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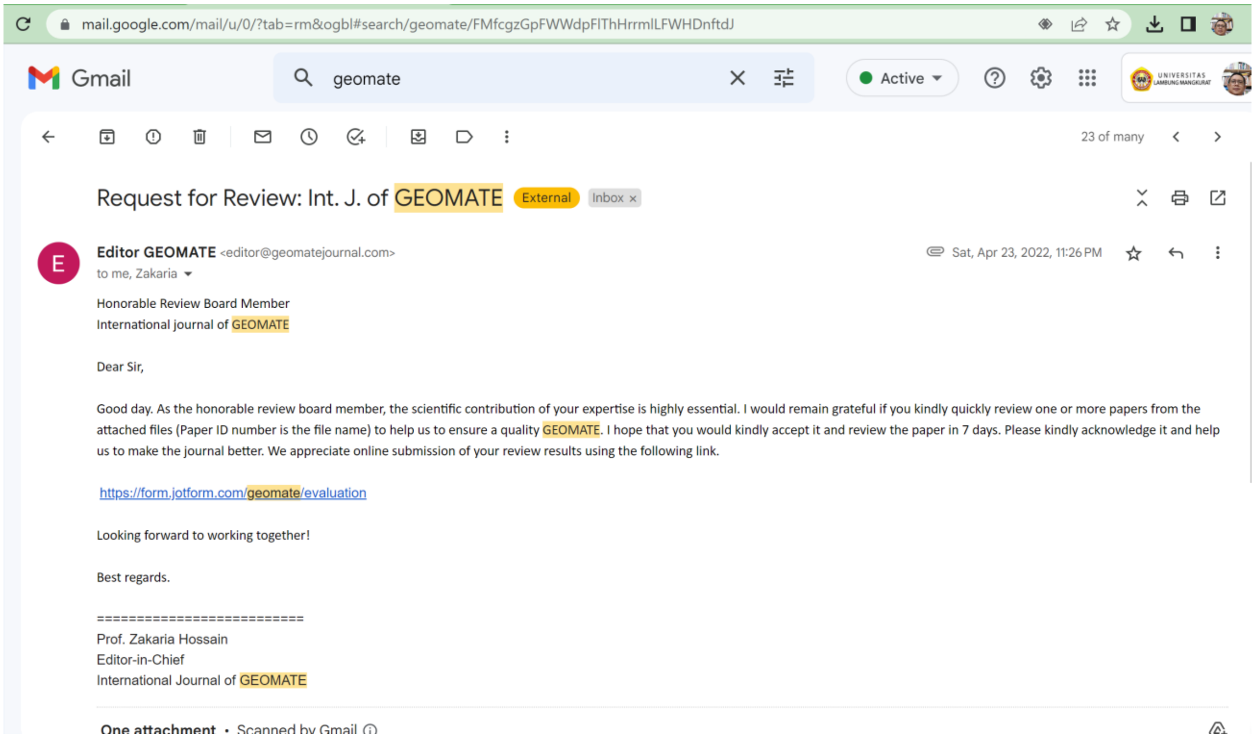

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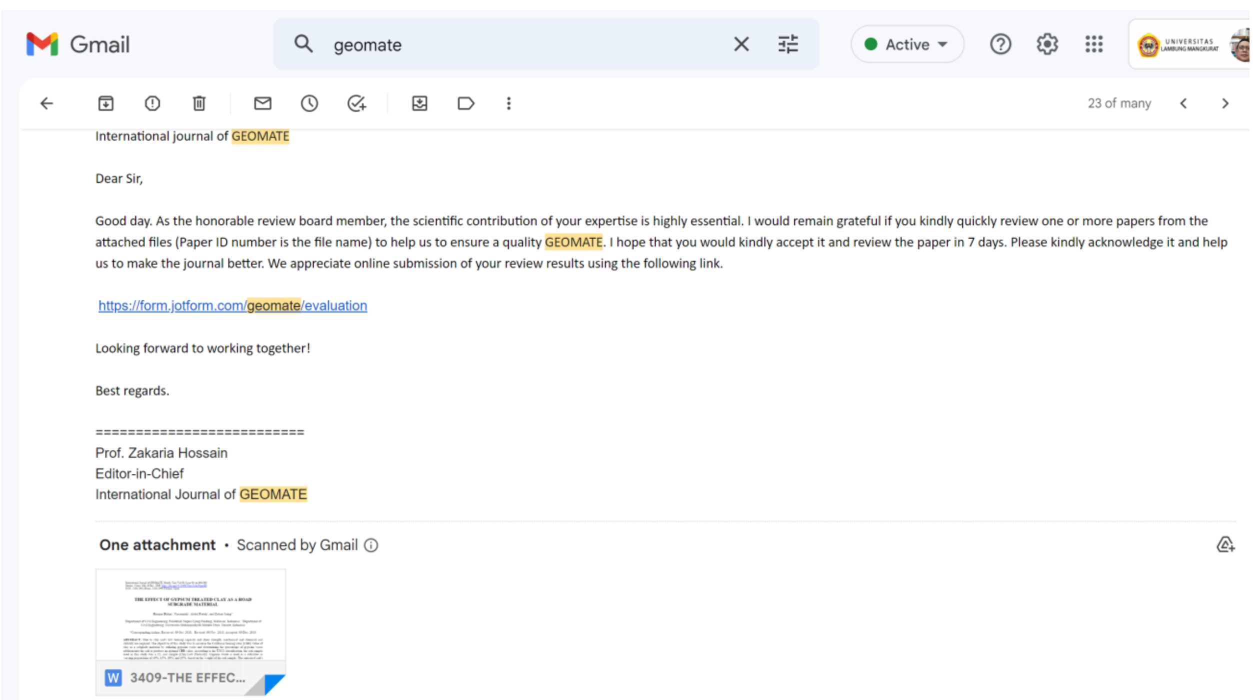

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i. Originality	4
ii. Quality	4
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iv. Presentation	4
v. Recommendation	4
Total (sum of i to v)	20
Opinion	2. Accept with minor revision
General comments	The manuscript is good enough
Mandatory changes	Please do the revisions of the suggested changes
Suggested changes	- Fig.1 : Word of "Garis" in English - Fig. 4 : the symbol of "CBR SOAKED" and "CBR UNSOAKED" should be made different - Fig. 5 : the symbol of "7 day, 21 day, 28 day" should be made different
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THE EFFECT OF GYPSUM TREATED CLAY AS A ROAD SUBGRADE MATERIAL

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ABSTRACT: Due to clay soil's low bearing capacity and shear strength, mechanical and chemical soil stability are required. The objective of this study was to increase the California bearing ratio (CBR) value of clay as a subgrade material by utilizing gypsum waste and determining the percentage of gypsum waste addition into the soil to produce an optimal CBR value. According to the USCS classification, the soil sample used in this study was a CL soil sample (Clay-Low Plasticity). Gypsum waste is used as a stabilizer in varying proportions of 10%, 15%, 20%, and 25%, based on the weight of the soil sample. The untreated soil's maximum dry density (MDD) was 1.53%, and the maximum water content was 23.91%. The addition of 25% gypsum resulted in a maximum dry density of 1.571 g/cm3 and an optimum water content of 18.95%. Furthermore, 25% gypsum-treated soil increased the value of both soaked and unsoaked CBR to some extent. The addition of 17% gypsum resulted in the best CBR value. The Unconfined Compression Test results revealed that the highest compressive strength (*qu*) was obtained at 21 days cured and 17% gypsum, with an MDD value of 1.593 kg/cm^2.

Keywords: CBR, gypsum, clay, stability, soil stress

1. INTRODUCTION

The very diverse soil conditions in various parts of Indonesia necessitate different handling in order to meet the density and carrying capacity requirements as the subgrade of the road pavement structure to be built on it. The most important aspect of road construction is the subgrade, which serves as the foundation of a road and supports all road construction as well as the traffic load on it. During road pavement work, it is frequently discovered that the subgrade or material surrounding the project site does not meet the requirements when used for pavement construction. Soil stabilization is one method for addressing this issue. Soil stabilization is the method of changing or improving the properties of the subgrade in order to improve the subgrade's quality. It is done to increase the subgrade's bearing capacity for the construction built on it.

Clay is one of the soil materials that necessitates additional effort to stabilize. The material is highly plastic, has a low bearing capacity, and has a high shrinkage value [1]. This clay material is almost evenly distributed throughout South Sulawesi and even throughout Indonesia [2]. Stabilization can be accomplished through various methods, including mechanical, chemical, or a combination of the two [3]. Compaction techniques are used in traditional soil improvement or mechanical stabilization to add particles that are not yet in the soil [4]. However, this method frequently raises concerns about its environmental impact and economic viability. Several forms of development of this method can be carried out practically using chemical stabilization. Chemical stabilization is accomplished by adding chemicals to the soil. Chemicals that can be added to the soil include Portland Cement, Asphalt, Sodium Chloride, Lime, Calcium Chloride, Papermill waste, Fertilizer Factory Waste (gypsum), Sulfuric acid, Lignins, and others [5-7].

Soil stabilization additives frequently contain cement or pozzolan properties, which act as catalysts in improving soil properties and stabilizing the soil. Meanwhile, adding lime to the soil stabilization process reduces the plastic index, water content, and shrinkage. The use of lime and cement as additives will impact the environment, namely an increase in carbon dioxide emissions during the manufacturing process [8].

Gypsum material is one of the materials that has recently been developed, particularly the use of gypsum waste material. It is a less expensive and more sustainable method of waste disposal. Gypsum is chemically known as calcium sulfate. Gypsum is commonly used in manufacturing cement and drywall, and gypsum waste can be obtained from plasterboard waste and used factory goods. Several studies have looked into the use of this waste, both in terms of improving the quality of flexible pavement, concrete, embankments, and soil improvement [9-11]. The gypsum material's cementitious properties were discovered to induce strength development in the primary material [12].

The high rate of road damage in South Sulawesi Province is caused by the subgrade, which is typically clay. This study improves weak clay soils with a low-cost, sustainable approach and offers alternative disposal options for waste material. As a result, the purpose of this study is to determine the effect of varying the percentage of gypsum waste material in the mixture on soaked and unsoaked CBR value. Finally, the objective of this study is to determine the optimal proportion of the best gypsum mixture for reducing swelling and increasing compressive strength.

2. RESEARCH SIGNIFICANCE

Many studies on the stabilization of clay soils have been conducted. There are numerous variations used in peat soil stabilization research, including gypsum. Some of the previous studies' findings regarding gypsum as a reference in this study are described below.

Soil improvement based on gypsum and cement in soil clay was investigated (Rangkuti, 2017) to determine the effect of adding gypsum and cement on the physical changes of clay in terms of CBR-based on the value of immersion time. According to the study's findings, the highest CBR value occurred in the addition of 5% gypsum and cement variations with the length of time the soil specimen was compacted before curing, at 41.54 percent. Because the soil-gypsum-cement mixture has solidified before collection, the voids between soil particles become denser, and thus the strength increases [13].

Expansive soil's strength and permeability characteristics with gypsum and rice husk ash (Edora and Ann, 2021) discuss the expansive soil's expansion-shrinkage behavior, which can cause cracking and settlement. As a result, this study was used in soil stabilization by varying the combination of gypsum and rice husk ash (RHA). Adding 10% rice husk and 15% gypsum increases the soaking CBR value [14].

To identify the effects of gypsum and NaCl on the engineering properties of high-compressibility clay (CH), untreated and treated soils with varying gypsum percentages and NaCl were subjected to a series of compaction tests and California Bearing Ratio (CBR) tests (3%, 8%, and 13%). The results show that as the percentage of gypsum and NaCl in the soil increases, the engineering properties of the soil, such as the MDD and CBR values, increase significantly compared to the soil properties [15].

The use of Gypsum and Bagasse Ash for Stabilization of Low Plastic and High Plastic Clay (Khan, 2019) is to investigate the effect of gypsum ash and bagasse on clay properties and assess the properties the potential for stabilization and improvement of the engineering properties of these soils. In this study, two types of swollen clay were used for stabilization: low plastic clay and high plastic clay. The findings demonstrated that gypsum and bagasse ash could provide an effective and cost-effective method for low and high plastic clay [16].

An experimental study on fly ash with lime and gypsum for quality improvement in pavement subgrade materials (Ray et al., 2020) was carried out to improve the subgrade material by adding fly ash at a percentage of 9.7–30% as the main additive. The test results show that lateritic soils such as *moorum* with silver sand used as a sub-pavement foundation material with a stabilizer can be used as a better substitute than the commonly used graded traditional coarse aggregate and fly ash used as a filler. The high correlation coefficient indicates that the CBR value can be accurately predicted based on the results of the UCS test [17].

Several previous studies have revealed that research into stabilizer materials to improve soil performance as a construction material is rapidly expanding. Meanwhile, advancements in development and technology force an area to provide quality materials that are not commensurate with their availability. This condition is a significant issue almost everywhere globally, including in Indonesia.

Furthermore, Indonesia has a significant expanse of clay potential. This clay soil problem necessitates specialized research to transform the soil's potential for swelling and shrinkage into a low-cost and effective construction material. This study aims to improve the performance of clay soil by stabilizing gypsum as a road foundation layer as an alternative to meet construction material requirements.

The use of local gypsum for local clay stabilization significantly improves soil performance as a road foundation layer in certain mixed conditions, as evidenced by an increase in CBR value and soil strength. Furthermore, these findings are compared to those of previous studies. As a result, the findings of this study have a significant impact on the problem of quality material requirements for road foundation layers. Furthermore, it will serve as a reference for soil improvement studies in the future by utilizing cutting-edge technology.

2.1 Clay Soil

Soil is also defined as a material made up of cemented solid mineral aggregates (chemically bonded to each other) and weathered organic matter (solid particles) with liquids and gases filling the pores. Casagrande proposed the soil classification system, later developed by the United States Bureau of Reclamation (USBR) and the United States Army Corps of Engineers (USACE). The American Society for Testing Materials (ASTM) then adopted USCS as the standard method for soil classification. This system is widely used in various geotechnical projects in its current form [18].

Coarse-grained soils are gravel and sand, with less than 50% of the soil passing through the No. 200 sieve (F200 5). The group symbol begins with G for gravel or gravel soil, while for sand or sandy soil, it begins with S. Fine-grained soil in which more than half of the soil passes through a No. 200 sieve (F200 50). For inorganic silt, the group symbol begins with M, while for organic silt and clay, it begins with O. Pt is the symbol for peat and soils with high organic content.

Clay is a plastic material with a medium to high water content made up of microscopic and submicroscopic-sized particles derived from the chemical decomposition of constituent rock elements [19]. Clay has the property of being hard when dry and soft, plastic, and cohesive when wet. It expands and shrinks rapidly, resulting in a significant volume change caused by the influence of water.

2.2 Soil Stabilization

Soil stabilization is a method of treating the soil with a stabilizing agent so that the soil becomes solid and resilient, advancing the properties of the soil and making it entirely suitable for construction. *Soil stabilization* is a technique used to improve the engineering properties of weaker soils by employing various stabilizing agents. After stabilization, the soil becomes more stable by reducing permeability, compressibility, and increasing shear strength, thereby increasing the soil's bearing capacity [20]. Steps that can be taken to improve soil properties include one or more of the following [21]: a) Adding inactive material to increase cohesion and/or shear resistance; b) Adding materials that cause chemical and/or physical changes in the soil; c) lowering ground water level; and d) replacing bad soil.

2.3 Gypsum As Stabilizing Material

Calcium sulfate is also known as gypsum (CaS0,-2H, O). In nature, it exists as a crystalline solid. Crystals form in semi-arid and arid climates when dissolved calcium sulfate precipitates due to groundwater evaporation. At room temperature, the solubility of gypsum is approximately 0.35 ounces per gallon (oz/gal). However, the actual solubility is determined by groundwater chemistry, which includes dissolved minerals such as carbonates and sulfates. Lower gypsum solubility is caused by higher carbonate and sulfate concentrations [22].

The following are the benefits of using gypsum in civil engineering work [23]: 1) Gypsum mixed with clay can reduce cracking because the sodium in the soil is replaced by calcium in gypsum waste, resulting in less expansion; 2) Gypsum can increase organic soil stability because it contains calcium, which binds soil with organic matter to clay, providing stability to soil aggregates; and 3) Gypsum can increase water seepage because it absorbs more water.

2.4 California Bearing Ration (CBR)

Penetration resistance experiments, such as the CBR test, are commonly used to assess the strength of compacted soil. CBR testing is a method of determining the strength of the road's subgrade. The California State Highway Department invented the CBR method for manufacturing, which was later used and improved by the United States Corps of Engineers. CBR testing can be classified into two types based on how the soil sample was obtained [24]: a) Field CBR testing; b) CBR testing in the immersion field; c) Point plan CBR / laboratory CBR testing, which can be divided into two types: soaked laboratory CBR and unsoaked laboratory CBR.

The CBR value is the percentage ratio of the pressure required to penetrate the soil with a 3 inch round piston at a penetration speed of 0.05 inches per minute to the pressure required to penetrate a specific standard material. The standard value is calculated by testing high-quality crushed stone material that has been compacted under the assumption of a CBR value of 100%.

$$\text{CBR value} = \frac{\textbf{load test value}}{\textbf{Standard load}} \text{ x } 100\ \% \text{........(1)}$$

As a result, the CBR value is the stated value of the subgrade quality compared to the standard load in the form of crushed stone, which has a CBR value of 100 percent in carrying the traffic load.

3. MATERIALS AND METHODS

3.1 Materials

The clay sample used in this study was soil from the Patalassang area of the Gowa Regency. This soil is formed by volcanic deposits of basalt and andesite rock. This soil appears brown, loose, and granular, similar to clay. In the meantime, the subsoil is generally darker in color, with a slight reddish tint in some cases. The underlying soil layer, which has clay properties, is plastic in moisture but hard and brittle in dry conditions.

The gypsum material used is reclaimed from construction waste. The previous material was typically gypsum board or gypsum board, an interior coating material for gypsum walls and ceilings and can also be used as a brick wall coating. The gypsum board waste was broken down and ground in this study by passing it through a 200-mesh sieve. The brick mortar was then mixed with 200 (0.75 mm). Using gypsum board waste aims to achieve a high compressive strength value in a 28-day test period.

3.2 Samples Preparation

The samples for each treatment were made up of native soil from the Patalassang area of Gowa Regency and a gypsum waste powder mixture. The percentages of gypsum used are 10%, 15%, 20%, and 25% of the soil dry weight basis, respectively.

3.3 Samples Testing

This study used a tool for the Water Content Test, Specific Gravity Test, Atterberg Limit Test, Compression Test, Free Compression Test, and other tools in the Soil Mechanics Laboratory.

4 RESULTS AND DISCUSSIONS

The findings will be divided into the following five sections: soil characteristics, Gypsum characteristics, physical properties of stabilized soil, and technical properties of the Proctor standard test and unconfined compression test.

4.1 Physical Properties of the Soil

The purpose of testing soil characteristics is to classify the type of soil used in the study. The results shown in Table 1 are the initial soil characteristics test results. The percentage of soil that passes through the filter no. 200 is 75.04 percent, with a liquid limit of 48.647 percent, as shown in the table. According to the USCS classification system, the data obtained in the form of the percentage of soil that passed the sieve no. 200 is 75.04 percent, and the liquid limit value is 48.65%, a plot on the graph is made to determine the soil classification. The soil obtained is included in the CL group, namely inorganic clay with low to moderate plasticity [25].

Table 1 Results of the original soil

Test	Result
Water content	31.945 %
Wet Density	1.425 gr/cm³
Atterberg Limit:	
▪ Liquid limit	48.647 %
▪ Plastic limit	23.277 %
▪ Plasticity index	25.370 %
% Passing Sieve No. 200	51.04 %

4.2 Physical Properties Test of Gypsum

Tests are conducted on the physical properties of gypsum material, including specific gravity, Atterberg Limit, and sieve analysis. The outcomes of this material test are shown in Table 2 below.

Table 2 The physical properties test results of gypsum

Test	Result
Specific gravity	2.084
Liquid limit	Non-plastic
Plastic limit	Non-plastic
Plasticity index	Non-plastic
% Passing Sieve No. 200	51.62

4.3 Proctor Standard Test Results

It was discovered in this test that there was a relationship between the optimal moisture content and the maximum dry weight content. In this study, the Standard Proctor compaction test method was used. Table 3 displays the compaction test results, while Fig. 1 displays the compaction curve. According to the results of the compaction tests, the optimum moisture content (W_{opt}) is 23.9%, and the dry density value (γd) is 1.53 grams/cm^3.

Table 3 Compaction test data of soil with gypsum

Test	Result
Optimum water content (γd_{max})	23.91 %
Maximum dry density (w_{opt})	1.53 gr/cm^3

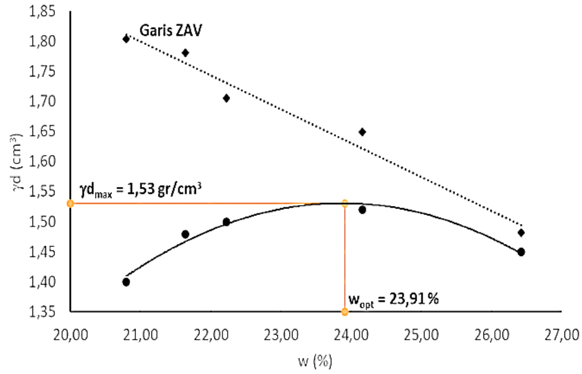

Fig.1 Density curve of soil with gypsum

The compaction test was performed on untreated and treated soil following the predetermined composition, and variations in water content were tried out to determine the optimum moisture content. Table 3 displays the results of standard compaction tests on both soils that have been mixed with varying amounts of gypsum powder.

Table 4 Compaction test results

Test	Max Dry Density (gr/cm³)	Water content (%)
Soil	1.530	23.91
Soil + Gypsum 10 %	1.568	23.09
Soil + Gypsum 15 %	1.550	21.83
Soil + Gypsum 20 %	1.567	18.35
Soil + Gypsum 25 %	1.571	18.95

The density increased as mixed materials were added to the untreated soil. Meanwhile, the optimal water content fell. The addition of the mixed material can fill the pore space of the soil, and because the mixed material can harden when mixed with water, it makes the soil hard, reducing the value of the optimum water content and increasing the value of soil density. It is illustrated in Fig. 2 and Fig. 3.

4.4 CBR Testing

For this CBR test, two treatments were administered: one without soaking (unsoaked) and one with soaking (soaked) for four days. Furthermore, the CBR Unsoaked and Soaked test results, as seen in Table 5 and Fig. 4.

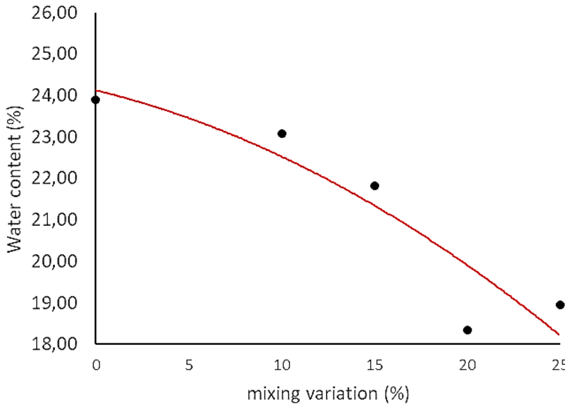

Fig.2 The correlation between the optimum water content (W_{opt}) of soil with gypsum variations

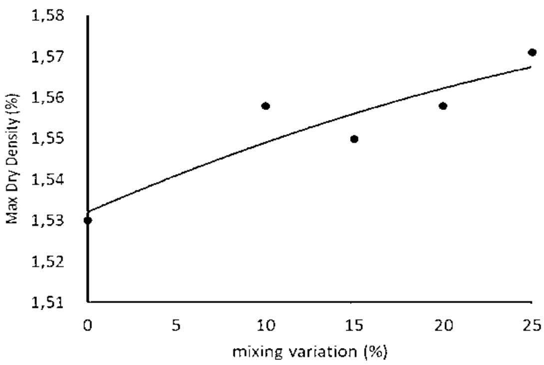

Fig.3 The correlation between the density (γd) of soil with gypsum variations

Table 5 CBR laboratory test results

Test	CBR Unsoaked	CBR Soaked
Soil	7.43	9.76
Soil + Gypsum 10 %	30.21	20.58
Soil + Gypsum 15 %	35.36	38.91
Soil + Gypsum 20 %	31.05	37.32
Soil + Gypsum 25 %	30.52	30.88

Based on Fig. 4, the highest soaked CBR value, namely soaked CBR with the addition of 10% gypsum powder, will nearly double the CBR value of 20.58 percent. The CBR value will increase to the optimum addition range with gypsum powder. Because the addition of gypsum powder in amounts greater than 20% tends to reduce the CBR value.

The results in Table 5 and Fig. 4 show that the CBR value in the wet condition is higher than the CBR value in the unsoaked condition, indicating that the CBR value in the wet condition is higher than the CBR value in the unsoaked condition.

This condition is caused by an increase in soil strength due to immersion. It is only to a certain extent due to the gypsum material's bond with water. Furthermore, the soil mixture with gypsum has solidified before clumping occurs, and the voids between soil particles shrink, giving the soil more strength.

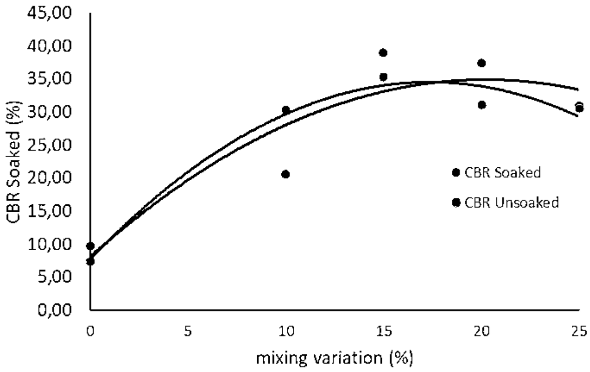

Fig.4 The correlation between the value of CBR_{lab} with gypsum variations

The results of the California Bearing Ratio show that the addition of gypsum powder to the clay increased the value of the California Bearing Ratio by about 17%. However, because soaked CBR is a condition frequently encountered in the field, the soaked CBR price is used as the basis for the calculation in building construction because water always affects and becomes a consideration in building construction.

4.5 Unconfined Compression Test (UCT)

Figure 5 depicts the relationship between the soil's free compressive strength (qu) and the variation of the added material with Gypsum.

According to Fig. 5, adding gypsum powder with a curing time of 21 days resulted in the highest value of free compressive strength (qu). The addition of gypsum material increases the value of the free compressive strength (qu). An increase in free compressive strength (qu) can reduce the soil's potential for expansion and shrinkage. The stabilizer will cover the porous soil grains, giving the soil strength and making it harder and more stable, reducing the potential for shrinkage. It is consistent with previous studies, which found that adding gypsum material as a stabilizing material could increase soil strength to a certain extent [26].

It is consistent with previous studies, which found that adding gypsum material as a stabilizing material could increase soil strength to a certain extent. Several previous studies have found that adding gypsum has the lowest value because gypsum, which contains calcium (Ca), calcium oxide (CaO), hydrogen (H), sulfur (S), and water, will react with refined clay grains that are negatively charged. Positive ions such as hydrogen ions (H+), sodium ions (Na+), potassium ions (K), and polarized water adhere to the clay surface but are not as firm as cement and lime because cement has a higher specific gravity value than gypsum, and gypsum has the lowest calcium silicate content when compared to cement and limestone. When limestone reacts with clay, it forms a solid and hard gel, namely calcium silicate, which can coat and bind clay particles to cover soil pores, but it is not as firm as cement because cement contains more calcium silicate and has a higher specific weight [27].

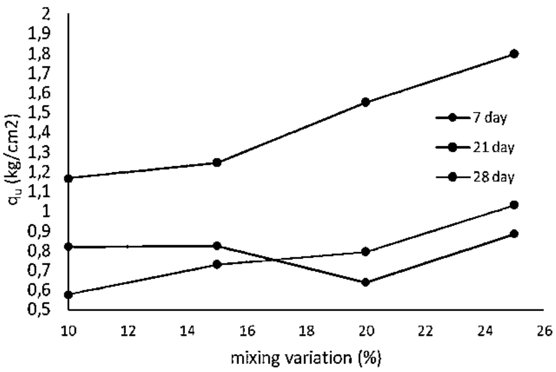

Fig.5 The correlation between unconfined compressive strength (qu) on soil with mixed stabilizer variations and soaking time.

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5 CONCLUSIONS

Several conclusions were reached based on the study's findings, which are as follows:

1. According to the USCS classification, the soil sample is classified as CL (Clay-Low Plasticity), and it has several physical properties, including maximum water content of 31.945% and a dry density of 1.425 gr/cm^3, as well as an Atterberg limit value for the liquid limit value of 48.647%. The limit for plastic is 23.277%, and the limit for plasticity is 25.370%. For the percentage of soils pass sieve No. 200 is 51.04%.
2. The standard Proctor test shows that when a stabilizing agent, such as gypsum powder is added, the water content decreases while the density increases. Untreated soil moisture content was 23.91%, and dry density was 1.53 grams/cm^3. While the maximum dry density of all mixtures was in the 25% gypsum, with 1.571gr/cm^3 and the optimum moisture content was 18.95%.
3. CBR values for untreated soil were 9.76% for soaked soil and 7.43% for unsoaked soil. To a certain extent, the addition of gypsum powder raises the value of both the soaked and unsoaked CBR.
4. The UCT value revealed that adding gypsum powder with a curing time of 21 days resulted in the highest free compressive strength (qu). The addition of gypsum material indicates that the free compressive strength (qu) value will increase as the amount of gypsum powder added to the clay soil varies. The highest qu value was obtained after 21 days of incubation, and the percentage of gypsum in the mixture was 25%, with a value of 1.789 kg/cm^2.

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