Stabilization of clay shale using propylene glycol and laterite on california bearing ratio

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Abstract. Clay shale in natural condition has a very high strength. Due to weathering caused by exposure with air and water, its strength will decrease significantly. Propylene glycol is established as an effective shale inhibitor in water-based muds. The effect of mixing propylene glycol with clay shale to increase its strength needs to be discussed. Sample of Citereup clay shale were mixed with propylene glycol with ratio 0.3, 0.5, and 0.7 of its optimum water content. California Bearing Ratio test have been performed to determine clay shale bearing strength. Result indicates that clay shale stabilization using 30% propylene glycol can increase strength in unsoaked condition. Laterite soil mix also give additional bearing strength to clay shale specimen.

1. Introduction
Clay shale is one of the problematic soil in geotechnical engineering. Clay shale is formed from claystone that is easily weathered by exposure to air and water. In natural conditions, the clay shale is usually hard, rigid, and difficult to dig without mechanical equipment. Degradation of clay shale soil which originally has natural form such as rocks, will change its form until it resembles fine-grained soil.

The wet-dry cycle in natural conditions is the major cause of weathering for clay shale. This weathering process due to water absorption and hydration of clay is the main cause for its strength instability. When water is in contact with clay shale, water absorption occurs directly. This process causes hydration and expansion of clay shale that changes stress and/or volume increase. The addition of stress will lead to cracks in rock formations, whereas the addition of volume will lead to a decrease in soil mechanical strength, development, and disintegration.

The weathering process can lead to significant reductions in strength (eg.: [2], [3]). Claystone shear strength can be drastically reduced into very softened weathered conditions when faced with wet and submerged conditions [4]. Clay shale often cause problems in geotechnical engineering, such as in the selection of embankment material, the bearing capacity of deep and shallow foundations, the stability of natural and man-made slope, etc. Improper planning of the clay soil may cause damage to the built-in infrastructure. Several problems caused by the clay shale can be found in Indonesia such as Cipularang toll road [5], the development area of Education Training Center and National Sports School (P3SON) at Bukit Hambalang Bogor, and on Semarang-Bawen Toll Road Project [6]. The illustration can be shown in Figure 1.
Several methods were developed to improve the strength of the problematic soil used as construction materials, one of the methods is utilizing chemicals, known as stabilization agents. These chemicals are further classified as inorganic and organic. Generally, inorganic materials such as cement, lime, fly ash, and mixtures have been used for soil reinforcement [7]–[10].

One of the chemicals which can be used is adding polymer solution to improve the stability of degraded or disrupted flake clays i.e. Propylene Glycol. Propylene Glycol is a polymer developed as an inhibitor at the time of drilling in shale layer [11]. This compound was chosen because of several factors: 1) Non-toxic, so it is safe for the environment; 2) Soluble in water; 3) Less expensive than derivative polymers. These polymers are also safe for the environment rather than other inhibitory solutions used in field applications. Propylene Glycol is used as a stabilizing agent in clay-sand mixtures [12]. It is commonly used as a drilling fluid because of its inhibitory properties to the soil. Not many have tested the effect of propylene glycol on soil strength characteristics.

Previous studies [13] has shown the potential of shale loam stabilization using propylene glycol. The result of this study indicate that organic polymeric materials have a potential of safe stabilizing agent for ecology used as soil strength enhancers, particularly in clay shale.

Based on the above description, a stabilization material is needed that will effectively increase the strength of clay shale and safe for the environment. Hence, the objective of this study is to explore the effect of various amount of propylene glycol used to increase soil bearing capacity. In addition, laterite soil that has a lot of clay content and uniform gradations of clay grain is also used in order to fill each void of the clay shale and create better bonds between particles.

2. Methodology

2.1. Material Characteristics
The soil selected in this study is clay shale material. Samples have gray color, created from weathered claystone. The sample location is the same like previous study [13] at Citereup, Bogor District, West Java Indonesia. Table 1 presents the index properties of this material.

| Properties                  | Clay Shale | Laterite |
|-----------------------------|------------|----------|
| Specific Gravity (Gs)       | 2.75       | 2.7      |
| Liquid Limit (%)            | 31.77      | 90.92    |
| Plastic Limit (%)           | 20.70      | 44.51    |
| Plasticity index, PI (%)    | 11.07      | 54.41    |
| Sand (%)                    | 1          | 3.54     |
| Silt (%)                    | 80.27      | 57       |
| Clay (%)                    | 18.73      | 39.31    |
In order to make smoother gradation for the soil’s grain size distribution, laterite soil which has many clay sized particles were added and mixed with clay shale. The addition of laterite soil is 10% from the clay shale total weight. The laterite soil was taken from Depok, Indonesia. Material properties of the laterite soil also presented in Table 1.

2.2. Stabilization Agent
Propylene Glycol (PG), a common solution founded in chemical stores, is used as the stabilization agent for this research. The physical form of Propylene Glycol is thick, clear and odorless. Variations of propylene glycol mixture used in this study were 30%, 50% and 70% of the optimum water content of clay shales and clay shale-laterite mixture. soil selected in this study is clay shale material. Samples have gray color, created from weathered claystone.

2.3. Sample Preparation
The Sample is prepared according to the current edition of the American Society for Testing and Materials (ASTM), volume 4.08. Standard proctor compaction test (ASTM D698) is performed on the clay shale and clay shale-laterite mixture material specimen to obtain the optimum moisture content of the soil. The samples were first oven dried, and each soil specimen was weighed to the nearest gram. Water is then added and blended by hand until uniform consistency of the soil was reached. The samples then undergo curing for at least 24 hours to ensure all void was filled with water. This procedure was used in all subsequent phases of testing.

The maximum dry density and optimum moisture content for each sample were calculated and used to determine the CBR specimen. At this stage, some of the water were replaced with propylene glycol. The dosage of propylene glycol for the calculated weighed ratio were 0.3, 0.5, and 0.7 of its optimum water content.

2.4. California Bearing Ratio
The CBR test is done according to ASTM D1833. The CBR specimens were molded to a density equal to approximately 100 percent of the clay shale or clay shale-laterite maximum dry density and at its optimum water content. The samples were molded in 6-inch mold in diameter with standard proctor hammer. After it is molded, the specimens are then tested using CBR machine. This test is called unsoaked CBR test. The load from the proving ring was noted and during the test, dial gauge reading were noted for each specified deflection readings. CBR value can then be calculated according to ASTM D1883. The bearing ratio can be shown in Figure 2.

![Figure 2. California Bearing Ratio apparatus](image-url)
After testing the unsoaked condition, the CBR specimens, along with its mold, is placed in a water tub with a controlled temperature. The samples are allowed to soak for a period of 96 hours. A surcharge stress about 3.64 kPa is applied using steel weights and volume change measurement are taken to obtain swelling behavior with dial gauge readings. After 96 hours soaking period, another CBR test are performed for the soaked sample.

A second test is performed using clay shale sample mixed with 10% laterite. The same procedure is used for this sample. After the test, the results are compared to the clay shale result to determine the effect of laterite and propylene glycol addition to clay shale strength.

3. Methodology

3.1. Clay shale CBR Result

The results from the clay shale sample proctor test are maximum dry density of 1.91 gr/cm³ and optimum moisture content of 13.4%. The test result can be seen in Table 2. There are no corrections to the obtained CBR values because all plots of penetration versus stress are initially linear. An increase in propylene glycol content decreases the CBR value, not as expected by the beginning of this study. The CBR value for soaked condition decreases due to the propylene glycol. During the CBR test, the soaked specimen is very soft and can be penetrated easily by only using a finger.

| Material                  | Average swell, % | CBR value unsoaked | CBR value soaked |
|---------------------------|------------------|--------------------|------------------|
| Clay shale                | 1.52             | 12.38              | 3.61             |
| Clay shale + 30% Propylene glycol | 1.11           | 16.25              | 2.83             |
| Clay shale + 50% Propylene glycol | 0.70           | 10.83              | 1.54             |
| Clay shale + 70% Propylene glycol | 0.53           | 9.28               | 0.51             |

From the results of CBR (unsoaked and soaked) testing on clay shale material, there is a significant difference between the unsoaked and soaked results. This is due to absorption of water of the clay shale sample when it is in soaked condition, which makes the expansion and bond of the granules between soil particles become weak. This change of behavior resulted in decrease of strength for the soil.

Liquid form of Propylene glycol makes soil particle separates and breaks the bond between it resulting into decrease of density for the specimen. However, increasing value of propylene glycol content is able to decrease swelling activity up to 60% when compared to the original sample.

On the other hand, swell measurements cannot be an indicator to predict the CBR value of clay shale. In theory, smaller swelling activity leads to better CBR value. But, this theory cannot be applied in clay shale material. The comparison of CBR can be shown in Figure 3 and Figure 4.
Figure 3. Comparison CBR result for clay shale and propylene glycol mixture unsoaked condition

Figure 4. Comparison CBR result for clay shale and propylene glycol mixture soaked condition
3.2. Clay shale + laterite CBR results

The CBR test results for clay shale + laterite mixture can be seen in Table 3 below. The control specimen test results are included for comparison. According to the table, adding laterite can increase the CBR unsoaked value of the clay shale, however it increases the swelling activity of the sample. From the results, it can be seen that the addition of propylene glycol does not improve the clay shale + laterite soil mixture.

**Table 3. Clay shale + Laterite CBR Results**

| Material                        | Average swell, % | CBR value unsoaked | CBR value soaked |
|---------------------------------|------------------|--------------------|------------------|
| Clay shale                      | 1.52             | 12.38              | 3.61             |
| Clay shale + Laterite           | 2.74             | 17.03              | 1.03             |
| Clay shale + 10% Laterite       | 1.52             | 15.48              | 0.77             |
| Laterite + 30% Propylene glycol | 0.80             | 13.16              | 0.51             |
| Clay shale + 10% Propylene glycol | 0.46          | 10.83              | 0.31             |

3.3. Clay shale + laterite CBR results

The AASHTO Guide for Design of Pavement Structure recommends that soil which is used in pavement should have minimum CBR value around 5 to give good performance. This study indicates that clay shale material is not a good construction material especially in soaked condition. This is due to its innate characteristic which is sensitive to water and will likely disintegrate and swell as can be seen in the CBR results of this research.

As presented in Figure 3, Figure 5, and Figure 6 clay shale mixed with laterite specimen have slightly higher CBR unsoaked value compared to original clay shale, although it still has a small CBR soaked value. It can also be inferred that solid material (laterite) can give more additional strength rather than liquid material (propylene glycol). By comparing the CBR test results between the original clay shale sample, the laterite mixture, and addition of propylene glycol to the sample as shown in Table II and Table IV, the most optimum mixture is using 10% laterite plus 30% propylene glycol. With this mixture proportion, there is an increase of CBR unsoaked value of 40.75%, while the value of swelling is relatively equal to the value of existing condition. There was no increase in the CBR value soaked, in fact it decreases in all of the samples. The decrease is due to the absorption of water of the sample by the laterite particles that are mixed together. In addition, the nature of clay itself allows degradation to occur with contact of water, causing the sample to lose its strength in soaked condition.

Increase of propylene glycol content can reduce the swelling potential of clay shale. As explained in previous studies, the mechanism of glycol is to act as an inhibitor by interfering hydrogen bonds between the water and the surface of the clay particles. The instability of clay shale when it interacts with water is due to its strong tendency to absorb water (hydration), leading to expansion and dispersion. This affects the hydrogen bond formation (H --- O) with water and silica or alumina groups
on the surface of the clay shale. Glycol can compete with water at the time of hydration around the cation that is absorbed in the clay shale, which, in the end, also affects the hydrogen bond [14].

**Figure 5.** Comparison CBR result for clay shale + laterite and propylene glycol mixture unsoaked condition

**Figure 6.** Comparison CBR result for clayshale+laterite and propylene glycol mixture soaked condition
The results of study were different with the previous research [13]. Previous studies stated that 75% propylene glycol can increase CBR soaked value up to 100%. This difference is possibly caused by: 1) Different disintegration degree of soil which is due to the fact that the material from the previous study was taken in dry season, while the material used in this study was taken in rainy season; 2) different spot of material source. Mineral identification is needed to make sure the material used in this study is the same as the previous study.

As discussed before, clay shale is not in a good condition when soaked which makes pavement with subgrade from clay shale soil should have a good drainage system to prevent clay shale from contact with water in long period.

4. Conclusion
The addition of propylene glycol does not significantly improve the CBR value of the soils tested. The only improvement happens for clay shale sample using 30% propylene glycol in unsoaked condition. At soaked condition, the addition of propylene glycol tend to have an optimum content to improve clay shale strength. Propylene glycol only reduces the swelling activity of the clay shale soil.

Clay shale bearing capacity is significantly affected by laterite instead of propylene glycol. Solid material (i.e. laterite soil) gives more additional strength compared to liquid material (propylene glycol). There needs to be a follow up study for another additive material to improve clay shale strength, especially in shear strength such as triaxial test.

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