2.** Expansive clay types (a), rate of expansive clay soil swelling (b) based on PI value before and after stabilization.

3.2. Mechanical Properties of Stabilized Expansive Soil

3.2.1. Unsoaked CBR Test

CBR value in unsoaked condition with 56x blows on Figure 3(a) shows the highest results compared to 25x blows (Figure 3(b)) and 10x blows (Figure 3(c)). Composition 1 showed the highest CBR value. The CBR value at 56x blows significantly increased in the untreated soil. The biggest increase was found at 83.25% and the smallest at 10x blows of 21.27% for Composition 1. The biggest increase was found at 76.49% and the smallest at 10x blows of 2.82% decrease for Composition 2. Meanwhile, the biggest increase was found at 74.74% and the smallest at 10x blows of 7.32% decrease for Composition 3. It was also found that the length of aging is proportional to the increase in CBR value. The average increase in CBR values in each composition was 30.24%, 34.43%, and 31.95% for Compositions 1, 2, and 3 respectively.

![Figure 3](image3.png)
3.2.2. Soaked CBR Test

The soaked CBR result at 56x blows on Figure 4(a) shows the highest value compared to 25x blows (Figure 4(b)) and 10x blows (Figure 4(c)). Composition 1 shows the highest CBR value, despite the decrease in the CBR value of the existing soil. For Composition 1, the decrease is 4.86% at 56x blows and at 10x blows is 73.15%. For Composition 2, the decrease is 17.82% at 56x blows and at 10x blows is 75.46%. Whereas for Composition 3, the most the decrease is 54.17% at 56x blows and at 10x blows is 82.18%. Similar to the results of unsoaked CBR test, the results also shows that the length of soil aging is proportional to the increase in CBR value. The average increase in CBR values in each composition were 83.77%; 75.66%; dan 122.57% for Compositions 1, 2, and 3 respectively.

3.2.3. UCS Test

UCS Test as seen in Figure 5(a) on Composition 1 shows that the axial strain that occurs at 0, 7, and 14 days of aging tends to be greater than that of 28 days of aging, and that there is a significant increase in compressive strength at 28 days. UCS Test results for Composition 2, shown in Figure 5(b), shows a behavior that is slightly different from the graph shown in Figure 5(a). Greater axial strain occurs only at 0 day of aging, while the strain at 7, 14, and 28 days of aging tend to be lesser. This finding indicates increasing compressive strength at 7, 14, and 28 days of aging. A similar phenomenon is also found in composition 3 as shown in Figure 5(c), suggesting that the longer the pressure is, the more compressive strength is obtained, which means improved soil stability.

Based on unconfined compressive strength test shown at Figure 5, the maximum $q_u$ obtained for Composition 1 is 8.741 kg/cm$^2$ at 28 days of aging, as seen in Figure 6(a). This composition tends to possess a greater $q_u$ value compared to that of other Compositions in this study. On the other hand, the value of $C_u$ found was half of unconfined compressive strength value, at 4.371 kg/cm$^2$ (Figure 6(b)). This value is proportional to the unconfined compressive strength, which tends to have a greater value than other compositions.
Based on the level of soil consistency [18], the $q_u$ value of Expansive clay from the untreated soil sample of 3.909 kg/cm$^2$, as shown in Figure 6(a), is classified as a level of hard soil consistency (>3.83 kg/cm$^2$). This also shows that the stabilized expansive clay with $q_u = 8.741$ kg/cm$^2 > q_u$ untreated expansive clay soil = 3.909 kg/cm$^2$, which also falls into the category of hard soil.

3.2.4. Swelling Test

Swelling test on the expansive clay soil ex. Godong, Grobogan has a fairly high expansion rate of 15.03% in undisturbed state and 13.96% in disturbed state (Figure 7(a)). The test results of all three Compositions indicate that all compositions lessen the potential for soil expansion compared to that of the soil in untreated state. Treatment with Composition 1 shows a gradual decrease in expansion potential from 5.92% at 0 days of aging, to 4.28% at 7 days of aging, and continues to decrease by 4.23% at 14 days of aging, until finally it reaches 2.49% at 28 days of aging. However, treatment with Composition 2 and 3 only reduced expansion potential at 0 to 14 days of aging, and an increased expansion potential was found at 28 days of aging (Figure 7(a)). This phenomenon may occur due to the influence of the higher levels of water absorption on the higher percentage of white soil, making the stabilized soil condense faster, which affects the potential for expansion of the soil.

The effect of the duration of soil aging which is inversely proportional to the expansion potential of the soil in Composition 1 treatment shows an improvement in soil conditions due to the effect of changes in water content. Meanwhile, the treatment of Compositions 2 and 3 can induce greater swell potential compared to Composition 1. Original expansive clay in disturbed conditions has an expansion pressure of 700 kPa and under undisturbed conditions it has an expansion pressure of 810 kPa (Figure 7(b)). On the other hand, the maximum expansion pressure of Composition 2 is 240 kPa (Figure 7(b)), indicating that the stabilized expansive clay has less pressure, so that the condition of this soil is better than the untreated expansive clay.
Figure 7. Comparison of potential expansion charts (a) and expansion pressure comparison charts (b) at 0, 7, 14, and 28 days of aging expansive clay soils are stabilized using composition 1, composition 2, and composition 3.

4. Conclusions
1. The addition of White Soil and H$_2$SO$_4$ has an effect on the physical and mechanical properties of stabilized expansive clay. The effects are making the soil inactive because the activity is smaller than 0.75, with high plasticity and is cohesive. The level of land expansion is still very high. However, the limit of plasticity and its expansion rate is 17.1% less than that of non-stabilized expansive clay. There is an increase in compressive and shear strength of 43.82%. The duration of aging affects the values of $q_u$ and $C_u$, in that the longer the aging, the more increase in $q_u$ and $C_u$ found. There is an increase in CBR values of 83.25% in unsoaked condition and unsignificant decrease is 7.4% in soaked condition. The duration of soil aging is found to be proportional to the increase in CBR values, both in soaked and unsoaked conditions. There is a decrease in swell potential between 82.16% and 45.77%, with a decrease in comparable swell pressure in between 90.71% and 65.71% respectively. Longer duration of aging tends to lower swell potential and pressure.

2. The composition that is most suitable to increase CBR value, compressive strength, and expansive clay shear strength, and is able to reduce the percentage of expansion is Composition 1, which is made of expansive clay soil mixed with 3% white soil and 5% H$_2$SO$_4$ + Water solution (OMC condition). CBR values increased by 83.23% unsoaked and unsignificant decrease by 72.45% soaked, compressive strength and shear strength increased by 43.82%, swell potential decreased by 82.16%, and swell pressure decreased by 90.71%.

Acknowledgments
The author would like to thank the Master of Civil Engineering Program, Department of Infrastructure Engineering Management, Universitas Diponegoro who facilitated this research, the supervisors who have provided consultation for this research, technicians of the Land Mechanics Laboratory, Civil Engineering Department, Faculty of Engineering, Universitas Diponegoro for their assistance in many testing processes, fellow classmates, and the Regional Research and Development Center of Denpasar Region II for supporting this research.

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