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Influence of the degree of compaction and plastic properties of expansively stabilized clay soil with a gypsum mix on the shear strength

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Abstract. The expansive soils have strong shrinkage capabilities, which negatively damage soil stability. Adding chemicals and gypsum materials is one approach to improving soil qualities. To measure soil parameters before and after mixing with gypsum material, soil analysis requires sieve analysis, Atterberg limits, standard proctors, and direct shear. The tests were carried out on 3 samples of gypsum mix, i.e. (5%, 10%, 15%) and aging of each soil for 10 days, 15 days, 20 days, 25 days. Initial soil characteristics: γd = 1340 g / cm3, shear strength Ø = 76.4 ° dan C = 0.071 kg / cm2, yield point = 69.07% and plasticity index = 45.02%. After adding 15% gypsum with a safe time of 25 days, γd = 1418 g / cm3, high shear Ø = 84.9 ° dan C = 0.441 kg / cm2, yield point = 47.94% and yield index = 11.94%. The stabilized density of the expanding soil influences the shear strength, the 5.6 ° increase in density takes advantage of the strong shear increase of Ø = 11.11% and C = 521.2%.

Keywords: Expansive Soil, Clay Soil, Gypsum, Shear Strength, Plastic Property, Degree of Compaction.

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1. Introduction

1.1 Background

The substructure is a crucial feature that can support the entire weight of the construction. Expansive soil is a type of soil that is significantly stimulated by water content material, has complex characteristics, and shrinkage is very fluctuating. Soil shrinkage frequently causes damage to building walls, sloping foundations, uneven roads, and other things. When the soil is clay with low bearing capacity and rapid shrinkage, the structure is frequently harmed. [1]–[3]

Since the strength of the substrate is crucial, it is critical to strengthen the soil with gypsum. This is due to the fact that gypsum soil stabilization is more suitable for a longer period of time and can emerge if there is a prolonged period of work after mixing and there is no risk of weight loss due to compaction. Stabilization is required to overcome the issue of damaged soil. In principle, stabilization is the mixing of soil with certain components in order to improve soil characteristics, or it is a method of modifying and improving soil properties. Mechanical and chemical soil stabilization are the two basic approaches utilized.

Mechanical stabilization improves the structure and mechanical properties of the soil to increase its strength and bearing potential, whereas chemical stabilization reduces the energy and bearing capacity of the soil or lowers technical dwellings that are significantly less ideal when mixing soil to land surface. Chemicals include lime, bitumen, cement, and specific additives. Previous research has not examined the connections between density levels and plastic characteristics in soils with high expansion under high shear [4]. As a result, more research into the use of gypsum is required.

1.2 Expansive Clay

One of the expanding soils is high plasticity soil, which in this case is clay soil. Soil properties with high plasticity [1]–[3], [5]:

1. Fine granule size < 0.002 mm
2. Very high-rate shrinkage
3. Slow consolidation
4. Low permeability
5. Cohesive
6. High capillarity

Table 1 Plasticity and soil type index values (Source: [6])

Plasticity Index	Characteristic	Soil Type	Cohesion
0	Non-Plastic	Sand	Non-Cohesive
<7	Low Plasticity	Silt	Cohesive
7-17	Medium Plasticity	Silty Clay	Cohesive
>17	High Plasticity	Clay	Cohesive

Sticky soil has a plasticity index greater than 17%. Clay is a fine-grained clay that absorbs a lot of moisture. Moisture content influences shrinkage and adhesion in fine-grained clay soils. Expansive clays are clay soils with a wide range of shrinkage. This expanding clay causes numerous construction damage, such as sloping highways and wall fractures.

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It is essential to comprehend the potential in terms of expanding clay at the level of analysis. This is significant because the potential hazards risks caused by infrastructure work can have an impact on the building's construction. Table 2 shows the relationship between the impact of expansive clay soil and its plasticity index.

Table 2 Connection of potential development with plasticity index (Source:[7])

Expansion Potential	Plasticity Index
Low	0-15
Medium	15-35
High	35-55
Very High	>55

Clay is therefore an aluminum silicate complex with the chemical formula Al2O3.nSiO2kH2O, in which an adequate form the numerical values of the solid molecules that break out all at once. Clay soils also seem to be micron to submicron soils presented by the erosion and chemical degradation of rocks with 0.002mm particle size. Clay hardens and becomes tough to remove by hand after hardening. Clay permeability appears to be relatively low, whereas plasticity appears to be medium. [5]

Clay can be many micro and submicroscopic particles as a result of chemical degradation of rock components and is ductile in pipes with mild to high water content. Once dry, it is hard to separate manually. Clay permeability could be very poor. For exceptionally tough, waxy or soapy clays, the term gumbo is used, which often includes minor amounts of sand and/or organic materials, particularly in the West American region. [5].

1.3. Gypsum

Gypsum comes as a result of gypsum rock, alabaster gypsum, glossy silk stick, and selenite. Gypsum is a hydrated calcium sulfate chemical with the material equation CaSO4.2H2O. Gypsum is made from minerals that are not soluble in water. Gypsum can also be classified by region, specifically sulfur-conformed volcanic fumaroles, Salt Lake residue, changing rapidly in limestone soils and karst, salt arches, iron oxide covers (gossan) in pyrite stores in limestone regions. Gypsum is among the few case studies of a type of mineral that consists relatively significant amounts of calcium and is found in minerals. [8]–[10].

The source of gypsum can be both natural gypsums, as described above, and manufactured gypsum. The unrefined substance for gypsum accessible is synthesized gypsum, which is made by preparing limestone with sulfuric acid. Because limestone is only used in small manufacturing structures, attempt to use gypsum synthesized gypsum, which is immensely beneficial and has a high monetary worth.. [11]

Table 3 Gypsum Chemical Composition
Source: [12]

Gypsum Chemical Composition	Amount %
CaO - Calcium Oxide	32,57
Ca - Calcium	23,28
H_2O - Water	20,93
S - Sulfur	18,62
H - Hydrogen	2,34

1.4. Soil Stabilization

Soil stabilization is a technique for improving soil qualities by adding particular compounds to it in order to increase soil strength and high shear. The benefit of soil stabilization is the strengthening and bonding of existing substances, resulting in a sturdy road structure and foundation. Improved soil qualities may include increased range stability, or bearing capacity, permeability, and durability. Elevated soil density, including inactive substances to increase adhesion and/or friction resistance, including substances that purpose chemical and/or physical modifications to the soil, lowering the groundwater table (soil drainage), and alternative of limited and expensive soils for stabilization. Soil stabilization is defined as an effort to improve soil characteristics.[1]–[3]

Chemical and mechanical stabilization types of techniques used. Mechanical stabilization is a method used to increase the bearing capacity of the soil by improving the form and mechanical beds of the soil, whereas chemical stabilization is an attempt to increase the bearing capacity of the soil. The procedure of minimizing and removing the topsoil poor structural beds by mixing the soil with selected chemicals. [5]

An efficient solution to the problem of poor topsoil is to exchange it with higher quality. As a result, they are aiming to overcome this problem by improving the physical qualities of the soil to prevent overloading by improving the physical properties of the soil from lower - class backgrounds, which is consistent with the civil engineering industry known as soil stabilization.

1.5. Compaction of the Soil

The standard Proctor test is intended for use on this examination because it can save time and the equipment utilized is not always overly complicated. Soil compaction seeks to enhance soil resistance so that soil strength capacity can be improved. The density of compacted soil can be determined by its dry volume rate (γd); the higher the dry volume value, the denser the soil. [3]

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The soil density is generally calculated by determining the dry weight, not by measuring the pores. In compaction, a cylinder of a specific length is used, and in writing, a 2.5 kg cultivator with a height of 30 cm is used. This is completed mechanically to compact the soil for any given compaction force, and the density obtained is dependent on the volume of water in the soilA comparatively higher weight indicates fewer holes and a higher density level. Then, to determine the best level, it is evaluated in a laboratory and shown by a graph of the dry volume to water content ratio. The proctor compaction test also determined soil density (γt), maximum dry soil density (γd), and optimal moisture content (Wc). The following equations are used to calculate the implications of this.: [3], [5]

$$\gamma t = Soil\,Weight\,(gr)\ \times Volume\,(m^3) \quad (1)$$

$$Wc = \frac{Water\,Weight\,(gr)}{Dry\,Soil\,Weight\,(gr)} \times 100\% \quad (2)$$

$$\gamma d = \frac{\gamma t}{1+W_c} \quad (3)$$

1.6. Direct Shear Test

Soil shear capacity is an indicator of the soil's capacity to endure loads without collapsing. Essentially, a strong soil shear test determines the characteristics of cohesiveness and shear angle among grains. The soil shear strength characteristics are used to compute the subgrade bearing capacity, slope stability, and lateral forces.[3] The direct shear test is assessed in accordance with the submerged soil test. Using a controlled ultimate shear system, this test is aimed to evaluate the forward shear force, internal shear angle, and cohesiveness in the original soil. Shear stress is the greatest shear stress applied by vertical and lateral forces to the soil. [3], [5]

In the machine, the test soil pattern may be constructed and exposed to continuous vertical stress (i.e normal stress). The shear stress is then provided in the example until the maximum value is achieved. This shear stress is caused by the use of a constant rate of motion (stress rate) that is relatively slow, allowing the strain in the pore water to remain constant. This approach assumes that it is merely an "overloaded" experiment that can be performed using a simple move tool. It is necessary to conduct experiments with different normal stresses in order to acquire the values of c' and. [3], [5]

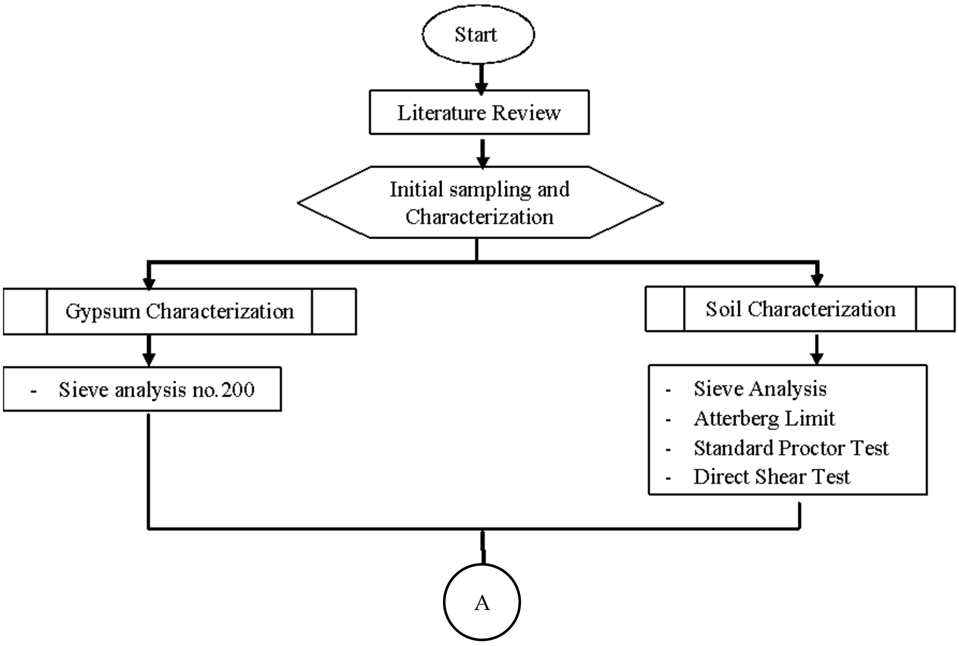
1.7. Soil Consistency (Atterberg Limit)

Soil texture is the strength of the cohesion of soil grains or the adhesion of soil grains to specific objects. These manifests itself in the resistance of the soil to forces which can alternate its shape. The fine texture blends seamlessly into the soil and now no longer sticks to the cultivation tools. Therefore, the soil may be obtained in a liquid state, consequently the texture properties of the soil ought to be adjusted to the soil conditions. [3]

In humid conditions, the soil is easy to treat until it becomes difficult to loosen. After drying, the soil can be soft or hard. Under alkaline conditions plasticity can be distinguished from plastic or its adhesion from non-sticky to sticky. [5]

2. Materials and Methods

Initial material consists of undisturbed soil and disturbed soil which has been examined with characterization as follow: Sieve analysis, Atterberg Limit, Standard Proctor Test, and Direct Shear Test. Soil and gypsum mixture has been aging for the time as planned on work flow before the samples tested by same characterization as initial material. The research work flow was described by figure 1.



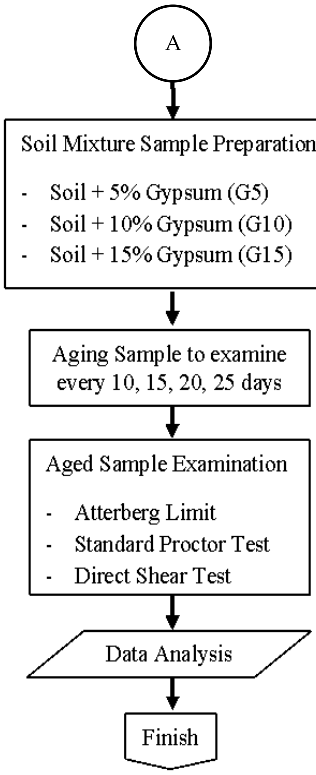


Fig 1 Work Flow diagram

3. Result and Discussion

3.1. Compaction Test

This test aims to obtain the value of soil water content and dry volume weight of both original and mixed soil gypsum.

Table 4 Recapitulation of Standard Proctor Test Results (Source: ITATS Soil Mechanic Laboratory, 2020)

Mixed Percentage	Aging Time							
	Day 10		Day 15		Day 20		Day 25	
	γdmax (gr/cm³)	W_{opt} (%)	γdmax (gr/cm³)	W_{opt} (%)	γdmax (gr/cm³)	W_{opt} (%)	γdmax (gr/cm³)	W_{opt} (%)
0%	1,340	30,35	1,340	30,35	1,340	30,35	1,340	30,35
5%	1,058	26,50	1,068	49,00	1,340	43,50	1,370	42,48
10%	1,065	31,00	1,072	46,00	1,380	47,00	1,402	39,50
15%	1,066	31,00	1,073	47,5	1,388	46,50	1,418	38,00

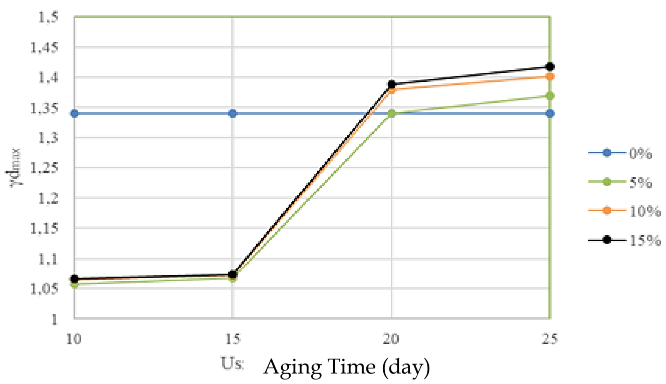


Fig 2 Relation of Aging time with γdmax (Source: ITATS Soil Mechanic Laboratory, 2020)

Figure 2 Shows the connection between aging time and γdmax value. The effects of the proctor test confirmed that aging on the age of 10 and 15 days in all versions of the addition of gypsum nevertheless had a decrease γdmax value than the original soil. This occurs due to the fact the chemical content material in the gypsum has been formed and might increase the density of the soil, so long as the γdmax is not increased. This is because of the chemical procedure contained in the clay that binds the unformed gypsum. However, after the aging procedure of 20 days, the γdmax value will increase to pass via the original medium. [10], [11], [13], [14]

3.2 Direct Shear

The direct shear takes a look at objectives to decide the value of cohesion (C) and friction angle (Ø). Direct shear may be measured immediately by weighing a consistent (normal) vertical load at the pattern and applying a certain shear pressure at a consistent and gradual charge to keep pore water retention at 0 till the most shear energy is reached. The first direct reduce parameter calculation is everyday strain and reduce voltage. Here's the way to calculate it:

Table 5 Recapitulation of direct Shear test (Source: ITATS Soil Mechanic Laboratory, 2020)

Mixed Percentage (%)	**Ø°**			
	Day 10	**Day 15**	**Day 20**	**Day 25**
0%	76,4	76,4	76,4	76,4
5%	77,2	79,4	82,3	83,3
10%	79,2	80,3	83,4	83,9
15%	79,4	83,3	83,9	84,9

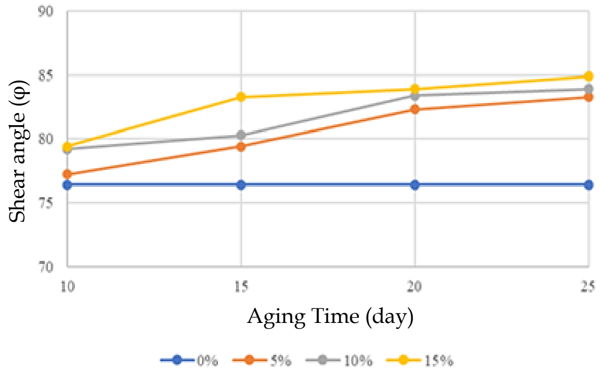


Fig 3 Graph of aging time connections with sheer angle

Table 6 Recapitulation of soil cohesion value results (Source: ITATS Soil Mechanic Laboratory, 2020)

Percentage Mixed (%)	**Cohesion**			
	Day 10	**Day 15**	**Day 20**	**Day 25**
0%	0.071	0.071	0.071	0.071
5%	0.123	0.183	0.245	0.297
10%	0.177	0.221	0.267	0.355
15%	0.211	0.233	0.298	0.441

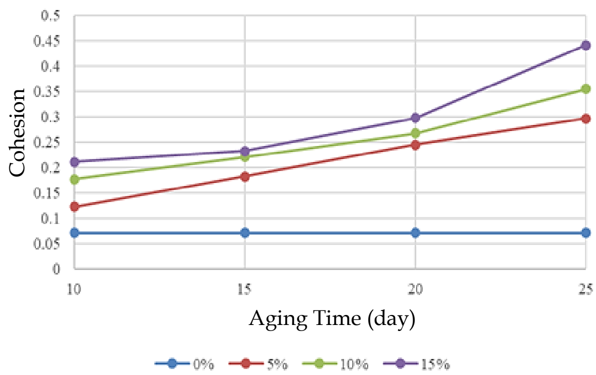


Fig 4 Graph of aging time with cohesion values

Based on the direct shear test results, it is recognized that the greater gypsum is added and the longer the aging time of the soil, the better the shear angle and the soil cohesion will be. At the addition of 15% gypsum with a 25-day acidification time the density rate rose 5.6% and strong sliding Ø = 11.11% and C = 521.2%; Based on Figures 2, 3 and 4, it is able to be visible that with the growth in the amount of addition of gypsum and the longer the aging time, the extent of expansive density of the soil will growth, in order that the shear strength additionally increases. [10], [11] 3.3 *Atterberg Limit*

Atterberg Limit testing was conducted on native soils and all variations of different time frames (10, 15, 20, 25 Days) with gypsum addition (5%, 10%, 15%, 20%) The following is a recapitulation of Atterberg Limit test

Table 7 Atterberg Limit Testing Recapitulation (Source: ITATS Soil Mechanic Laboratory, 2020)

Liquid Limit of original soil and Gypsum Addition (%)				
Mixed Percentage	10 Days	15 Days	20 Days	25 Days
0%	69,08	69,08	69,08	69,08
5%	66,705	66,10	57,395	56,14
10%	66,185	64,87	56,39	55,13
15%	65,08	63,43	52,5	47,94
Plastic Limit of original soil and Gypsum Addition (%)				
Mixed Percentage	10 Days	15 Days	20 Days	25 Days
0%	24,05	24,05	24,05	24,05
5%	29,98	29,78	27,28	27,33
10%	35,69	35,36	29,91	29,82
15%	39,71	38,62	35,84	36,00
Plastics Index of original soil and *Gypsum* Addition (%)				
Mixed Percentage	10 Days	15 Days	20 Days	25 Days
0%	45,02	45,02	45,02	45,02
5%	36,72	36,32	30,11	28,81
10%	30,49	29,51	26,48	25,31
15%	25,37	24,81	16,66	11,94

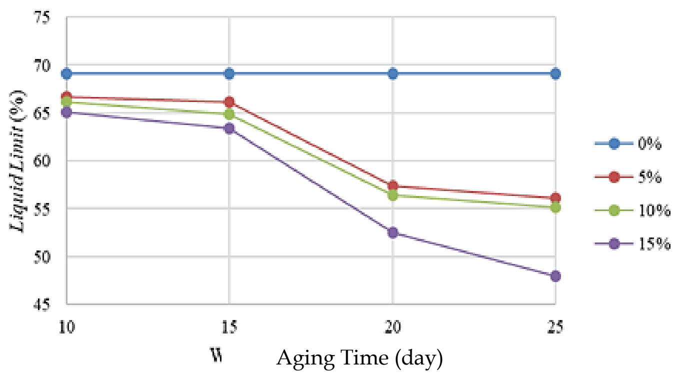


Fig 5 Graph of connection of aging time with liquid limit value

The check results display that the extra gypsum is delivered and the longer the aging time, the decrease the liquid limit value. This suggests that the addition of gypsum impacts the water content required for the soil to attain the liquid limit [10], [11], [13], [14]

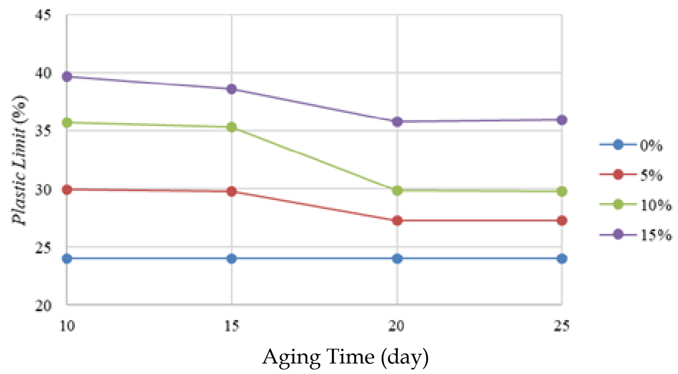


Fig 6 Graph of Connection of Aging Time with Plastic Limit Value

The plastic limit (ASTM D4318, 1998) is described because the water content in the soil among the plastic and semisolid phases. When the water content material in the soil decreases, the soil will become more difficult and has the capacity to face up to deformation. The plastic limit test determines the quantity of water contained in the soil pattern as it flows from the plastic phase to the semisolid phase or vice versa. The Plastic Limit Value may have features that are inversely proportional to the Liquid Limit Value. According to Figure 6, the higher the amount of gypsum mixture, the higher the plastic limit value. [10]

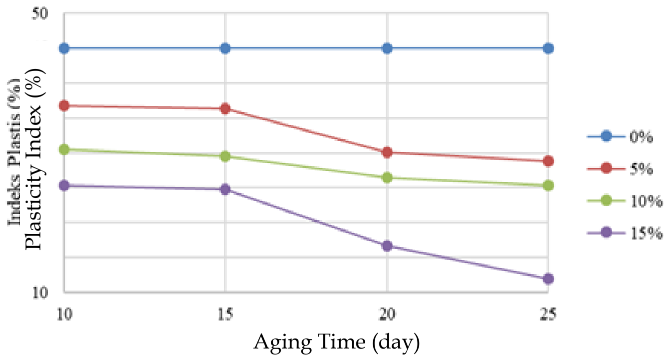


Fig 7 Graph of the connection of aging time with plasticity index value

The greater the plasticity index number, the more likely the soil is in a plastic state. According to Figure 7, the addition of gypsum can also diminish soil plasticity. The plasticity index is a metric that is calculated by subtracting the Liquid Limit from the Plastic Limit. The amount of CaO (calcium oxide) in gypsum can influence soil plasticity. Excessive plastic index readings indicate that the soil is sensitive to changes in moisture-containing elements and has particularly good shrinkage qualities, which has a negative impact on the soil's bearing potential or strength. [10], [11], [13], [14]

4. Conclusion

The degree of expansive soil density that has been stabilized has an impact at the shear energy, the growth in density through 5.6% makes use of a sturdy growth in shear Ø = 11.11% and C = 521.2%. Because of its properly plasticity, the capacity for improvement is low, if there's an extrude in moisture content. The more the addition of gypsum and the longer the time of aging of soil density and the character of soil plasticity the better, based totally absolutely on the strength value of the shear is increasing, the rate of liquid limit and index plasticity have come to be smaller. Characteristics of the authentic soil fee γd = 1,340gr / cm^2, shear energy Ø = 76.4° dan C =0.071kg / cm^2, liquid limit = 69.07% and Index plasticity = 45.02%. After the addition of gypsum 15% with a secure time of 25 days, the fee of γd = 1,418gr / cm^3, sturdy shear Ø = 84.9 ° dan C= 0.441kg / cm^2, liquid limit= 47.94% and Index plasticity = 11.94%.

References

[1] O G Ingles; J B Metcalf, *Soil stabilization: principles and practice*. Sydney: Butterwoths, 1972.
[2] H. C. Hardiyatmo, *Soil Stabilization for Highway Pavement*. Yogyakarta: Gadjah Mada University Press, 2010.
[3] Bowles J.E, *Physical and Geotechmical Properties of Soils*, Second Edi. Singapore: McGraw-Hill, 1984.
[4] W. Hassan, M. Ahmad, A. Farooq, A. Ajwad, H. Ali, and Y. Ilyas, "Correlation of Maximum Laboratory Dry Density and Optimum Moisture Content of Soil with Soil Parameters," Feb. 2020, doi: 10.24081/nijesr.2017.1.0003.
[5] ASTM, *Annual Book of ASTM Standards*, Section 4,. West Conshohocken: International Barr Harbor Drive, 2003.
[6] R. E. Hunt, *Geotechnical Engineering Analysis and Evaluation*. New York: Mc Graw – Hill Book Co, 1986.
[7] T. H. T. Ralph B. Peck, Walter E. Hanson, *Foundation Engineering*, Second Edi. New York: John Wiley & Sons, Inc., 1991.
[8] ANSARIKIMIA, "KALSIUM OKSIDA 'KAPUR TOHOR': FUNGSI & APLIKASI," *Wawasan Ilmu Kimia*, 2014. https://wawasanilmukimia.wordpress.com/2014/04/22/kalsium-oksida-kapur-tohor-fungsi-aplikasi/.
[9] ANDRIAN VERNANDES, "Magnesium Sulfat (MgSO4), Kalsium Sulfat (CaSO4) dan Kalsium Karbida (CaC2)," 2016. https://www.avkimia.com/2016/11/magnesium-sulfat-mgso4-kalsium-sulfat-CaSO4-Kalsium-karbida-CaC2.html.
[10] G. Prasetyo, "Stabilisasi Tanah Gambut Rawa Pening Menggunakan Campuran Gypsum Sintetis (CaSO4. 2H2O) Dan Garam Dapur (NaCl) Ditinjau Dari Pengujian," 2014.
[11] Maryati and Y. Apriyanti, "Analisis Perbandingan Penggunaan Limbah Gypsum Dengan Semen Sebagai Bahan

Stabilisasi Tanah," *Forum Prof. Tek. Sipil*, vol. 4, no. 1, pp. 49–64, 2016.
[12] Web Mineral, "Gypsum Mineral Data," 2007. http://www.webmineral.com/data/Gypsum.shtml#.YopjiqhBw2z.
[13] G. S. Utami, "Clay soil stabilization with lime effect the value CBR and swelling," *ARPN J. Eng. Appl. Sci.*, vol. 9, no. 10, pp. 1744–1748, 2014.
[14] G. S. Utami, T. MCA, and L. D. Andriani, "Stabilisasi Tanah Dasar (Subgrade) dengan Menggunakan Pasir Untuk Menaikkan Nilai CBR dan Menurunkan Swelling," *Semin. Nas. Sains dan Teknol. Terap. III 2015*, pp. 587–594, 2015.