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Effect of Gypsum ($CaSO_4$) on Soil using California Bearing Ratio Test

[*] ISWANDARU, [1] RULLY NURHASAN RAMADANI,
[1] EKA ADHITYA KURNIAWAN

[*, 1] Universitas Islam Bandung, Bandung, Indonesia
Correspondance author: liswandaru@unisba.ac.id [*]

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Abstract

Clay soil is a type of soil that has characteristics, namely low carrying capacity and large swelling and shrinkage; this makes clay soil a poor material for construction work. Civil building construction subgrade shear strength and California Bearing ratio (CBR) value influence the planning of a building. CBR is a comparison between the test load and the standard load and is expressed as a percentage. The CBR value is developed to measure the bearing capacity and soil load. The soil stabilization process includes mixing with gypsum material (C_2SO_4) to obtain the desired gradation so that soil properties become better with calcium levels which bind organic matter soil to clay and also absorbs more water which is very useful for strengthening the soil. Testing the California Bearing Ratio (CBR) and direct shear strength of the soil (Direct Shear Test) by adding a different percentage of Gypsum ($CaSO_4$) occurs in the addition of 6% Gypsum in 56 collisions generated a value of 48%, 10 and 25 collisions with the percentage of 7% gypsum result in the CBR value optimum of 27.48% and 28.5%, and the effect of adding gypsum on the cohesion value and the optimum internal friction angle occurs in the addition of 6% lime with a value of 0.017 MPa and 24.93°.

Keywords: California Bearing Ratio (CBR); Clay Soil; Gypsum Material.

Introduction

Soil is an inseparable part of civil engineering building planning. Each type of soil has different specifications, so it requires different handling both mechanically and chemically (Muhyi, 2022). Clay soil is a type of soil that has characteristics, namely low carrying capacity and large swelling and shrinkage which makes clay soil an inadequate material for construction work (Iswandaru, 2020). Low bearing capacity can result in the instability of a building foundation erected on clay soil and the swelling and shrinkage properties of clay soil can cause cracks in the highway pavement; it can also cause rupture or failure on the ground floor of the dam. In the construction of civil buildings, the shear strength of the subgrade soil and the value of the California Bearing Ratio (CBR) have an effect on the planning of a building, thus soil stabilization should be carried out before the soil is used.

Soil stabilization aims to increase the carrying capacity of the soil by enhancing soil parameters such as density, shear strength, and CBR value. CBR is a comparison between the test load and the standard load and is expressed as a percentage. The CBR value was developed to measure the bearing capacity, soil load, and road pavement load. There are several soil stabilization methods that can be carried out, two of which are mechanical soil improvement and chemical soil improvement. The method of mechanical soil improvement is conducted by forcing changes in soil mass through the use of piles, soil compaction, and so on. Meanwhile, the method of chemical soil improvement is carried out by adding a chemical that has special properties that can help obtain a more stable soil mass, for example, mixing Portland cement with lime, coal ash, tras, and zeolite; several studies have used tras (Kapantouw et al, 2018) and gypsum (Wibawa, 2015).

Stabilization of clay soil using gypsum waste by Arif Wibawa (2015) is done by adding gypsum waste to clay soil which is then subjected to direct shear testing. The test results show that there is an increase in the value of the soil that is not mixed with gypsum waste and soil that has been mixed with gypsum waste. Stabilized clay with 5% to 10% gypsum waste shows an increase in the CBR value of immersion up to 10% gypsum waste content and after 15% content the CBR value begins to decrease according to the graph (Nasrani et al, 2020).

Another method is the use of gypsum waste as a stabilizing agent. Gypsum is an effective stabilizing agent that is easy to obtain. Gypsum is an example of a mineral with a calcium content that binds soil with organic matter to clay and also absorbs more water which is very useful for strengthening the soil. In terms of economic value and the lack of utilization of gypsum waste and its advantages, it is hoped that such a method can provide a way to increase the carrying capacity of clay soil.

Research Method

Preparation and Sampling Stage

This preparatory stage is the initial stage for inventorying supporting data, determining locations for sampling clay soil, and preparing gypsum as the main raw material in the research. Administratively, the research area is located in Taman Mekar Village, Pangkalan District, Karawang Regency, West Java Province. The research area is located at coordinates 744000 mE - 756000 mE and 9288000 mN - 9230000 mN Zone 48 Southern UTM WGS84. Sampling in the area is based on material conditions that physically have different characters with different colors with a total of 3 samples.

Clay

Clay is an aggregate of microscopic and submicroscopic-sized particles derived from the chemical decomposition of rock constituent elements, and is plastic in the medium to wide water content range. In a dry state, it is very hard and is not easy to peel off with just your fingers. The permeability of clay is very low (Terzaghi, 1987). Chemical weathering results in the formation of groups of particles of colloid size (< 0.002 mm) known as clay minerals.

The characteristic of clay is that in a dry state, it will be hard, and if it is wet it will be soft, plastic, and cohesive, expands and shrinks quickly, so that it has a large volume change occurs due to the influence of water. Clay is a colloidal fine-grained soil composed of minerals that can expand. Expansive clay has a special property, namely a very high ion exchange capacity when there is a change in water content. If the water content increases, the expansive clay will expand accompanied by an increase in pore water pressure and expansion pressure. On the contrary, if the water content drops to its shrinkage limit, the expansive clay will also experience a fairly high shrinkage (Bowles, 1989).

Chemical Process of Soil Stabilization with Gypsum and Cement

The stages of the chemical process in soil stabilization using lime are as follows: Water absorption, exothermic reaction, and expansive reaction at temperatures below 350º C; the calcium

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oxide component of raw gypsum reacts with water to produce calcium hydroxide as well as heat liberation. The equation below shows that 56 units by weight of pure calcium oxide will hydrate with 18 units by weight of water. On the other hand, it would take 320 liters of water to hydrate one tonne of CaO. The reaction is as follows:

$CaO + H_2O$	→	$Ca(OH)_2$ + heat
(Calcium Oxide)		(Calcium Hydroxide)
(Quicklime)		(Hydrated Lime)

(Heat of Hydration -272 kcal/kg CaO)

Ion Exchange Reaction

Clay grains in the soil are fine and negatively charged. Positive ions such as hydrogen ions (H+), sodium ions (Na+), calcium ions (K+), and polarized water are all attached to the surface of the clay grains.

If gypsum and cement are added to the soil under the above conditions, ion exchange occurs immediately, and sodium ions from the lime solution are absorbed by the surface of the clay grains. Thus, the surface of the clay grain loses its repulsion force and cohesion occurs in the grain, resulting in an increase in the strength of the soil consistency.

Pozzolanic reaction

The reaction occurs between silica (SiO_2) and fine aluminum (AL_20_3) contained in clay soil with reactive mineral content, so it can react with lime and water. The result of the reaction is the formation of calcium silicate hydrates such as tobermorite, calcium aluminate hydrate 4CaO. $A1_2O_3$. $12H_2O$, and gehlenite hydrate 2CaO. Al203. $SiO_2.6H_2O$ which are insoluble in water. The formation of these compounds takes place slowly causing the soil to become harder, denser, and more stable. Conditions that will occur from the stabilization using Gypsum and cement include: 1) Increasing the strength of the subgrade for the construction of new roads or rehabilitating existing roads; 2) Reducing the PI of the original pavement and subgrade material and increasing the volume stability for the top layer of the selected material; 3) Modify the subbase layer to increase pavement strength.

Stage of Addition of $CaSO_4$

Gypsum is an example of a mineral with a predominant calcium content. The most commonly found gypsum is a type of hydrate calcium sulfate with the chemical formula of $CaSO_4.2(H_2O)$. Gypsum is one of the few minerals that evaporate. Other examples of these minerals are borates, carbonates, sulfates, and nitrates. These minerals are deposited on the seabed, lakes, and caves. Due to the concentration of ions by evaporation, when hot water or water has a high salt content, gypsum turns into basanite ($CaSO_4.H_2O$) or anhydrite ($CaSO_4$). In a balanced state, gypsum which is above a temperature of 108 °F or 42 °C in pure water will turn into anhydrite.

The research begins with the preparation stage, which is the initial stage, to inventory supporting data and preparation of $CaSO_4$ and clay as the main raw materials. Sample testing includes composing the soil constituent material (clay), determining the optimum content of the material, and making variations of the mixture.

The addition of certain chemicals, namely $CaSO_4$, into an alloy of soil materials will produce a chemical reaction between the soil and the materials mixed which can produce new materials with better mechanical properties. The mixing with clay material is expected to be able to create a reaction that forms a stable mixed structure which can then increase the parameter value of the tested clay material mechanically in the form of increasing the cohesion value (c) and internal friction angle (Φ) and CBR value in soil mechanics testing. Later, it will be used as one of the parameters for analyzing slope stability and bearing capacity of soil.

The mixing process is conducted as follows: the levels of $CaSO_4$ are made into several different compositions, namely 5%, 6%, 7%, 8%, 9% and 10% of the amount of clay material which will then be tested. The lime content used in this study was taken from the total weight of the material (Table 1).

Laboratory Testing

Basic Physical Properties Test

This test is carried out by measuring the density and natural water content of the soil using the ring gamma test. Other quantities that can be derived are void ratio (e), porosity (n), and degree of saturation (Sr).

The testing of soil physical properties refers to ASTM D7263–09: Laboratory Determination of Density (Unit Weight) of Soil Specimens and ASTM D2216-10: Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. The test sample used in testing the physical properties of the soil is in the form of clay in natural conditions and clay that has received lime addition with a waiting time for testing. The equations used in this test include:

Natural Density

$$\frac{Wn}{\left(\frac{(Wwc - Ws)}{1}\right) - \left(\frac{(Wwc - Wn)}{1,15}\right)} \quad (1)$$

Dry Density

$$\frac{\rho n}{1 + \left(\frac{w}{100}\right)} \quad (2)$$

Natural Water Content

$$\frac{Wn - Wo}{Wo} \times 100\% \quad (3)$$

As a support, soil density testing was carried out which refers to ASTM D698 – 07: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort and SNI 1742:2008 on Light Density Test Methods for Soil. The sample used in this test is clay in natural conditions.

Direct Shear Test

The purpose of direct shear strength testing in slope stability analysis is to determine the mechanical properties of the soil which, when given a shear force accompanied by a load, is still able to withstand and provide force resistance. The strength of the rock/soil sample in receiving this shear force is expressed in several parameters such as cohesion (c), internal friction angle (Φ), normal stress (σn), and the value of shear strength. Shear failure criteria that are often used in slope stability analysis based on the parameters that have been obtained from the test results are the Mohr-Coulomb criteria which are written in the equation as follows:

$$\tau = c + \sigma_n (\tan \Phi) \quad (4)$$

Stage of Sample Testing and Data Analysis

This sample testing phase includes the composition of the soil constituent material (clay) in the form of physical properties consisting of specific gravity, optimum material content, and sieve analysis. Mechanical testing is carried out by varying the mixture of clay and gypsum. The sample will be made manually and printed on a cylindrical mold with a composition based on clay mass for direct shear strength testing (Direct Shear Test) and CBR Test. The research flowchart is shown in Figure 1 below.

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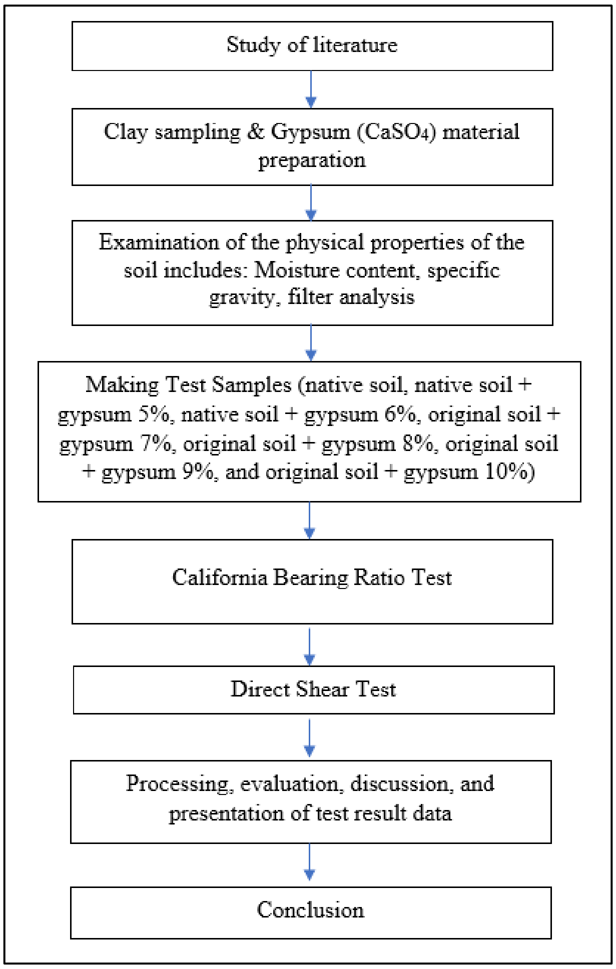

Figure 1. Research Flowchart

Results & Discussion

Physical Properties Test

Tests of physical properties carried out include soil density and soil moisture content (Table 1).

Table 1
Soil Physical Properties

No	Parameter	Value
1	Height of Ring	1.9
2	Diameter of Ring	5.2
3	Volume of ring/volume of soil (cm^3)	40.33016
4	Weight of Cylinder Ring (gr)	44.62
5	Weight of natural soil + cylinder ring (gr)	106.81
6	Weight of Container (gr)	9.11
7	Weight of dry soil + container (gr)	46.86
8	Weight of Natural soil (gr)	62.19
9	Weight of dry soil (gr)	37.75
10	Weight of water (gr)	24.44
11	Water content (%)	64.742
12	Soil density (gr/cm^3)	1.542
13	Dry soil density (gr/cm^3)	0.936

Sieve Analysis Test

Sieve analysis is a procedure used to measure the particle size distribution of a material. Particle size distribution is very important to determine the naming of a material. The percentage of material passing is shown in Figure 2. Based on the soil sample used, the results of the sieve analysis show that the largest pass percentage is silt-clay material at 61.4%; this value shows that most of the material is the silt-clay size (Table 2). The coefficient of uniformity (Cu) is 5.958, while the gradation coefficient is 1.504.

Table 2
Size Distribution of Sieve Analysis Test Results

No	Sample Code	Grave (%)	Coarse To Medium (%)	Fine Sand (%)	Silt-Clay (%)	Cu	Cc
1	BTA 2	0.00	10.83	27.78	61.40	5.958	1.504

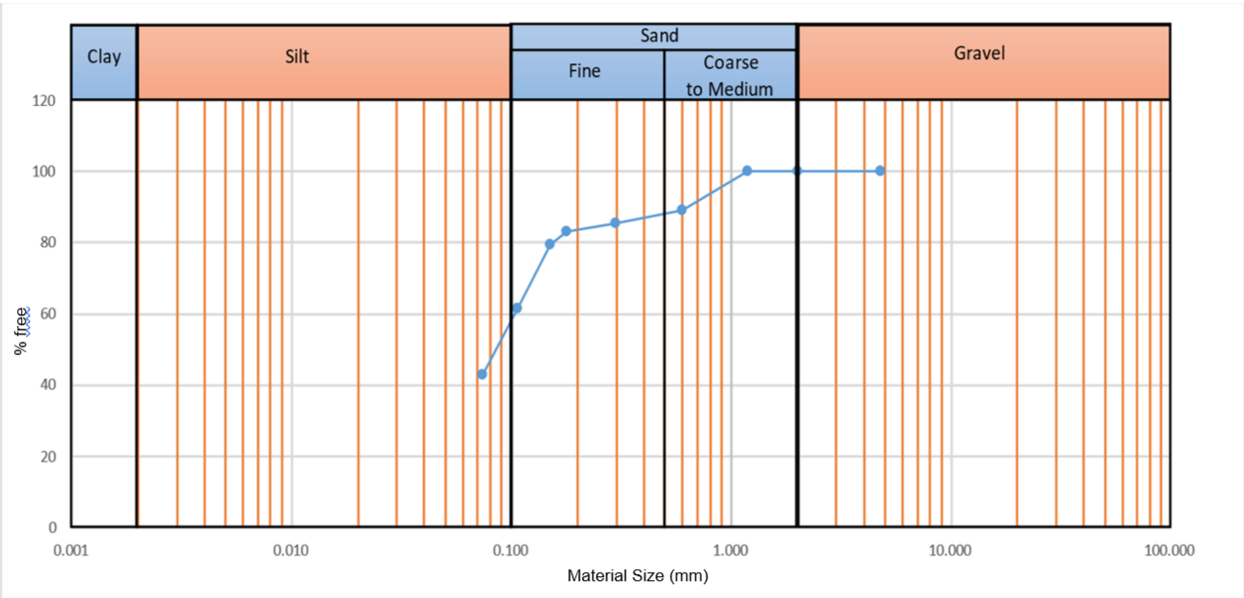

Figure 2. Sieve Analysis Result

California Bearing Ratio (CBR) Test

The percentage of passing material of soil bearing capacity experiment developed by the California State Highway Department aims to increase the bearing capacity of the soil by adding gypsum as soil stabilization by mixing the percentages of 6%, 7%, 8%, 9%, and 10%. The collisions made during the test with the number of 10, 25, and 56 collisions are the established standards. Recapitulation of the results of the CBR test with the addition of percentage gypsum generated the CBR value and density of the material as shown in Table 3. The greater the CBR and density values, the better the bearing capacity of the soil.

Table 3
Result of Gypsum Percentage to CBR Value

Sample Code	% Gypsum	Impact	CBR Value Average (%)	γ (gr/cm^3)
Clay 5 %	5%	10 Times	4.88	1.737
		25 Times	8.14	1.935
		56 Times	24.42	2.054
Clay 6 %	6%	10 Times	10.18	1.739

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		25 Times	25.44	1.947
		56 Times	48.00	2.073
Clay 7 %	7%	10 Times	27.48	1.741
		25 Times	28.50	1.938
		56 Times	38.67	2.061
Clay 8 %	8%	10 Times	19.34	1.712
		25 Times	22.39	1.926
		56 Times	28.50	2.046
Clay 9 %	9%	10 Times	8.14	1.483
		25 Times	14.25	1.651
		56 Times	25.44	1.786
Clay 10 %	10%	10 Times	10.18	1.480
		25 Times	13.23	1.649
		56 Times	16.28	1.765

The results of the CBR test with the addition of gypsum showed that the percentage of 7% had the greatest CBR value of 37.48% with 10 collisions and 28.5% with 25 collisions. The percentage of 6% has the largest CBR value of 48% with 56 times collisions (Figure 3). In the process of pounding which occurs in 3 conditions, ideally, more pounding will produce a greater value of bearing capacity with the most ideal composition: the mixing of 6% gypsum with clay with a value of 48% becomes a reference to be used as one of the standards carried out in the field. Field conditions will be increasingly dense along with the compaction process carried out by mechanical means and weather factors.

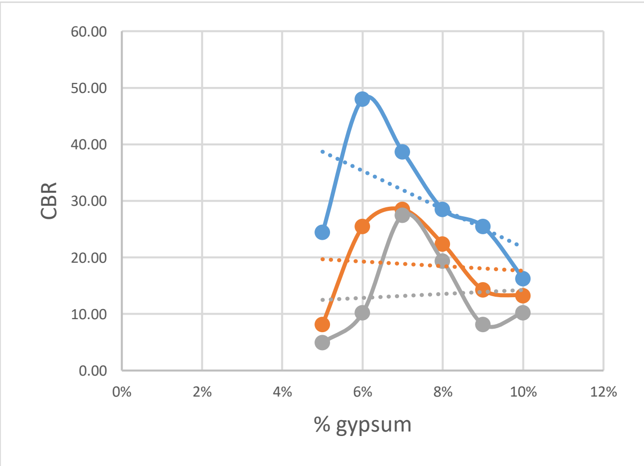

Figure 3. Relationship of Gypsum Percentage and Number of Collisions with CBR Value

The density value obtained from the results of the CBR test in Figure 4 shows a relatively constant value up to a percentage of 5%-8% and decreased in the percentage of 9% and 10% in each collision. The more collisions, the higher the density value; this is due to the pore and air compositions which are getting smaller according to the results shown in Figure 4.

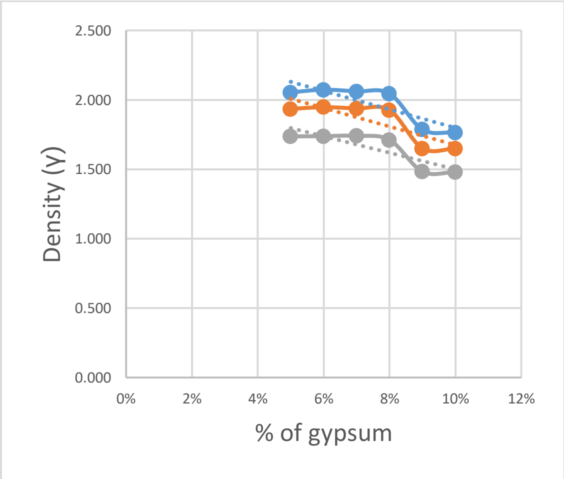

Figure . Relationship of Gypsum Percentage and Number of Collisions with Density Value

Direct Shear Test

Testing of soil mechanical properties using direct shear test aims to obtain the value of cohesion and internal friction angle with a mixture of Gypsum ($CaSO_4$) and soil composition of 5%, 6%, 7%, 8%, 9%, and 10% to gain optimal cohesion and interior angle values. The following table shows the recapitulation of the results of the direct shear strength of the soil on various mixtures of different compositions and the results of the direct shear test of the soil.

The relationship between the mixture of soil composition and different percentages of gypsum for the value of cohesion and friction angle can be seen in Figure 5-6.

Table 4
Recapitulation of Soil Shear Strength Test to Gypsum Percentage

No	Sample Code	Cohesion (C) (MPa)	Cohesion (C) (kg/cm²)	Internal Friction Angle (°)
1	Clay 5 %	0.016	0.16	22.04
2	Clay 6 %	0.017	0.17	24.93
3	Clay 7 %	0.017	0.17	23.52
4	Clay 8 %	0.017	0.17	20.27
5	Clay 9 %	0.013	0.13	15.36
6	Clay 10 %	0.013	0.13	14.51

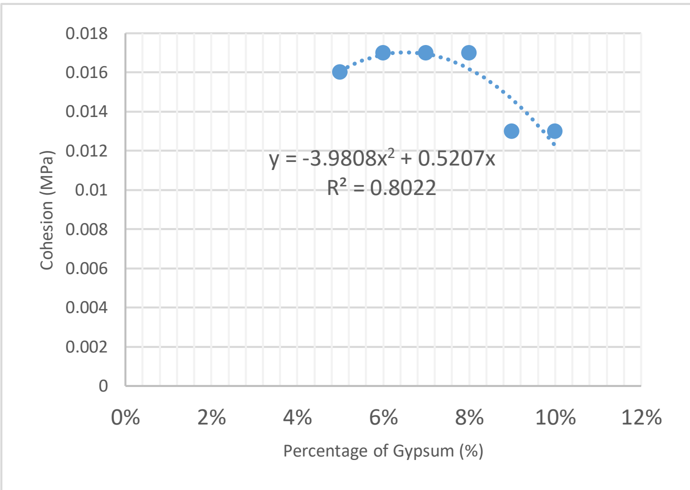

Figure 5. Effect of the Addition of Gypsum on Cohesion Value

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The effect of the addition of gypsum on the cohesion value in Figure 5 shows that the addition of 6%, 7%, and 8% is the optimal condition to obtain the highest cohesion value in various conditions for the formation of mixing percentage of the sample. The addition of the percentage of gypsum needs to be based on the results of the optimal internal friction angle at a certain mixing. The mixing conditions of >8% showed a decrease in value due to the chemical reaction between gypsum and clay that was not completely reacting to the surface area of the clay material.

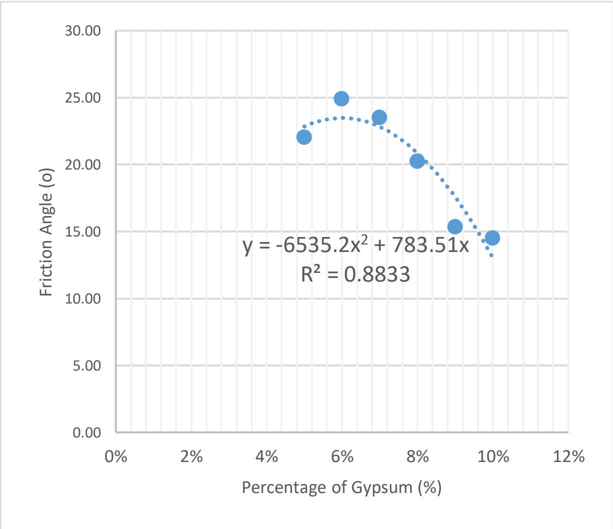

Figure 6. The Effect of theAddition of Gypsum on the Value of Internal Friction Angle

The effect of the addition of gypsum on the value of the internal friction angle in Figure 6 shows that the percentage of 6% has the highest value compared to other mixing conditions. The mixing conditions of 7% - 10% showed a lower internal friction angle; this was due to the chemical reaction between gypsum and clay that did not react evenly on the surface of the clay, most of which became additional material and weak areas when pressure was applied to the test.

Conclusions

This research is conducted by testing the California Bearing Ratio (CBR) and direct shear strength of the soil (Direct Shear Test) by adding different percentages of Gypsum ($CaSO_4$). Sieve analysis based on AASHTO classification shows the percentage of material that passes filter no. 140 of 61.4% and passed the filter no. 200 of 42.93% and shows the material in the form of clay; the optimum water content value of the proctor test results obtained in the clay soil of 17.05% at dry density conditions of 2.27 gr/cm3; and the effect of adding lime to the value of California Bearing optimum ratio (CBR) occurs at the addition of 6% gypsum on the collision 56 times with a value of 48%, on the collision 10 and 25 times the value of the Optimum CBR occurs in the percentage of 7% gypsum with a value of 27.48% and 28.5%, and the effect of adding gypsum on the optimum value of cohesion and internal friction angle occurs with the addition of 6% lime with a cohesion value of 0.017 MPa and an internal friction angle of 24.93o. Overall, the test to get the optimum soil bearing capacity by adding the percentage of gypsum mixture to the clay is at a percentage of 65 with the optimum value for bearing capacity, cohesion, and internal friction angle.

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