Repairment of clay shale soil by stabilization method using a cement binder

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Abstract. Clay shale is a type of clay that is easy to expand when it comes into contact with water because of the montmorillonite clay mineral it contains. The effect of water also causes a decrease in strength in the clay shale. As a result of the clay shale behavior, some buildings become damaged or landslides occur on the slope. The soil stabilization method with a cement binder is one solution to improve the detrimental properties of the clay shale. The selected cement content variations are 20, 30, and 40%. Cement Water Factor 35% for all variations. Laboratory testing is carried out at 0, 7, 14, and 21 days. Tests carried out in the form of specific gravity, swelling, atterberg limits, unconfined compressive, cation exchange capacity, X-Ray Diffraction (XRD), and Scanning Electron Microscope (SEM). Tests show that the most optimum mixture is 30% clay shale-cement (CS-C30). CS-C30 produces changes in clay shale parameters including an increase in compressive strength without any decrease, and a reduction in the expansive nature as indicated by the decrease in the value of swelling pressure, and cation exchange capacity. Changes in these parameters are suspected because it already does not contain montmorillonite in CS-C30 based on XRD.

1. Introduction
Clay shale is a type of soil that can increase in volume or swelling when interacting with water due to the mineral content of clay in the form of montmorillonite. Ca\(^{2+}\) and Na\(^{+}\) are several cations in the montmorillonite mineral which tend to be hydrated or bind to water molecules. The montmorillonite hydration process occurs because of the weak bonds between the outer layers of particles which make it easier for water molecules to enter the gap between layers [1]. Based on the nature and content it has, clay shale, including expansive soils.

The main components of clay minerals that make up clay shale particles consist of montmorillonite, illite, and kaolinite [1]. The differences between clay shale and clay in general, in addition to having clay minerals, they also contain iron-containing minerals in the form of glauconite, volcanic glass, biogenic silica, and phosphatic material formed from sedimentation [2].

Summary of characteristics and parameters of clay shale soil results of soil investigations carried out on clay shale as native soil on the slopes of the Cisomang bridge by Shouman et al. [3] are explained in Table 1 which is completed with Table 2 to Table 4.
Table 1. Characteristics and parameters of clay shale around the Cisomang bridge slopes.

| No | Characteristic       | Unit | Value | Information                                      |
|----|----------------------|------|-------|-------------------------------------------------|
| 1  | Specific Gravity     | -    | 2.58  | Soil includes organic clay                     |
|    |                      |      |       | (Hardiyatmo, 1992)                              |
| 2  | Atterberg Limits     | LL   | %     | 65.37                                          |
|    |                      | PL   | %     | 20.41                                          |
|    |                      | PI   | %     | 44.96                                          |
| 3  | Swelling Pressure    | kg/cm² | 0.192 | Soil includes high swelling clay              |
|    |                      |       |       | (Chen, 1975)                                   |
| 4  | Swelling             | %     | 25.32 | Mineral lempung yang terkandung:               |
| 5  | X-Ray Diffraction (XRD) | - | - | 1. Quartz                                        |
|    |                      |      |       | 2. Halloysite                                   |
|    |                      |      |       | 3. Muscovite                                    |
|    |                      |      |       | 4. Gismondine                                   |
|    |                      |      |       | 5. Calcite                                      |
|    |                      |      |       | 6. Montmorillonite                              |
| 6  | Exchange Capacity Cation | meq/100 gr | 22,52 | -                                              |

Table 2. Soil type based on specific gravity value.

| Soil Type    | Specific Gravity |
|--------------|------------------|
| Gravel       | 2.65 - 2.68      |
| Sand         | 2.65 - 2.68      |
| Anorganic Silt | 2.62 - 2.68      |
| Organic Clay | 2.58 - 2.65      |
| Anorganic Clay | 2.68 - 2.75      |
| Humus        | 1.37             |
| Peat         | 1.25 - 1.80      |

Table 3. Correlation of plastic limits with types of soil and their characteristics.

| Plastic Limit | Plasticity Level | Soil Type    | Cohesi Level |
|---------------|------------------|--------------|--------------|
| 0             | Non Plastic      | Sand         | Non Cohesion |
| < 7           | Low Plasticity   | Silt         | Partial Cohesion |
| 7 - 17        | Medium Plasticity| Silty Clay   | Cohesion     |
| > 17          | High Plasticity  | Clay         | Cohesion     |

Table 4. Correlation of plasticity index with swelling potential.

| Plasticity Index | Swelling Potential |
|------------------|--------------------|
| 0 - 15           | Low                |
| 15 - 35          | Medium             |
| 35 - 55          | High               |
| > 55             | Very High          |

The clay shale layer on the slope in contact with water will reduce the shear strength and increase the shear stress which causes the water content in the clay shale to increase, so that the weight of the soil
volume increases and the slope burden becomes heavier. If the shear stress exceeds the shear strength, then landslides will occur. As a result of the clay shale's behavior, it is not uncommon for some buildings to be damaged. Adverse properties of the clay shale are interesting to be improved, one of which is the soil stabilization method with a cement binder to change the clay shale parameters.

This research will test and analyze the formula of clay shale-cement mixture which produces optimum properties. Determination of variations in the value of cement content and cement water factor based on previous studies.

2. Method

The method used in the form of laboratory testing is property, mechanical, and chemical. Laboratory testing consists of proper testing of specific gravity and atterberg limits. Laboratory testing mechanically consists of swelling and unconfined compression. Then, chemical testing of the laboratory consists of cation exchange capacity, x-ray diffraction, and scanning electron microscope.

Tests carried out in laboratories with a number and form of certain samples in accordance with the tests carried out. The composition of each sample used for testing in accordance with predetermined variables. The number and composition of samples are explained in Table 5 and Table 6.

| Test                        | Total | Shape | Diameter (mm) |
|-----------------------------|-------|-------|---------------|
|                            |       |       | Diameter      | High  |
| Swelling                    | 12    | Slinder | 60            | 20    |
| Specific Gravity            | 9     | Powder | -             | -     |
| Atterberg Limit             | 9     | Pasta  | -             | -     |
| Unconfined Compression      | 24    | Slinder | 38            | 76    |
| Cation Exchange Capacity    | 1     | Powder | -             | -     |
| X-Ray Diffraction (X-RD)    | 1     | Powder | -             | -     |
| Scanning Electron Mircoscope (SEM) | 1 Piece | -     | -             |

3. Result

Laboratory testing is carried out to find the optimum mixture that produces superior character. Mixtures that reduce the expansive nature and produce high compressive strength, so that the shortage of clay shale can be minimized. The following is a summary of the results from testing in a soil laboratory:
Figure 1 shows that the greater the value of the cement content used in the mixture, the greater the density value of the clay shale-cement mixture. This shows that the addition of cement material to the clay shale has increased the value of its specific gravity.

The cementation process in the soil will cause reduced water in the mixture and gluing between particles that are hard and difficult to penetrate water [4]. This results in a reduction in the volume weight of the water and an increase in the volume weight of the solids mixture, thereby increasing the value of specific gravity which is the ratio between the weight or the volume weight of solid granules with the weight volume of water.

Figure 2 shows that the decrease in the value of the plasticity index with concomitant addition of cement content. The decrease in the value of the plasticity index occurs because of an increase in the value of the plastic limit, where plastic is a condition of minimum water content when a soil is still in a plastic state. This plastic boundary shift occurs due to the absorption of water by cement during the cementation process, the higher the addition of cement content, the higher the absorption of water. In a sense, the mixture will be higher the minimum water content limit in achieving plastic conditions.

Figure 3 shows that the more age of the sample, the lower the value of swelling pressure. The decline in the value of swelling pressure occurs because clay minerals that play a role in binding water have reacted with cement paste.

Figure 4 shows that the compressive strength value increases with age in each mixture, but on the 21st day there is a decrease in CS-C40 so that the highest compressive strength value is shown by CS-C30 whose compressive strength continues to increase. The decrease in compressive strength that occurs
in CS-C40 is suspected from the high increase in cement content which makes the mixture more brittle. In addition, the decrease can occur due to the high amount of water in the mixture that fills the cavity.

Based on a series of laboratory tests that have been carried out, it is known that the mixture of clay shale - cement 30% (CS-C30) at the age of 21 days is the most optimum mixture with the highest qu value, which is 19.476 kg/cm². Table 7 shows a summary of the results of soil testing.

| Table 7. Summary of clay shale – cement mixture soil test. |
|-----------------------------------------------------------|
| **Sample** | **Day** | **Swelling Pressure (kg/cm²)** | **Compressive Strength / qu (kg/cm²)** | **Specific Gravity** | **Plasticity Index (%)** |
| Clay Shale - Cement 20% (CS-C20) | 0 | 0.466 | 2.70 | | |
| | 7 | 0.268 | 12.52 | | 2.64 | 34.21 |
| | 14 | 0.178 | 14.31 | | |
| | 21 | 0.097 | 16.54 | | |
| Clay Shale - Cement 30% (CS-C30) | 0 | 1.534 | 2.32 | | |
| | 7 | 0.191 | 15.58 | | 2.68 | 32.57 |
| | 14 | 0.100 | 18.65 | | |
| | 21 | 0.110 | 19.48 | | |
| Clay Shale - Cement 40% (CS-C40) | 0 | 0.123 | 1.29 | | |
| | 7 | 0.163 | 14.02 | | 2.69 | 30.17 |
| | 14 | 0.114 | 19.59 | | |
| | 21 | 3.000 | 18.81 | | |

In addition to soil testing, chemical testing is also carried out, namely cation exchange capacity testing, X-Ray Diffraction (X-RD), and Scanning Electron Mycroscope (SEM). The following is a summary of the results of chemical tests.

| Table 8. Summary of CS-C30 chemistry test. |
|-------------------------------------------|
| **Test** | **Original Clay Shale** | **Clay Shale - Cement 30% (CS-C30)** |
| Cation Exchange Capacity (me/100g) | 22.52 | 4.66 |
| X-Ray Diffraction | Quartz, halloysite, muscovite, gismondine, calcite. | Quartz, calcite, kaolinite, illite, albite, montmorillonite |

**Figure 5.** Scanning electron mycroscope test result.
Table 8 shows that montmorillonite clay minerals are not found in CS-C30. This decreases the ability of the clay shale cation to react with water cations as indicated by the decreased value of cation exchange capacity. So that the expansive nature decreases. Figure 5 also show that the solid granules in CS-C30 are locked by cement paste and have less sockets when compared to the original clay shale, thus making CS-C30 has a higher strength.

4. Discussion
All laboratory test results show that Clay Shale - Cement Mixture 30% (CS-C30) is the most optimum mixture. This is presumably because CS-C30 has the most suitable mixture composition to react with clay mineral content in clay shale, so CS-C30 does not show a decrease in clay shale properties such as CS-C20 and CS-C40. 

Water composition is also very influential in the reaction of clay shale with cement, water is also needed in the cement hydration process. The variation of the mixture used in the study had a 35% cement water factor limit. So that further testing is needed to see the nature of the mixture when given additional variations in the cement water factor.

5. Conclusion
The clay shale-cement mixture formula has been obtained from a series of laboratory tests. Clay Shale - Cement Mixture 30% (CS-C30) is the optimum mixture chosen. CS-C30 mixture produces changes in parameters and characteristics of clay shale in the form of:

- Swelling pressure decreased by 42.71%, from 0.192 to 0.110 kg/cm².
- Decreased plasticity index by 27.55%, from 44.95% to 32.57%.
- Increasing the compressive strength value that continues without any decrease, at the age of 21 produces a compressive strength value of 19.476 kg/cm².
- The decrease in expansive nature was also demonstrated through the XRD test with no montmorillonite clay particles being found after the addition of cement, which was strengthened by the reduction in the value of the cation exchange capacity of 79.31%, from 22.52 to 4.66 me/100g.

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