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Stabilization of Weathered Clay Shale Using Propylene Glycol and Potassium Chloride as An Embankment Material Alternative

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Abstract. The strength value of unweathered clay shale stacked beneath the soil surface is high. Clay shale will deform and lose its strength if exposed to the surface and changes in weather conditions due to brittleness caused by weathering. Thus, it would be dangerous if used as embankment material due to its sensitiveness. This study analyses the effect of adding propylene glycol and potassium chloride to weathered clay shale. Propylene glycol and potassium chloride are commonly used as a drilling fluid to prevent the degradation of the shale layer. They can increase the stability of clay shale by making it more durable when in contact with the wetting and drying process. The results from this study show that propylene glycol, added to clay shale, can increase the value of soaked CBR to twice the initial value and decrease the swelling percentage. Adding potassium chloride to the clay shale can also increase the value of soaked CBR to twice the initial value and reduce the swelling percentage. However, the combination of Propylene glycol and potassium chloride cannot increase the value of soaked CBR and could even shrink the sample and reduce the optimum water content.

Keywords: Clay shale; CBR Value; Potassium Chloride; Propylene Glycol; Stabilization

1. Introduction

The engineering behavior of shale is a highly complex subject. Clay shale is firm and stable in undisturbed conditions or when stacked underneath the ground surface, thus showing high undrained shear strength. If it is exposed to the open air, sunlight, and water, it will be weathered quickly and transform from hard rock to soft clay (Alatas et al., 2015) an change properties from high shear strength value to low shear strength value (Adisurya & Makarim, 2022; Lee et al., 2001). It can be caused by shale's brittleness and its low durability, which is its primary characteristic (Widjaja, 2008), especially when it has contacted to water or if it is exposed to the surface, as shown in Figure 1 (Sadisun et al., 2010).

Occasionally, the soil near the location of embankment construction did not meet the specifications of materials. There are some options to solve this situation, including transporting soils from other locations that are further away from the location or using additives to improve the local soil material (Yusuf & Zava, 2019). Due to the scarcity of material around the embankment location in several parts of the globe, including the United States of America, shale is often used as the embankment material. Yet, the usage of shale

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as embankment material usually comes with a high cost of maintenance and repair due to the condition of the shale that can deteriorate following the degradation of physical and mechanical properties caused by the characteristic of the shale itself. Therefore, the most common issues discovered when using shale as an embankment material are excessive settlement and instability as the embankment material degrades due to weathering. A more serious problem will occur, especially in wet areas where the embankment is subjected to repeated wetting and drying conditions. This condition will lead to faster shale degradation and embankment stability issues (Gomez-Gutierrez, 2013).

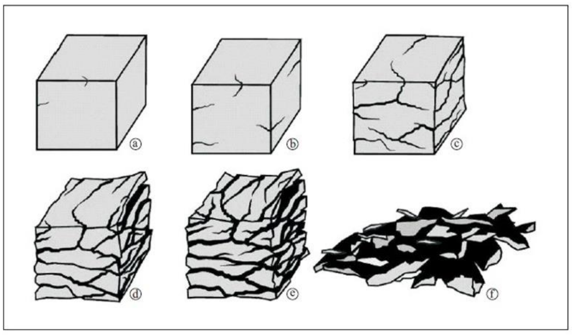

Figure 1 Illustration of physical disintegration of clay shale (Sadisun et al., 2010)

According to the geological map of Indonesia, there is a pretty large clay shale formation in Sentul, West Java, and some of them are exposed to the surface. Figure 2 depicts the Jatiluhur formation (shown in green color). Some construction problems have been documented related to the clay shale deposits near the Sentul area, e.g., a landslide during the construction of Wisma Atlet Hambalang (Alatas et al., 2015), as well as some local problems such as crack and collapse road, and slope failure in the Sentul Area (Nuryanto, 2021) that give disadvantages for the surroundings. It is assumed that these problems are related to the degradation of the clay shale layer.

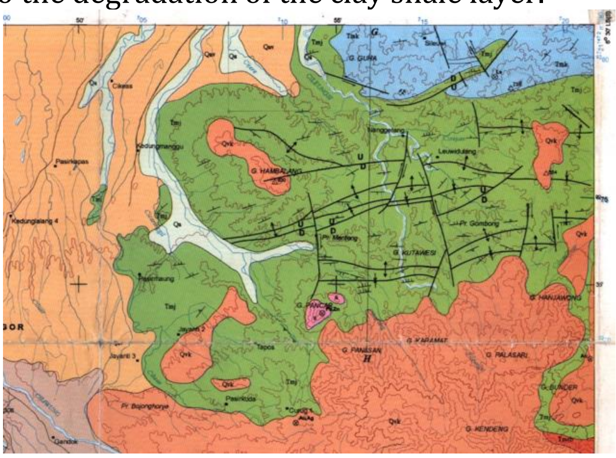

Figure 2 Jatiluhur clay shale formation in Sentul, West Java (Systematic Geological Map, Indonesia)

Referring to the conducted research (Widjaja, 2008; Oktaviani et al., 2018), clay shale from Sentul, West Java, has a range of durability values ranging from low to high depending on the samples taken. The XRD result shows that clay shale in this formation, especially for the minerals that comprise the Clay Shale in Sentul Area, shows less potential for swelling than quartz minerals. However, it also contains montmorillonite and illite (Oktaviani et al., 2018).

Most shale layers are also stacked beneath the ground surface and discovered during the drilling process. Because of the shale's water-sensitive nature, this usually results in the boring well-becoming unstable. An important consideration in the drilling process is protecting the water-sensitive shale and reducing problems caused by water absorption (Patel, 2009). Drilling fluid is one of the solutions that can be implemented to prevent shale formation degradation during the drilling process. Water-based drilling fluids, such as inorganic salts and organic polymers, are widely used due to their relatively low environmental impact (Lee et al., 2001). The presence of salts in clay shale materials reduces swelling potential while increasing shale strength (Lyu et al., 2018). One example of inorganic salt is potassium chloride, which is known as one of the inhibitors for preventing shale layer degradation. High concentrations of potassium salts, such as potassium chloride, are mostly used due to the effective inhibition level among solutions (Zhong et al., 2016). The concentration of such additives between 2% to as high as 37% is frequently recommended in treating drilling fluids to minimize swelling of the sensitive clay. Salt will prevent swelling through various mechanisms (Patel, 2009). Potassium chloride is also a common inhibitive agent to prevent the shale from swelling. When it interacts with clay minerals, it has higher bonding energy, preventing water from inhibiting the clay mineral more than another cation. It also requires only minor heat to form a non-expandable compound (Ghaleh, et al., 2020). According to the Unified Soil Classification System (USCS), KCl or potassium chloride can also increase the consistency of clay soils and change the clay class from clay with low plasticity to silt with low plasticity (Arasan & Yetimoglu, 2007).

In addition to inorganic salts, polymer additives are commonly used to reduce shale hydration. In addition to inorganic cations, polymer additives and water-soluble organic polar compounds such as glycerol, glycol, and sorbitol, can also provide shale stabilization and swelling inhibition. Due to their slightly moderate viscosity, hygroscopicity, colorlessness, and odorlessness, glycols with a molecular weight of less than 200, such as ethylene glycol, propylene glycol, butylene glycol, are suitable for this purpose (Lee et al., 2001). Meanwhile, intercalation is the process by which an organic polymer compound inhibits clay minerals. This intercalation process will prevent the hydration of clay minerals when in contact with water that may cause disintegration and reduction of durability (Zhang, et al., 2016)

Because clay shale has a tendency to soft soil behavior after being exposed to the surface, it must be stabilized to improve its strength. One solution is adding cement to the soil (Damoerin et al., 2015). This research uses potassium chloride and propylene glycol as additives to stabilize clay shale and prevent its degradation when used as embankment material. The experiment aims to observe the change of characteristics of clay shale.

2. Methods

This study used four variants of samples (each with three samples) that were tested to demonstrate the significant effect of additives on stabilizing compacted clay shale and preventing strength degradation when the clay shale comes into contact with water. The California Bearing Ratio (CBR) test was used to assess the strength of the clay shale sample. The other tests related to the physical properties and mineralogy of clay shale samples' physical properties and mineralogy physical properties of clay shale samples include the hydrometer test, Atterberg's limit test, and swelling measurement. The following section goes into full depth about the experiment. The results of each variant's tests will be compared to show the significance of the additive effect. The compositions of the original sample will be determined using X-Ray Diffraction.

2.1. Clay Shale Sample

Weathered clay shale has brittle and crumbly characteristic as shown in Figure 3. This condition of clay shale would be the sample for this study and was taken from Surface Area in Sentul, West Java (Jatiluhur formation). The objective of the weathered material is to represent the field implementation in which the shale is crushed into smaller sizes, moisturized, and compacted for embankment material. The weathered clay shale was obtained from the clay shale layer's surface area and shallow depth. Instead of using the unweathered sample and the wetting and drying method, this method was used to obtain naturally weathered clay shale.

Figure 3 Physical Condition of Weathered Clay Shale in Sentul, West Java

2.2. Sample Variants

This study uses propylene glycol and potassium chloride as additives for clay shale to maintain the strength of compacted clay shale. Hence the stability of clay shale as an embankment can be increased.

Table 1 shows four variants; the first is clay shale with a moisture content of 14.45%, which is the optimum moisture content (the optimum moisture content was obtained in advance from the standard proctor test as in ASTM D698), and no additive. The optimum moisture content that was obtained from the test will be assumed and considered as the optimum moisture content for all the variants. It will represent the standard for the proportion of the additive that will be applied in the variants.

For the second variant, propylene glycol was added to the sample as much as 75% of the optimum moisture content. In the third variant, potassium chloride was added to the clay shale sample, which had the highest moisture content when only water was used. The potassium chloride concentration is 3% of the shale sample's dry weight, and the recommended additive concentration to prevent swelling is 2% to 37% (Patel, 2009). In the fourth variant, the shale sample with the addition of 3% potassium chloride (as in the third variant) was mixed with the same amount of propylene glycol as in the second variant.

Table 1 Variants of Experiment

Sample Variant	Water (%)	Propylene Glycol (%)	Potassium Chloride (KCl) (%)
1	100*	-	-
2	25*	75*	-
3	100*	-	3**
4	25*	75*	3**

*Percentage in respect of optimum moisture content of clay shale sample;
**Percentage in respect of dry weight of clay shale sample

2.3. Physical Properties Tests

Some tests were conducted on the original sample of weathered clay shale to determine the physical properties of the sample used in the research. The first test was the particle distribution test according to the ASTM D422 standard, and the second was Atterberg Limit according to the ASTM D 4318.

2.3. Method of Mixing

The clay shale used in this study has been prepared to pass through a 4.76 mm sieve. Water was added to the sample at a specific value for the first variant to achieve the optimum moisture content. The sample was left for one day to allow the water to distribute evenly. This method was also applied for the second variant, which contained a mixture of propylene glycol and water. Before adding the water to the third variant, potassium chloride was mixed with the shale sample and left for a few hours (2-4 hours). Water was added to the sample after mixing it with potassium chloride to reach the optimum moisture content. For the fourth variant, the original shale sample was mixed with potassium chloride before m mixing with propylene glycol and water.

2.4. California Bearing Ratio Test

The California Bearing Ratio (CBR) test in ASTM D1883 was conducted on the compacted sample using the standard proctor method as in ASTM D1557.

The CBR test was conducted on the dry (unsoaked) and soaked samples. The CBR value is defined as follows:

$$\boldsymbol{CBR} = \frac{\boldsymbol{test\ unit\ load\ (psi)}}{\boldsymbol{standard\ unit\ load\ (psi)}} \boldsymbol{x100}\% \qquad (1)$$

2.5. Swelling Test

In this research, the swelling test was done by two methods. The first method was applied to the soaked samples following the CBR test. The swelling of the sample was measured on the fourth day of soaking using the swelling dial set. The second method used the oedometer test, which was adopted as suggested in ASTM D 4546.

3. Results and Discussion

3.1. Physical Appearance

Figure 4 depicts the physical appearance comparison of sample variants. When compared to the first variant, there is no difference in color. In comparison to the first variant, the fourth variant is more brittle.

Figure 4 Physical Appearance of the Variants

3.2. Particle Size Distribution

According to the hydrometer test, the particle size distribution of Sentul clay shale is as follows: 15% clay, 75% silt, and 10% sand, as shown in Figure 5. A previous study of Sentul clay shale by Widjaja (2008) yielded a different result that guides the presentation of particle size as follows: The composition is 50-59% clay, 40-50% silt, and less than 10% sand.

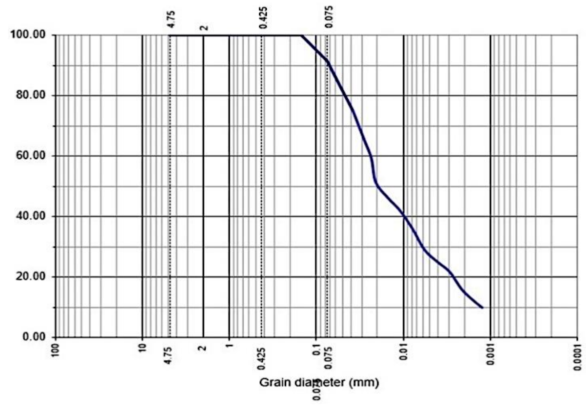

Figure 5 Particle size distribution of clay shale sample

The difference could be due to the difficulties of unraveling clay shale particles to a smaller size. Sentul clay shale took quite a long time to deteriorate naturally. The particles that had not been unraveled might be considered the biggest in the hydrometer test, affecting the result. The difference could also be explained by a difference in sample depth between this research and previous research. However, the fine-grain materials remain the majority in both cases (i.e., clay and silt).

3.3. Plasticity Index of Samples

Table 2 displays the results of Atterberg's limit tests, which are plotted on the plasticity chart in Figure 5. According to these findings, Sentul clay shale has low plasticity. Widjaja (2008) states that clay with low plasticity tends to be more stable and has a lower potential for swelling. The results were also plotted above the A-line in Figure 6, indicating that these shale samples are mainly composed of clay minerals.

Table 2 Atterberg Limit Result of the Clay Shale Samples

Number of tests	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	43.12	23.91	19.21
2	41.62	21.32	20.30
3	41.02	21.72	19.30

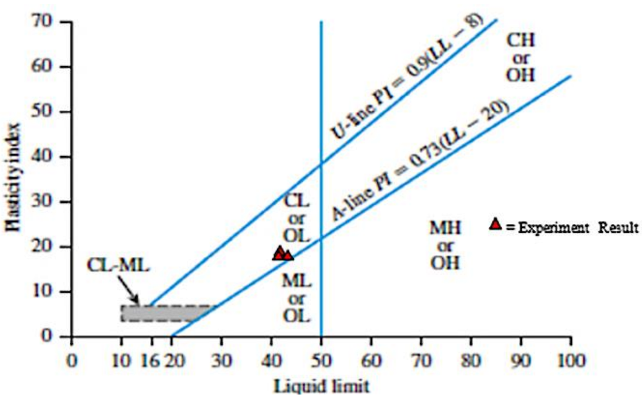

Figure 6 Soil Type Based on USCS Graph with Atterberg Limit Result

3.4. XRD Result

X-Ray Diffraction (XRD) test was conducted to determine the mineral composition of Sentul clay shale. The results reveal that it is composed mainly of Quartz (34.5 %), as illustrated by Oktaviani et al. (2018). Table 3 and Figure 7 show that the sample is also composed of kaolinite and montmorillonite.

Table 3 Minerals Composition of Sentul Clay Shale

No	Mineral	Percentage (%)
1	Quartz	34.5
2	Calcite	19.9
3	Be F_2	12.5
4	Kaolinite	11.6
5	Montmorillonites	8.7
6	Bementite	5.4
7	Pyrite	1.6
8	Mn Fe_2O_4	1.6
9	Siderite	1.5
10	Periclase	1.3
11	Chromite	1.2
12	Calcium Oxide Lime	0.3

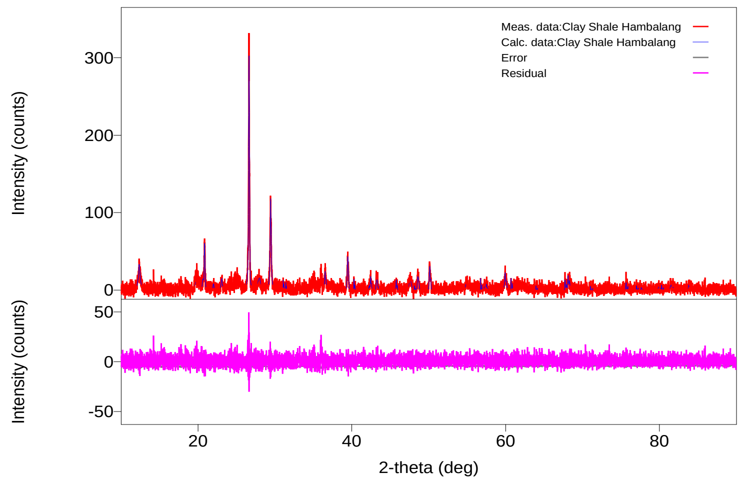

Figure 7 X-Ray Diffraction Result from Clay Shale Sample

3.5. California Bearing Ratio Result

The CBR test was conducted on all four shale variants in unsoaked and soaked conditions. Table 4 reveals the CBR test results. In comparison to the other sets of samples, the first variant has the highest CBR value, which is 15% for the unsoaked condition. This contrast with the CBR value for the soaked condition, which was 2.5%. Though the clay shale of Sentul contains a strong compound that can deteriorate for quite a long time and quartz mineral is one of the stable clay minerals, this significant difference in CBR value in unsoaked and soaked conditions on the first variant indicates that the clay shale is sensitive to water.

The unsoaked CBR value of the second variant was lower than that of the first variant, whereas the soaked condition had a higher CBR value. This result could be caused by the intercalation process when propylene glycol interacts with the clay shale molecule. This process increased the space between clay shale molecules, which were then filled with the propylene glycol molecule (Decker, et al., 2011), so that the clay shale molecule does not interact with the water molecule when the two molecules come into contact, which could lead to clay shale strength degradation. Yet the stability increases in soaked conditions due to the intercalation process, which prevents water from contacting clay shale molecules (Lee et al., 2001).

Table 4 Value of CBR for Samples of Test

Variants	Value of CBR		Remarks
	Unsoaked	*Soaked*	
Variant 1	15%	2.5%	Initial Sample
Variant 2	8-10%	5-6%	CBR Soaked increased 100% from 1st variant
Variant 3	4-6.9%	5-6%	CBR Soaked increased 100% from 1st variant
Variant 4	0.7-0.9%	0.7-0.9%	CBR soaked decrease

In the third variant, the CBR value in the unsoaked condition was lower than in the first and second variants. This condition could be caused by the interaction of potassium chloride molecules with clay shale molecules. Inorganic salt could increase the plasticity of the clay, resulting in a decrease in the strength of the clay shale sample. Yet, in soaked condition, it had the same CBR value as the second variant. In this study, the cation of inorganic salts (K+) could react with the anion of clay shale preventing the water molecule from interacting with the anion of clay shale when submerged (Zhong et al., 2016).

The fourth variant had the lowest value of CBR either in unsoaked or soaked conditions. Table 4 shows that the combination in the fourth sample with a water content of 14.45% cannot be used as an embankment. This result might be caused by the combination of propylene glycol and potassium chloride.

In addition, a compaction test was also conducted on the fourth variant with the lowest result to determine whether there was a change in the optimum moisture content condition from the sample. According to the result, the fourth variant has a different optimum moisture content than the first variant, as illustrated in Figure 8. This alteration of moisture content indicates that the moisture content determined for the fourth variant in the CBR test is not optimal. As a result, the outcome may be low.

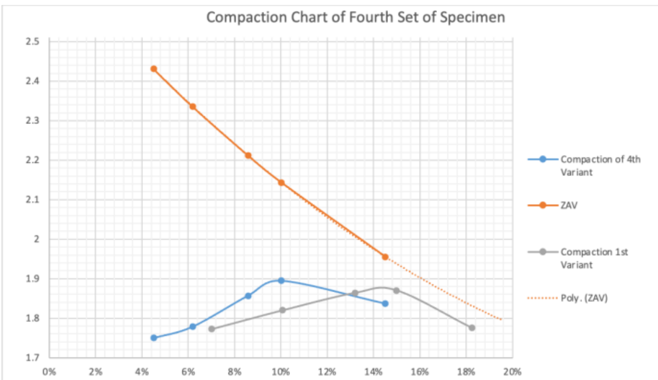

Figure 8 Compaction Result for the Fourth Variant

3.6. Swelling Test

According to the clay shale sample swelling test results, Sentul clay shale has a low to medium swelling potential. It could be related to the mineral composition of Sentul Clay shale, which is composed of stable clay minerals as obtained in the X-Ray Diffraction result. The low plasticity also indicates that the swelling potential of this weathered clay shale is low.

As shown in Table 5, propylene glycol and potassium chloride both have the advantage of reducing the swelling potential of the soil sample. The mixture of additives and soil mineral prevent the water from reacting with soil mineral. The different result of swelling obtained from the CBR sample and oedometer tests shows that the size of the sample also affects the swelling percentage; as is delivered in Table 5, the swelling rate measured from samples for CBR is higher than the one measured in the oedometer test. The combination of propylene glycol and potassium chloride gives a significant result, causing the soil sample to shrink and the swelling value to become negative.

Table 5 Swelling Percentage of Variants

Variant	Swelling Percentage (CBR Samples) (%)	Variant	Swelling Percentage (Oedometer Test) (%)
1	2.5%	1	1.3%
2	0.28%	2	0.11%
3	0.08%	3	0.03%
4	-0.3%	4	-0.3%

Potassium chloride had a more significant effect on swelling reduction in the clay shale sample than propylene glycol. The organic polymer still caused vertical displacement in the sample during the intercalation process, causing the clay shale sample to swell more than the potassium chloride additives. In the third variant, K^+ (positively charged ions) from potassium chloride had an electrochemical attraction with negative charge ion from clay that will flocculate, causing the shorter distance to each element. The shorter distance made a smaller void that might cause a smaller swelling number (Carter & Bentley, 2016).

4. Conclusions

Sentul Clay shale is composed mainly of clay minerals with low plasticity and swelling potential. Nonetheless, degradation of clay shale still occurs due to the primary characteristic of shale that degrades when exposed to water on the surface. The initial CBR result of the unsoaked condition of compacted clay shale is 15%, but the CBR result for the soaked sample has a significant difference from the unsoaked condition, which is 2.5%. Propylene glycol and potassium chloride can stabilize clay shale minerals by preventing them from coming into contact with water, which causes clay shale to degrade. When mixed with clay shale, propylene glycol can increase the value of soaked CBR by up to twice that of the first set of soaked samples and reduce swelling percentage from 2.5% to 0.3%. Adding potassium chloride to clay shale may also increase the value of soaked CBR twice as much as the first set of soaked samples and reduce swelling potential from 2.5% to 0.08%. The mixture of propylene glycol and potassium chloride will cause the change in optimum moisture content from the sample. The mix of these additives may also be ineffective at increasing the value of unsoaked and soaked CBR in clay shale samples. When combined, these additives cause a negative swelling number in the clay shale sample, causing it to shrink.

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