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EFFECTIVENESS OF PORTLAND CEMENT TYPE 1 IN STABILIZING SOFT CLAY SOIL AS SUBGRADE FOR ROAD CONSTRUCTION

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ABSTRACT

Sawah Lunto – Talawi road segment (STA 139 + 700 m) in Sawah Lunto city, West Sumatera province has sustained major damages and been the scene of several accidents since the past few years. The degression of soft clay subgrade, which has a limited bearing capacity and makes it structurally impractical to sustain road construction, was discovered to be the source of these damages. As a recent option for enhancing soil qualities, soil stabilization by employing a variety of pozzolanic and industrial materials has gained popularity. The objective of this study is to investigate the effectiveness of Portland cement type 1 as stabilizing material in improving the soil properties and carrying capacity requirements for soft clay soil used as subgrade in road construction. To accomplish the objectives of this study, a laboratory testing procedure was implemented. Unconfined Compressive Strength (USC) values on natural soil and treated soil with Portland cement type 1 admixture were measured and compared during laboratory experiments. Soft clay soils were stabilized with varying percentages of Portland cement type 1 with the proportions of approximately 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 10% by dry weight of soil during a 7-days curing period. Laboratory testing were performed in compliance with Indonesian National Standard (SNI): SNI 3420-2008 for testing Unconfined Compressive Strength. According to the results of laboratory testing, the UCS values increased roughly from 0.634 kg/cm2 (undisturbed natural soil) to 2.832 kg/cm2 (treated soil) by adding 3% of Portland cement type 1, and up to 8,024 kg/cm2 (treated soil) by adding 10% of Portland cement type 1. Based on the findings, it can be demonstrated that Portland cement type 1 can enhance clay soil's properties used as a subgrade for road construction, can create more stable road conditions, and can ultimately meet the technical feasibility requirements for the subgrade carrying capacity, particularly at the Sawah Lunto - Talawi road segment (STA 139 + 700 m).

Keywords : *Portland Cement Type 1; Soft Clay Soil Stabilization; Subgrade of Road Construction; Unconfined Compressive Strength (UCS)*

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1. INTRODUCTION

Subgrade serves as foundation or the base for any pavement or road construction (Zumrawi, 2015). Consequently, the structural design of the road pavement system is controlled by subgrade features (Shafabakhsh et al., 2014). The features of the soil subgrade have a significant impact on the performance of flexible pavement. Road construction costs can be decreased by reducing the thickness of the layers by building pavement layers on subgrade with outstanding to good characteristics. However, due to a number of limitations, it is impossible to avoid building pavements on substandard ground.

Due to low subgrade support values and moisture-induced volume fluctuations, subgrades built with fine-grain soils can seriously damage the pavement. Weak subgrades are a result of the expansive soil propensity to expand significantly when it comes into contact with water. As a result, it becomes vital to detect and remediate problematic subgrade soils. Replacement of the soil subgrade is the most popular method for treating bad subgrade soil, but because of the huge volume of road construction, it is both expensive and unfeasible. Additionally, soil subgrade can be stabilized by mixing a number of pozzolanic and industrial substances, such as cement, bentonite, calcium or sodium chloride, fly ash, lime, and others with different viscoelastic substances, such as bitumen etc. with various percentage and curing period (Rahman et al., 2021). Over the past several years, soil stabilization has increased in popularity as a means of enhancing the soil's current qualities to fulfil technical needs (Amhadi & Assaf, 2021; Chen & Lin, 2009; Kolias et al., 2005; Pandey & Rabbani, 2017; Putri et al., 2020; Yaghoubi et al., 2021; Zumrawi, 2015).

There are several different varieties of cement on the market, including original Portland cement, cement from blast furnaces, sulfate-resistant cement, and high alumina cement. Typically, the type of soil to be treated and the required ultimate strength are often factors in cement selection. In general, a small quantity of cement is adequate to enhance the engineering properties of the soil and further enhance cation exchange of fine-grain soil. However, the amount of cement that might be used varies depending on the type of the soils. The application of cement can alter and enhance the quality or properties of the soil or turn it into a cemented mass with greater strength and durability (Kowalski et al., 2007)

Since the past few years, Sawah Lunto – Talawi road segment (approximately at STA 139 + 700m) in Sawah Lunto city, West Sumatra province has been damaged by the degression of subgrade soil, resulting in the form of longitudinal cracks, bleeding or embossing in the surface pavement. Furthermore, passing vehicle accidents frequently result from the deterioration to this route. Numerous times, related agency (particularly the Bina Marga Office of West Sumatra Province), have repaired the surface road. It has been recorded that there were 4 times repairing done on the road segment (in 2004, 2008, 2011 and 2015), but regrettably, the damage keeps happening often with the same pattern. The sounder test revealed that the subgrade is soft clay soil with a limited bearing capacity and high plasticity, making it physically impractical to sustain road construction at this time. So that the subgrade conditions cannot satisfy the essential technical standards and therefore stabilization of the subgrade soil must be recommended. The addition of stabilizing material such as cement is expected to increase the quality and improve soil properties of subgrade.

According to the previous studies, soil stabilization is recognized to be a successful alternative for enhancing soil properties. Cement, as the oldest binding agent, might be regarded as the most well-known stabilizing agent since they have been used to stabilize a variety of soils especially for sand and fine grain soil with low to middle plasticity (Amhadi & Assaf, 2021; Kolias et al., 2005; Pandey & Rabbani, 2017; Putri et al., 2020; Wang & Baaj, 2021; Zumrawi, 2015). Unfortunately, application of cement in stabilizing soft clay soil with high plasticity is not yet tested. Therefore, this study attempts to check the performance of cement in stabilizing soft clay soil with high plasticity.

This study aims to investigate the effectiveness of a stabilizer material (Portland cement type 1) in stabilizing the soft clay soil used as subgrade for road construction through testing the Unconfined Compressive Strength (UCS). The authors investigated whether adding stabilizing material in the form of Portland cement type 1 may increase the soil UCT values, enhance the soil properties and ultimately can meet the carrying capacity requirements to fine-grain soil used as subgrade in road construction. A series of UCS tests were performed on untreated original samples and number of treated samples with various addition of Portland cement type 1 (1%, 2%, 3%, 4%, 5%, 6%, 7%, and 10% by the dry weight of soil) with a 7-days curing period. The laboratory investigations are expected to provide the useful information to the local government and civil engineering manager in Sawah Lunto city.

2. MATERIALS AND METHODS

This section introduces the location of the study area, the laboratory investigations that has been conducted, materials used and the testing procedure carried out in order to complete the research study. The following are the detailed descriptions for each sub-section:

2.1. Study Area

This study is carried out at Sawah Lunto – Talawi road segment, located around Baringin II (STA 139 + 700m), in Sawah Lunto city, West Sumatera province which is lying approximately at latitude of 0°38.45'53" S and longitude of 100°45,18'9" as shown in Figure 1. The penetration tests have been carried out in the study area for every 20 cm between 0 to 3.2 m depth and it is found that natural soil has low bearing capacity. The natural soil samples were collected from the site and then it was setup to be tested approximately about three time for every kind of test, in example for testing the compressive strength etc.

2.2. Investigation in Laboratory

The laboratory testing process was implemented to accomplish the objectives of this study. Unconfined Compressive Strength (USC) values on natural soil and treated soft clay soil with Portland cement type 1 admixture were measured and compared during laboratory experiments. Soft clay soils were stabilized with varying percentages of Portland cement type 1 (approximately 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 10% by dry weight of soil) with 7 days curing period. The laboratory investigation was performed to find out the influence of Portland cement type 1 on engineering properties of the soft clay soil utilized as subgrade in road construction. The laboratory tests were conducted in compliance with Indonesian National Standard (SNI): SNI 3420-2008. The investigation was carried out in the Laboratory of Soil Mechanics, Department of Civil Engineering, University of Andalas, Padang.

2.3. Materials Used

The materials employed in the study are consisting of soft clay soil and Portland cement type 1. Soft clay soil sample was collected from Sawah Lunto – Talawi Road segment in Sawah Lunto city, West Sumatera Province. Before testing, the soil sample taken from the surface was air dried, ground to pass through 4 microns sieving and then dried in an oven. The physical and mechanical properties of natural soft clay soil were further tested. In this study, authors emplyed Portland cement type 1 as stabilizer materials. Based on previous study, it is stated that the most effective type of cement used in soil improvement work is Portland cement (Ingles & Metcalf, 1972). The reason is because the Portland cement particles are relatively fine (± 20 microns), which pass through the sieve no. 300, so the hydration process is becoming faster and the use of Portland cement provides an additional shear strength of up to 40% (Ingles & Metcalf, 1972).

Figure 1. Description of the Study Area

2.4. Testing Procedure

Initially, the physical and mechanical properties of natural soil including soil specific gravity, moisture content, dry density, Atterberg limits, compaction and Unconfined Compressive Strength (UCS) were measured based on SNI. SNI 1964-2008 was applied as standards calculation for soil specific gravity, SNI 1965-2008 was applied as standard for calculation of water moisture, SNI 1967-2008 was used for calculation of Atterberg limit, Bulk density was calculated by following SNI 1970-2008, Unconfined Compressive Strength (UCS) was calculated by following SNI 3420-2008 and compaction procedure is following SNI 1742-2008. For each variation of the sample, the sample were preparing for three times testing. The natural soil was then stabilized with Portland cement type 1. The amount of Portland cement type 1 for stabilization is taken in the proportions of 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 10% by dry weight of soil during a 7-day curing period. Using these proportions, each variation of mix samples were prepared for three time testing, average values were performed to determine the values of Unconfined Compressive Strength (UCS). Finally, the UCS values of natural soil and treated soil were compared in order to investigate the influence of Portland cement type 1 on fine-grain soil properties utilized as subgrade in road construction.

3. RESULTS AND DISCUSSION

3.1. Physical and Mechanical Properties of Natural Soil in Study Area (at Sawah Lunto – Talawi Road Segment)

Based on laboratory tests, the physical and mechanical properties of natural clay soil in the study area which is located at Sawah Lunto -Talawi road segment is presented in Table 1 and Figure 2, while the compaction result is presented in Figure 3.

Table 1. Physical properties of natural soil in Sawah Lunto -Talawi road segment

Parameters	Values	Unit
Moisture Content		%
Specific Gravity	2.592	-
Dry density	1.732	g/cm^3
Atterberg Limit:		
LL	47.559	%
PL	29.112	%
PI	18.447	%
UCS Test:		
Natural (Undisturbed)		
Maximum Stress (q_u)	0.634	Kg/cm^2
Minimum stress (q_u)	0.606	Kg/cm^2
Natural (Remolded)		
Maximum stress (q_u)	0.528	Kg/cm^2
Minimum stress (q_u)	0.515	Kg/cm^2

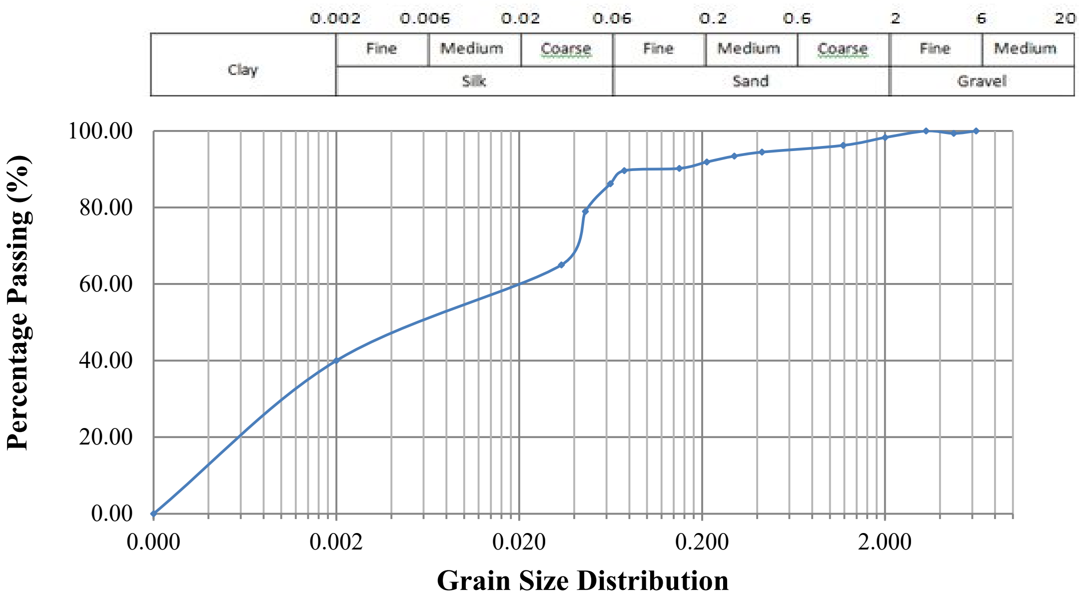

Figure 2. Results of Sieving Analysis for natural soil at study area

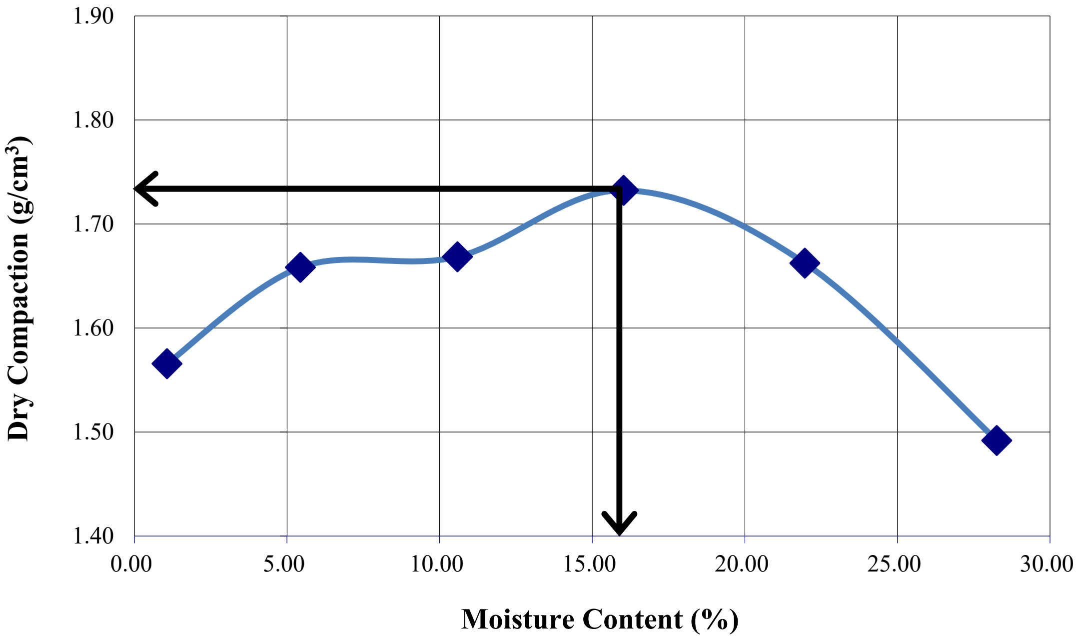

Figure 3. Compaction results for natural soil in Sawah Lunto -Talawi road segment

Based on Figure 2, it can see clearly that the natural soils at study area are clay. According to the value of PI or Atterberg Limit (in Table 1), we can demonstrate that the natural soil at the study area is soft clay with high plasticity and cohesive. Besides, based on Figure 3, it can be determined that the optimum moisture content of the natural soil is approximately about 16.03 % and the maximum dry density of the natural soil is approximately about 1.732 g/cm^3.

3.2. UCS Values for Mix Samples or Treated Soil (Natural Soil + Cement)

Table 2 and Figure 4 present the values of UCS tests for stabilized soil or mix samples (natural soil + several proportion of Portland cement type 1). The amount of Portland cement type 1 for stabilization is taken in the proportions of 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 10% by dry weight of soil during 7-day curing period.

Table 2. UCS values for stabilized soil

Parameters	Values	Unit
UCS Tests:		
Stabilized soil (cement 1%)		
Maximum Stress (q_u)	2.715	Kg/cm^2
Minimum stress (q_u)	1.338	Kg/cm^2
Stabilized soil (cement 2%)		
Maximum stress (q_u)	2.828	Kg/cm^2
Minimum stress (q_u)	1.452	Kg/cm^2
Stabilized soil (cement 3%)		
Maximum Stress (q_u)	2.832	Kg/cm^2
Minimum stress (q_u)	1.620	Kg/cm^2
Stabilized soil (cement 4%)		
Maximum stress (q_u)	2.268	Kg/cm^2
Minimum stress (q_u)	1.253	Kg/cm^2
Stabilized soil (cement 5%)		
Maximum Stress (q_u)	5.095	Kg/cm^2
Minimum stress (q_u)	1.873	Kg/cm^2

Parameters	Values	Unit
Stabilized soil (cement 6%)		
Maximum stress (q_u)	5.547	Kg/cm^2
Minimum stress (q_u)	2.813	Kg/cm^2
Stabilized soil (cement 7%)		
Maximum Stress (q_u)	5.011	Kg/cm^2
Minimum stress (q_u)	3.330	Kg/cm^2
Stabilized soil (cement 10%)		
Maximum stress (q_u)	8.024	Kg/cm^2
Minimum stress (q_u)	4.699	Kg/cm^2

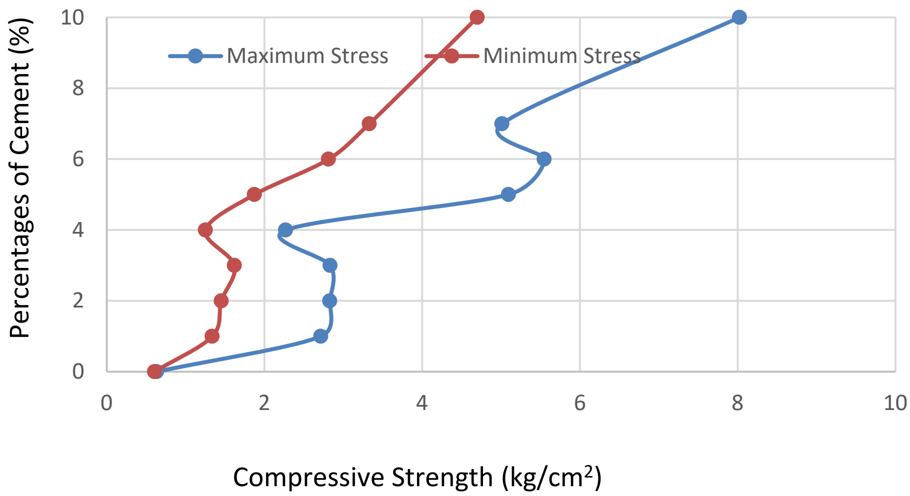

Figure 4. UCS values for treated soft clay soil

Based on Tables 1 and 2, the findings of the laboratory experiment show that adding Portland cement type 1 into natural soil (stabilized soil) increases its Unconfined Compressive Strength (UCS) values when compared to un-stabilized soil (natural soil). By adding 3% of Portland cement type 1 into natural soil, the UCS values increase roughly from 0,634 kg/cm2 (undisturbed state) and 0,528 kg/cm2 (remolded condition) to 2.832 kg/cm2. In addition, UCS values are somewhat reduced slightly when Portland cement type 1 is added between rate of 3% and 4% into natural soil which is from 2.832 kg/cm2 to 2.268 kg/cm2. Unfortunately, the authors are unable to identify the source of the slight reduction between rate of 3% and 4% because UCS values have been steadily rising by adding 5% of Portland cement type 1 to 10% of Portland cement type 1. According to the results of laboratory testing, the UCS values increased from 0.634 kg/cm2 (undisturbed natural soil) to 8,024 kg/cm2 with adding 10% of Portland cement type 1. The results finding showed that Portland cement type 1 can improve clay soil's properties utilized as a subgrade in road construction, can produce more stable road conditions, and can finally meet the technical feasibility requirements for the subgrade carrying capacity, particularly at the Sawah Lunto - Talawi road segment (STA 139 + 700 m).

By increasing the UCS values from 0.634 kg/cm2 to 2.832 kg/cm2 with approximately about 347% (stabilized soil with adding 3% of Portland cement type 1 into natural soil) is already considered giving the sufficient improvement for the natural soft clay soil utilized as subgrade of road construction at Sawah Lunto -Talawi road segment, allowing for more stable road conditions and meeting the technical feasibility requirements for the subgrade function of the road. Higher percentages of Portland cement over 3% of the total dry weight of natural soil can significantly raise the cost of road construction due to inefficiency of the work and expense.

Previous study stated that cement is an attractive binder option because of its effectiveness in increasing soil strength, relatively low cost and easy availability (Omotosho &; Eze-Uzomaka, 2008). Cement will increase the rigidity of the stable layer and will provide better load transfer to the pavement foundation below (Abdulhussein, et.al., 2014). Therefore, make the soil material more impermeable, so as to minimize the process of soil infiltration.

3.3. Free compressive strength (stress-strain for natural soil and treated soil)

Figure 5 presents the values of free compressive strength for natural soil and treated soil (by mixing 1%, 2%, 3%, 4%, 5%, 6%, 7% and 10 % of cements).

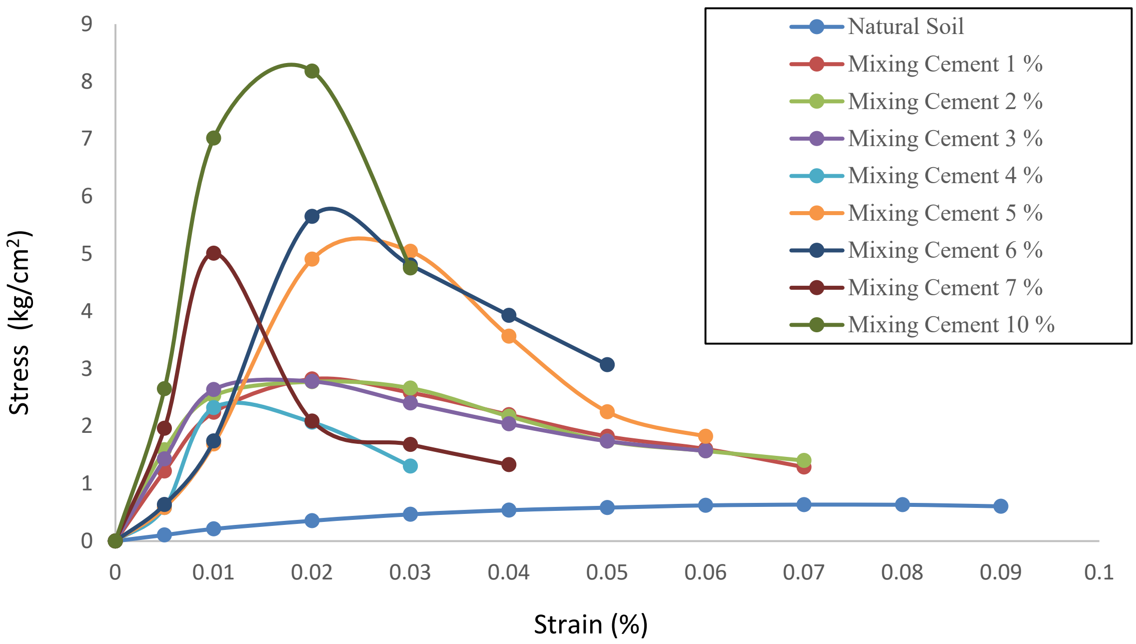

Figure 5. Free Compressive Strength (strain-stress diagram) for natural soil and treated soil

Based on the results of UCS testing before mixing the natural clay soil with cement, it can be seen in Table 1 that the original qu value for natural clay soil in Sawah Lunto - Talawi road segment is 0.634 kg/cm^2, while the remoulded qu value for disturbed clay soil in the study area is 0.528 kg/cm^2. So, it can be concluded that the sample has a higher free compressive strength value when the sample is original (soil structure has not been disturbed).

Besides, when the natural clay soil was added to some percentages of cements, based on Figure 5, it can be illustrated that the increase of percentages of cement in natural soft clay soil could increase the free compressive strength for that clay soil, but in this research, we have found that there is decreasing values of compressive strength when we added cement approximately 3% and 4% compared to 1% and 2 % cements in natural clay soil. Result showed that by adding 1%, 2%, 3%, 4%, 5%, 6%, 7% and 10% of cements in natural soft clay soil, it can offer 2.58 kg/cm^2, 2.66 kg/cm^2, 2.4 kg/cm^2, 2.3 kg/cm^2, 5.04 kg/cm^2, 5.65 kg/cm^2, 5.01 kg/cm^2 and 8.18 kg/cm^2 of free compressive strength in natural clay soil.

4. CONCLUSION

Portland cement which is widely recognized as highly effective soil stabilization could give benefit of higher strength of clay soil utilized as subgrade in road construction. It is less expensive to stabilize fine-grain soil with cement than to remove and replace existing material or to thicken the foundation to relieve subgrade stress. Hydration products from cement raise the subgrade materials' strength and support characteristics and improve the treatment's durability.

Based on the results of this study, it can be concluded that the UCS values on natural subgrade soil at the Sawah Lunto - Talawi road segment can increase by adding Portland cement type 1 into natural soil. As a result, Portland cement type 1 can works well to enhance the bearing capacity as well as the clay soil's physical and mechanical characteristics as soil subgrade at the Sawah Lunto - Talawi road segment (STA 139 + 700 m).

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