JOURNAL OF THE CIVIL ENGINEERING FORUM

Vol. 5 No. 2 (May 2019)
RESEARCH ARTICLE
https://doi.org/10.22146/jcef.43792

Comparison of the Use of Cement, Gypsum, and Limestone on the Improvement of Clay by Using Unconfined Compression Test

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SUBMITTED 25 February 2019 **REVISED** 06 April 2019 **ACCEPTED** 18 April 2019

ABSTRACT Soil stabilization is an effort to improve soil properties by adding additives in the soil to increase the soil strength and maintain the shear strength of the soil. There are many materials which can be used as stabilizers. The materials used in this study were cement, gypsum, and limestone, then the compressive strength values were compared by using the Unconfined Compression Test (UCT). The mixture combinations used in this study were 1% to 10% of cement, gypsum, and limestone on clay by curing for 14 days. The compressive strength value resulted from the unconfined compression test on the original soil sample was 1.4 kg/cm^2. The original soil was classified as moderately sensitive soil because the sensitivity value of the original soil was 2. After being stabilized with various mixtures of cement, gypsum, and limestone, soil stabilization using cement obtained the maximum unconfined compressive strength value is 3.681 kg/cm^2 in the mixture of 10%. Similarly, the soil stabilization using limestone and gypsum also obtained its maximum unconfined compressive strength value in the mixture of 10% is 3.307 kg/cm^2 and 2.975 kg/cm^2, respectively.

KEYWORDS Clay; Improvement of Soil; Cement; Gypsum; Limestone; Unconfined Compression Test

1 INTRODUCTION

Soil is one of the construction materials available in the field. The examples of constructions that use soil are dams, levees, embankment, and highways. Before use, the soil must go through the quality control process. If the soil is hardened carelessly, it can lead to low stability and large soil degradation. Changing the physical properties of soil, such as the bearing capacity, compressibility, permeability, ease of work, swelling, and sensitivity to changes in water content can be done by compaction and stabilization (Bowles, 1979).

Soil stabilization can be carried out by increasing the soil density, adding inactive materials to increase the cohesion or friction resistance, increasing materials for chemical and physical changes of the soil, reducing the groundwater surface, and replacing poor soil. In general, soil stabilization can be done in two ways, namely mechanical stabilization and chemical stabilization (Silitonga, Levacher and Mezazigh, 2010). Mechanical stabilization is a method to increase the bearing capacity of soil by improving the structure and repairing the physical properties of soil with various mechanical equipment, such as rollers, while chemical stabilization is a method to increase the strength and bearing capacity of soil by reducing or eliminating the unfavorable physical properties of soil and mixing soil with chemicals (Das, 2014).

Many materials are commonly used as stabilizers, such as cement, lime, bottom ash, fly ash, and others. The present study developed and examined the use of three kinds of additive materials, namely cement, gypsum, and limestone. Cement, gypsum and limestone composition consists of Silica and calcium; Silica (SiO_2) and calcium are the main constituent element in cement formation, thus cement, gypsum, and limestone have pozolanitic properties. Pozolanitic properties have the behavior of binding to other minerals in the clay so that they become harder in a certain period (Bowles, 1979). These three materials can improve the structure of soil with low bearing capacity so that the structure will be harder and resistant to water. The Unconfined Compression Test is a test performed to determine the compressive strength value by providing a compressive strength to the soil until the soil becomes separated from the granules. This test also measures the strain of soil due to pressures received by the soil (Lambe and Whitman, 1969). The classification of soil based on the unconfined compression test is shown in Table 1.

The axial stress applied to the test specimen is gradually increased until the specimen collapses. When the soil collapses because of $\sigma_3 = 0$, the scheme of the unconfined compression test is shown in Equation 1 and Figure 1.

Table 1. Classification of Soil According to the Unconfined Compression Test

Soil Properties	Unconfined Compression Strength (kg/cm^2)
Very soft	< 0.25
Soft	0.25 – 0.50
Firm	0.5 – 1
Stiff	1 – 2
Very stiff	2 – 4
Hard	> 4

$$\tau_f = \frac{\sigma_1}{2} = \frac{q_u}{2} = c_u \quad (1)$$

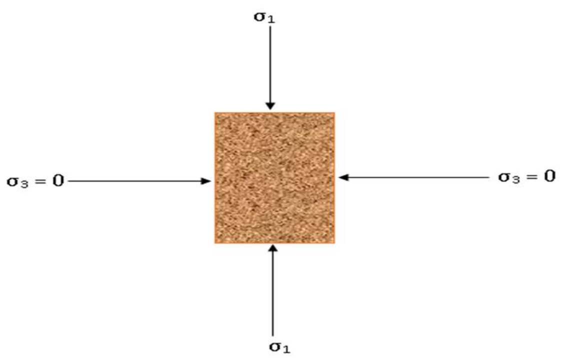

Figure 1. The scheme of the Unconfined Compression Test

2 LITERATURE REVIEW

2.1 Stabilization with cement

Soil stabilization with cement is a process of mixing the crushed soil, cement, and water and compacting it which will produce a new material namely soil-cement in which the deformation characteristics, strength, resistance to water, weather, and other aspects can be adjusted to the needs (Bowles, 1979).

The cement used in the study was Portland cement type-I. The advantages of using cement as a stabilizer includes:

a) Improve strength and stiffness.
b) Better volume stability.
c) Improve durability.

The stages of a chemical process in soil stabilization using cement are as follows:

a) Water absorption and ion exchange reaction.

If Portland cement is added to the soil, calcium ion Ca^{++} will be released through the hydrolysis process, and ion exchange will continue on the surface of the clay particles. The clay granules in the soil content are smooth and negatively charged. Positive ions, such as hydrogen ions (H^+), sodium ions (Na^+), calcium ions (K^+), and polarized water form calcium silicate and calcium aluminate which increase the soil strength. Pozzolan reaction in which all are attached to the surface of clay granules makes the clay particles clump which results in better soil consistency (Suardi, 2005).

b) The reaction of calcium silicate and calcium aluminate formation.

In general, hydration is as follows:

$2(3CaO.SiO_2) + 6H_2O\ 3CaO.2SiO_2.\ 3H_2O + 3\ Ca\ (OH)_2$
$2(2CaO.SiO_2) + 4H_2O\ 3CaO.2SiO_2.\ 3H_2O + Ca\ (OH)_2$

The reaction between Silica (SiO_2) and soft Alumina (Al_2O_3) is contained in clay with reactive mineral content, so it can react with lime and water. The reaction product is the formation of calcium silicate hydrate, such as tobermorite, calcium aluminate hydrate $4CaO.Al_2O_3.12H_2O$, and hydrate gehlenite $2CaO.Al_2O_3.SiO_2.6H_2O$ which are water-insoluble. The formation of these compounds is slow which causes the soil harder, denser and more stable. Thus, cement commonly used for soil stabilization is ordinary Portland cement or also known as cement type I (Suardi, 2005).

2.2 Stabilization with gypsum

Gypsum ($CaSO_4$ ($2H_2O$)) is a fraction of hydrated limestone, namely calcium sulfate dihydrate which is a salting and evaporation fraction. In its pure state, the color of gypsum is white. Moreover, gypsum ($CaSO_4$ ($2H_2O$)) is useful as an industrial material and soil stabilization because:

a) Soluble easily in water hydration when heated
b) When water is added, it will return to the original hydrate, collect, and harden the gypsum. These two phenomena which are dehydration and rehydration are the basic technology of gypsum.

Moreover, Calcium Sulfate Dehydrate ($CaSO_4.2H_2O$) is the initial material before dehydration and the final product after rehydration. A substantial quantity of gypsum is used as a retarder agent of cement hardening (Roesyanto *et al.*, 2018).

2.3 Stabilization with limestone

Mixing lime with soil causes many chemical reactions to occur, so it is difficult to examine each reaction. Only a few processes can be followed to a certain extent. Among many processes which are occurred, there are three processes that should be known.

a) Ion Replacement and Structure Change

Mixing limestone with soil can make the soil less sticky and easy to work with. This phenomenon occurs because of one or two reasons, or a combination of both. The first reason is that calcium cation from lime shifts the ions from weak sodium and hydrogen on the surface of clay granules. Second, there is an addition of calcium cations which fills the surface of clay particles. The two processes change the ions on the surface of clay particles; thus, the previously sticky soil changes to sand and its plasticity decreases.

b) Cementing Action

Another important point in mixing limestone with soil is the fermentation process that occurs from this mixture. It occurs because calcium and mineral in the soil form new elements, such as aluminum and silica minerals. It is noteworthy that the mixture must be compacted after the curing process was finished to achieve the expected hardening.

c) Carbonation

The reaction that occurs between carbon dioxide and calcium hydroxide will form calcium carbonate. If this process occurs in limestone after mixing the soil, the hardening result will not be satisfactory. Therefore, the lime to be used should be stored properly. Based on the process above, the process of mixing soil with limestone will change the physical properties of the soil. (Utami.GS, 2014)

3 METHODOLOGY

The samples in this study consisted of soil which was not given stabilization materials, referred as original soils, and soil which was given chemical stabilizers by adding soil with cement, soil with gypsum, and soil with lime in mixed variations. The research process carried out in this research includes preparatory work, laboratory test work, and analysis of laboratory test results.

The sampling procedure performed was as follows:

a) The location where the soil was collected was determined, and it was carried out in PTPN II Kebun Patumbak, Deli Serdang.
b) The pests and plant root around ±30 cm from the surface were cleaned if the soil was contaminated by it.
c) The soil that would be used for the research was collected. Undisturbed soil was used for the original soil test whereas disturbed soil mixed with the stabilizer materials such as cement, gypsum, and lime were used for the mixed soil test.
d) The test performed was the Unconfined Compression Test of the original soil sample taken by using tools for dispensing soil samples from the undisturbed soil tube and inserted into the sample mold for UCT.

3.1 Materials

The materials used in the study were cement, gypsum, and limestone.

Cement is a hydraulic adhesive because the compounds contained in the cement can react with water and will form a new substance that is adhesive to rocks. Table 2 presents the chemical composition of limestone.

Table 2. Chemical composition of limestone

No	Parameter	Result (%)
1	Silica oxide (SiO_2)	20.6
2	Calcium oxide (CaO)	63.1
3	Alumina oxide (Al_2O_3)	6.35
4	Iron (III) oxide (Fe_2O_3)	3.6

In general, gypsum is written in the chemical formula as ($CaSO_4$ ($2H_2O$)). Gypsum is the most minerals in soft sedimentary rocks when it is pure. The percentage of the chemical composition of gypsum can be seen in Table 3.

Table 3. Chemical composition of gypsum

No	Parameter	Result (%)
1	Silica oxide (SiO_2)	1.73
2	Calcium oxide (CaO)	25.3
3	Alumina oxide (Al_2O_3)	2.21
4	Water content	9.47

Nowadays, gypsum is widely used in building decoration, the basic material of cement and fertilizers, paint fillers, and various other purposes. The advantages of using gypsum in civil engineering work include:

a) Clay-mixed gypsum can reduce cracks because the sodium in the soil is replaced by calcium in gypsum, so the expanding is smaller.
b) Gypsum can increase the stability of organic soil because it contains calcium that binds organic materials to clay which gives stability to the soil aggregates.
c) Gypsum increases the speed of water seepage because gypsum absorbs more water.

Gypsum as the mineral adhesive has better properties than organic adhesives because it does not cause air pollution, cheap, resistant to fire and chemicals, and resistant to deterioration by biological factors.

The use of lime in soil stabilization is not a new thing. The lime described here is pure lime, namely calcium oxide or CaO. In nature, lime is usually mixed with other compounds, such as calcium carbonate ($CaCO_3$) containing 56% calcium oxide (CaO) and 44% carbon dioxide. Pure calcium oxide usually contains 71% calcium and 29% carbon dioxide.

3.2 The making of samples

The making of samples was done by trial and error; in other words, the disturbed soil was made by seeking the water content in the soil mixture, soil with cement, soil with gypsum, and soil with limestone. The process was done repeatedly until both water content levels were relatively similar. If the soil sample with the appropriate water content has been obtained, the next test can be performed. The mixture used was soil + 1% gypsum – 10% gypsum, soil + 1% cement – 10% cement, and soil + 1% lime – 10% limestone.

3.3 Testing of samples

The equipment used in this research were tools for the Water Content Test, Specific Gravity Test, Atterberg Limit Test, Compression Test, Unconfined Compression Test, and other tools in the Soil Mechanics Laboratory.

4 RESULTS

The results will be discussed in three subsections, namely physical properties, soil mechanics with stabilizer, and engineering properties (Proctor Standard and Unconfined Compression Test).

4.1 Physical properties of soil

Table 4 presents the percentage of soil passing the sieve no.200 was 51.38% with the liquid limit of 52.43%. Based on the AASHTO soil classification system, the minimum percentage to pass the sieve no.200 is 36%, has a liquid limit of at least 41%, and has a plasticity index of at least 11% so that the soil samples can be classified in the soil type A-7- 6.

Based on the soil classification of USCS, the data obtained was the liquid limit value of 52.43%, and the percentage of soil passing the sieve no.200 was 51.38%; thus, the soil samples were included in the CL group that was inorganic clay with low to medium plasticity(Lubis *et al.*, 2018).

Table 4. Results of the original soil

No	Test	Result (%)
1	Water content	34.43
2	Specific gravity	2.65
3	Liquid limit	52.43
4	Plastic limit	24.34
5	Plasticity index	28.09
6	Sieve analysis	51.38

4.2 Physical properties test of cement, gypsum, and limestone

The test results of the physical properties of the materials used in the study can be seen in Table 5.

Table 5. The physical properties test results of stabilizers

No	Test	Cement	Gypsum	Limestone
1	Specific gravity	3.15	2.74	2.59
3	Liquid limit	Non-plastic	Non-plastic	Non-plastic
4	Plastic limit	Non-plastic	Non-plastic	Non-plastic
5	Plasticity index	Non-plastic	Non-plastic	Non-plastic
6	Sieve analysis	56.41%	51.62%	45.69%

4.3 Physical properties test of soil with cement, gypsum, and limestone

As seen in Figure 2, the plastic limit value of the original soil was 24.34%, soil with the addition of 10% cement was 28.98%, soil with the addition of 10% gypsum was 30.67%, and soil with the addition of 10% limestone was 31.93%.

Figure 3 shows that the plasticity index decreased due to the addition of stabilizers. As shown in Figure 4, the plasticity index value of the original soil was 28.09%, whereas the plasticity index values of soil with the addition of 10% cement, soil with the addition of 10% gypsum, and soil with the addition of 10% limestone were 20.01%, 17.02%, and 13.89%, respectively.

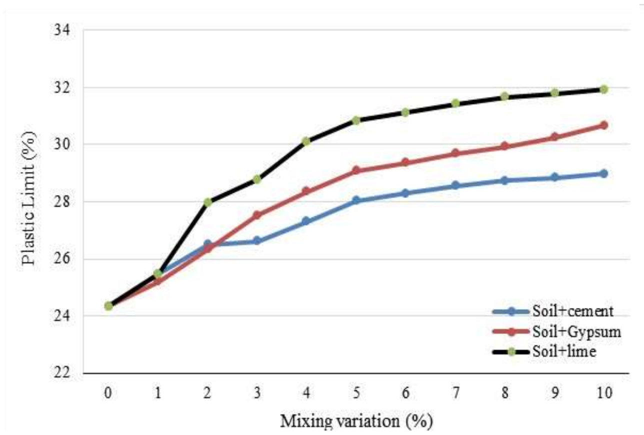

Figure 2. Graph of the relationship between the plastic limit of soil with cement, soil with gypsum, and soil with limestone

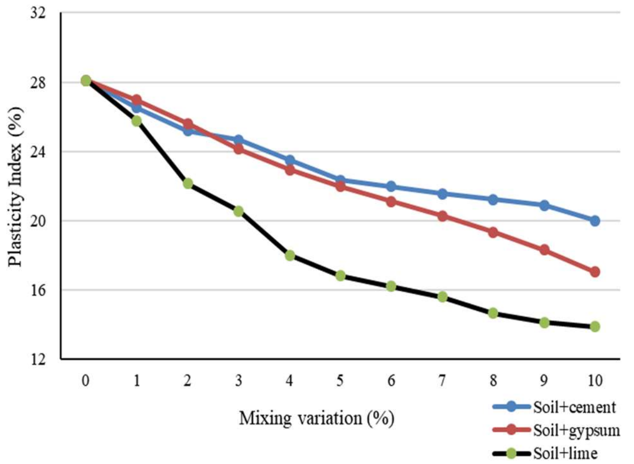

Figure 3. Graph of the relationship between the plasticity index of soil with cement, soil with gypsum, and soil with limestone

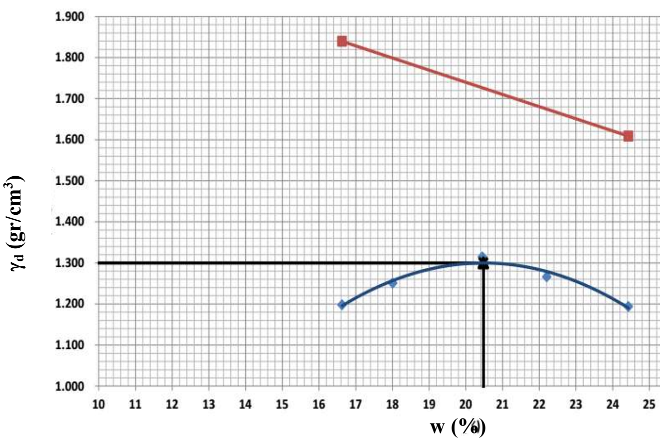

Figure 4. Density curve of the original soil

4.4 Proctor standard test results

In this test, there was a correlation found between the optimum water content and the maximum dry content weight. The Proctor Standard compaction test method was used in the study. The Proctor Standard Compaction Test results are shown in Table 6, while the compaction curve is shown in Figure 4.

Table 6. Compaction Test Data of the Original Soil

No	Test	Result
1	Optimum water content	20.48%
2	Maximum dry density	1.3 gr/cm^3

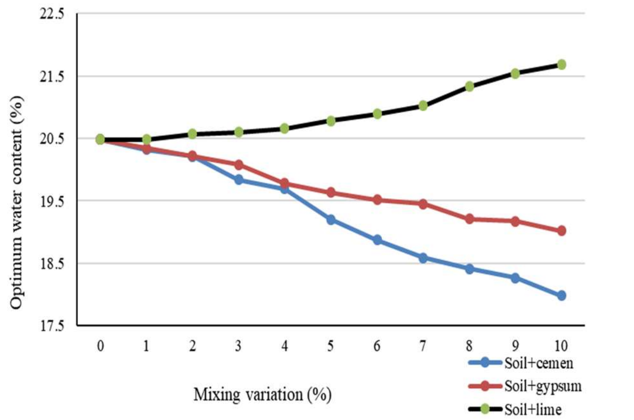

Figure 5. Graph of the correlation between the optimum water content (W_{opt}) of soil with mixed stabilizer variations

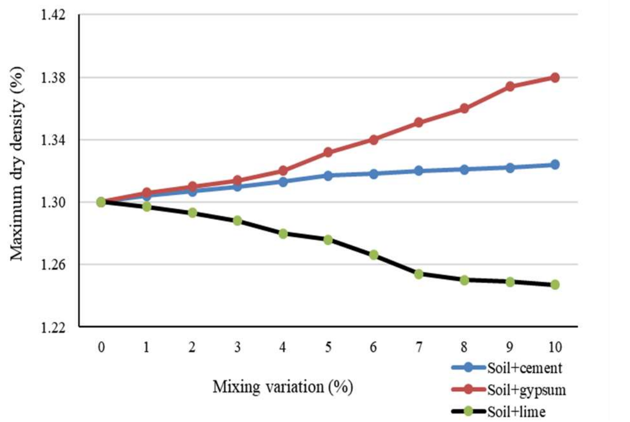

Figure 6. Graph of the correlation between the maximum dry density (γd max) of soil with mixed stabilizer variations

Figure 5 shows the comparison of changes in the optimum water content (W_{opt}) values due to the addition of cement, lime, and gypsum. In the addition of cement and gypsum, the optimum water content (W_{opt}) values decreased while in the addition of lime, the optimum water content (W_{opt}) values increased. The increase in the optimum water content (W_{opt}) in limestone occurred due to the enlargement of cavities between particles which caused an increase in the soil pores that could be filled with water.

Figure 6 shows the comparison of changes in the values of maximum dry weight (γ_{dmax}) due to the addition of cement, lime, and gypsum. In the addition of cement and gypsum, the maximum dry weight (γ_{dmax}) values increased whereas, in the addition of lime, the maximum dry weight (γ_{dmax}) values decreased. The decrease in the values of the maximum dry weight

(γ_{dmax}) in lime occurred because the specific weight of the original soil was greater than the specific weight of the lime. Furthermore, the enlargement of cavities between particles of the soil mixture had an impact on the decreasing dry content weight compared to the original soil condition.

4.5 Unconfined compression test (UCT)

The correlation between unconfined compressive strength (q_u) on soil with mixed stabilizer variations is shown in Figure 7.

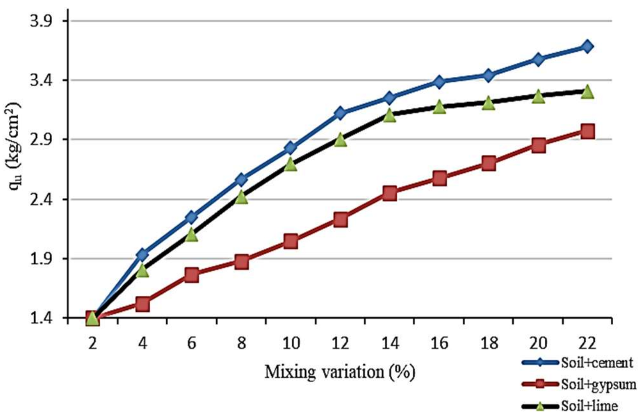

Figure 7. Graph of the correlation between unconfined compressive strength (q_u) on soil with mixed stabilizer variations

Figure 7 depicts that the highest unconfined compressive strength (q_u) value was obtained by soil with the addition of cement compared to soil with the addition of gypsum or limestone. In contrast, the lowest unconfined compressive strength (q_u) value was obtained by soil with the addition of gypsum. The soil samples used in this study had a sensitivity ratio of 2.00 and classified into moderate sensitivity soil. It means that the structural damage experienced by the soil does not have a significant effect on the changes in the compressive strength or shear strength of the soil. The addition of cement, gypsum, and lime stabilizers has shown that the unconfined compressive strength values (q_u) would increase. This is due to the increase in the unconfined compressive strength (q_u) can reduce the potential for expansion and shrinkage of the soil. Due to the presence of these stabilizers, the porous soil granules will be covered with stabilizers which ultimately give strength to the soil, so the soil becomes harder, more stable, and the potential of shrinkage will decrease.

The addition of cement had the highest value because soil mixed with cement would get the alkaline cation exchange process (Na^+ and K^+) from the soil and replaced by the cement cation. Thus, the bulk granules increase (flocculate) and form a binding material consisting of calcium silicate or aluminate silicate which will bind the soil particles with the appropriate water mixture to become pozzolan/cementation which makes the soil have a strong unconfined compressive strength value. The addition of gypsum had the lowest value due to gypsum which contains calcium (Ca), calcium oxide (CaO), hydrogen (H), sulfur (S), and water would react with fine and negatively charged clay granules. Positive ions, such as hydrogen ions (H^+), sodium ions (Na^+), potassium ions (K^+), and polarized water were attached to the clay surface but not as strong as cement and lime due to the specific gravity value of cement which was greater than gypsum, and gypsum had the lowest calcium silicate compared to cement and limestone. When limestone mixed with clay reacts, it will form a strong and hard gel namely calcium silicate which can coat and bind the clay particles so that it covers the soil pores, but it is not as strong as cement because cement has higher calcium silicate and has a greater specific weight. (Lambe and Whitman, 1969; Bowles, 1979; Suardi, 2005; Das, 2014)

5 CONCLUSIONS

Based on the study carried out on the comparison of cement, gypsum, and limestone on clay stabilization, it can be concluded that the type of soil used according to USCS was Clay – Low Plasticity (CL), while it was classified as the A7-6 type according to AASTHO. Based on the Proctor Standard result, the optimum water content of the original soil was 20.48%, and the maximum dry content weight was 1.3 gr/cm^3. The optimum water content of the cement-soil mixture was 1.324 gr/cm^3, the soil-gypsum mixture was 1.38%, and the soil-lime mixture was 1.247%. The largest unconfined compressive strength value was found in the soil mixed with 10% cement with 3.681 gr/cm^2, whereas the unconfined compressive strength values obtained from the soil mixed with 10% gypsum and soil with 10% limestone were 2.975 gr/cm^2 and 3.307 gr/cm^2, respectively.

ACKNOWLEDGMENT

The authors gratefully acknowledge that the present research is supported by the Laboratory of Soil Mechanics, Department of Civil Engineering, University of Sumatera Utara.

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