The effect of gypsum plafond waste on shear strength of soft clay soil

Reffanda Kurniawan Rustam¹, Ayu Resti¹, Herri Purwanto¹, Muhammad Firdaus¹

¹Civil Engineering Department, Faculty of Engineering, Universitas PGRI, Palembang, 30263, Indonesia

E-mail : reffandakurniawan@yahoo.com

Abstract. One type is soft clay soil which has a low compressibility and high water content that causes the carrying capacity of the soil to be low. In this research, soil improvement was carried out chemically by soil stabilization method using a mixture of gypsum plafond waste with a percentage of 5%, 10%, 15%, 20%, and 25% in a laboratory scale. Soft clay samples used for the study were taken in the Pakjo area of Palembang, South Sumatra. The use of gypsum plafond waste as a mixture was expected to increase the shear strength of soft clay. Tests carried out include testing Direct Shear. Based on the USCS classification, the soil was classified as CH and based on AASHTO classification was A-7-6. The value of $w_{o}$ is 22% (optimum moisture content) and the value of $\gamma_{dmax}$ is 1.74 gr/cm³ (maximum dry weight). The maximum cohesion (c) value is 24.20 kPa from 15% mix of gypsum plafond waste (WPG15) sample. For the maximum value internal friction angle (ϕ) is 16.36 °C from 5% mix of gypsum plafond waste (WPG5) sample. The maximum shear strength (τ) is 26.57 kPa from 5% mix of WPG15 sample.

1. Introduction

The city of Palembang, especially the Pakjo area with various types and characteristics of the existing soil, makes the construction process of a construction in it more varied. One type of soil that is quite common in the Pakjo area is red soil. Red soil in the Pakjo area of Palembang which has been studied is soft clay soil [1]. Soft clay soil is a type of soil that has a low bearing capacity and high compressibility [2]. Soft clay soil is a soil that has a high content of clay minerals and water content so that the soil shear strength is low. In addition, soft clay soils also have high soil degradation values, causing the soil’s bearing capacity to be low.

Stabilization is an effort made to improve and change the nature and parameters of native soil to achieve the expected quality of the comparison of the original soil. Effective soil stabilization is by adding certain chemicals so that it can affect the characteristics of the soil in order to increase the bearing capacity and shear strength of the soil. Based on the above, the authors conducted further research on stabilization by using gypsum plafond waste in a laboratory scale. It is expected that this research can increase the bearing capacity of the soil with the parameter of soft clay soil shear strength.

Research from [3] had been used a direct shear test (shear box) to determine the mixture of clay-sand. [4], examined the stabilization of clay soil with a mixture of gypsum and paddy ash. This
research uses UCT (unconfined compressive strength) and CBR (California Bearing ratio) tests. [5], in his research using a mixture of gypsum and fly ash on peat soil. Gypsum percentages in range 0-20 % and fly ash percentage 10 %. [6] also uses a mixture of gypsum and NaCl for silty clay soil. Salt mixture uses a percentage of 15 %, 20 %, and 25 %. [7] describes research on the behavior of clay soil stabilized by coal fly ash. The mixture from coal fly ash is from 15-30 % and for lime mixture is added 3 %. A mixture of recycled bassanite to stabilize soft clay soil had been used by [8]. The stabilization method uses the waste demolition in the expansive design [9]. [10] uses a mixture of plastic waste and cement for soil stabilization processes. The stability of soft clay soil was investigated by [11] using a chemical stabilization method with a recycled gypsum mixture. [12] uses large shear testing to test the stabilization of soft clay soils in Bangkok. Stabilization process using soil cement column.

2. Materials and Method

The methodology had been used was laboratory testing conducted at the Soil Mechanics Laboratory of Sriwijaya University and Sriwijaya Polytechnic Palembang. Soft clay soil (red soil) samples were taken at a depth of 0.5-1 m in the Pakjo area of Palembang, South Sumatra Province. The collection of soft soil samples is disturbed soil sampling. Research from [13] describes techniques for solving the problems in the preparation of sample specimens and soil stabilization testing. Soil properties tests include: Moisture Test (ASTM D-2216-90 standard); Testing Specific Gravity (Gs) of Soil Granules (ASTM D-854); Atterberg Limit Testing (ASTM D 42366 and ASTM D 424-74); and Sieve Analysis Test (ASTM D 421 and ASTM D 422). Standard soil compaction testing was carried out before testing the shear strength test with Direct Shear equipment. The results of this test is to acquire the optimum water content value from the soft clay soil. Testing of SEM and EDX had been done to be able to see the texture of the soil and to find out the elements contained in soft clay soil.

In this research, the soft clay stabilization process uses gypsum plafond waste. The steps of making test specimens are as follows: soil that has been dried and sieved in No. 4 filter mixed with gypsum plafond waste. The percentage of addition of gypsum plafond waste is obtained from the percentage of added material added to the weight of the original soil. The percentage addition of gypsum plafond waste mixture is 5 %, 10 %, 15 %, 20 %, and 25 % of the dry weight of the original soil. Then mix the water into a mixture of soil and gypsum plafond waste according to the optimum water content that has been obtained from the results of standard soil compaction testing. Furthermore, standard soil compaction has been carried out with a 4 diameter and 943 cm mold.

Then the soil sample is ready for direct shear testing. Figure 1 shows the type of soil and gypsum plafond waste used. While Figure 2 shows standard and direct shear soil compaction equipment. A total of 45 samples of specimens were prepared to analyze the effect of adding a mixture of gypsum plafond waste to soft clay soil shear strength. The obtained soil shear strength parameters are: cohesion ($c_u$) and shear angle ($\phi$).

---

(a) Soft Soil Clay

(b) Gypsum Plafond Waste

Figure 1. Research material
3. Results and Discussions

The tests that have been carried out in this research will be obtained parameter data such as: soft clay soil properties, standard soil compaction testing (optimum water content, $w_{opt}$ and maximum dry weight $\gamma_d$), direct shear test (cohesion, $c$, internal friction angle, $\phi$, shear strength, $\tau$), and SEM-EDX test results.

3.1. Soft clay soil properties

Table 1 describes the results of physical properties of soft clay soil (red soil) and soil classification [1]. Soil property index testing such as: moisture content ($\omega$), density ($G_s$), grain analysis and Atterberg boundaries in the form of liquid limits (LL) and plastic limits (PL). While mechanical testing is in the form of direct shear testing. The recapitulation of the properties index test results (water content, specific gravity, Atterberg boundaries and sieve analysis) and soil classification based on AASHTO and USCS. From Table 1, the classification of soil obtained based on soil classification according to AASHTO (American Association of State Highway and Transporting Official) is A-7-6 (clayey soils). Whereas according to USCS (Unified Soil Classification System) inorganic clay with high plasticity / fat clay (CH).

![Figure 2. Equipment for testing](image)

| No. | Test                              | Results |
|-----|-----------------------------------|---------|
| 1   | Water Content ($\omega$, %)       | 27.70   |
| 2   | Specific gravity ($G_s$)          | 2.67    |
| 3   | Sieve Analysis No.40 (0.425 mm, %) | 94.48   |
| 4   | Sieve Analysis No.200 (0.075 mm, %) | 82.56   |
| 5   | Liquid Limit (LL, %)              | 66.00   |
| 6   | Plastic Limit (PL, %)             | 25.13   |
| 7   | Index Plastic (IP, %)             | 40.87   |
| 8   | Classification AASHTO             | A-7-6   |
| 9   | Classification USCS               | CH      |

Test results in the laboratory on soil properties index testing showed that the soil taken from Pakjo Palembang had original moisture content ($\omega$) of 27.70 %, soil specific gravity ($G_s$) of 2.67, liquid limit (LL) 66.00 %, plastic limit (PL) 25.13 % and plasticity index (IP) of 40.87 % which indicates that the soil is clay soil with very high expanding potential based on Table 4.1. Classification of red soils based on the USCS classification system (Table 4.3) is clay or CH. Whereas based on the
AASHTO classification system (Table 1) the type of soil obtained is A-7-6 which has very poor criteria (clayey soils).

3.2. Results of direct shear test

Standard soil compaction testing is carried out on native soil before direct shear testing. This test is to get the optimum water content value. Standard soil compaction testing is carried out at the Soil Mechanics Laboratory of the Civil Engineering Department of Sriwijaya University Inderalaya. The results of standard soil compaction testing on clay soil obtained optimum water content \( (w_{opt}) \) of 22% with maximum dry weight \( (\gamma_{d, max}) \) of 1.74 gr/cm³. Direct shear test aims to determine the parameters of soil shear strength, namely the value of cohesion \( (c) \) and the inner shear angle \( (\phi) \). Direct shear testing was conducted at the Land Test Laboratory of the Civil Engineering Department of the Sriwijaya Polytechnic Palembang. This test uses the Humboldt Material Testing Software program. The soil samples that have been added with gypsum plafond waste with a variation of 5%, 10%, 15%, 20%, and 25%. The direct shear testing with 3 different normal loads. Normal stresses for direct shear testing in this research are: 49 kPa, 98 kPa and 196 kPa.

Direct shear test results obtained shear force, horizontal stress, strain and shear stress data. Soil direct shear test data were analyzed to obtain the soil shear strength parameters. Shear stress is calculated by dividing the shear force value from direct shear test with the area of the soil sample. Then the value of the shear stress and horizontal displacement of each soil sample at each loading is plotted in a graph of the relationship between horizontal stress and shear stress. In Figure 3 below is given a graph of the relationship between horizontal stress and shear stress for soft clay soil (red soil) sample 1 gypsum plafond waste WPG 1 sample. Whereas Figure 4 describes a graph of the relationship between normal stress and maximum shear stress of sample gypsum plafond waste WPG 1 sample.

![Figure 3. Graph Relation between horizontal stress and shear stress of WPG 1 sample](image)

Waste of Plafond Gypsum (WPG) 5%  Waste of Plafond Gypsum (WPG) 10%

![Figure 3. Graph Relation between horizontal stress and shear stress of WPG 1 sample](image)

Waste of Plafond Gypsum (WPG) 15%  Waste of Plafond Gypsum (WPG) 20%

![Figure 3. Graph Relation between horizontal stress and shear stress of WPG 1 sample](image)

Waste of Plafond Gypsum (WPG) 25%
Waste of Plafond Gypsum (WPG) 5 %  
Waste of Plafond Gypsum (WPG) 10 %  
Waste of Plafond Gypsum (WPG) 15 %  
Waste of Plafond Gypsum (WPG) 20 %  
Waste of Plafond Gypsum (WPG) 25 %

A linear line of peak tangent is pulled so that the linear line equation is obtained. From this linear line, we can know the cohesion value and the inner shear angle ($\phi$). Recapitulation of the results of soft clay soil cohesion ($c$) and internal friction angle ($\phi$) obtained from the direct shear test can be seen in Table 2. From the results of cohesion and internal friction angle values obtained shear strength parameters ($\tau$) soft clay soil. Table 3 shows the recapitulation of the results of the shear strength ($\tau$). All parameters obtained from the direct shear test are shown in Figure 5. Based on Table 2, Table 3, and Figure 5 can be seen that the maximum cohesion parameter value ($c$) is found in the mixture of gypsum plafond waste with a percentage 15 % is 15.65 kPa. The value of the internal friction angle ($\phi$) is found in the mixture of gypsum plafond waste with a percentage of 5 % at 16.92 kPa. For soft clay soil shear strength parameters, the maximum value is found in the mixture of gypsum plafond waste with a percentage of 15 % of 26.90 kPa.

Table 4 shows the results of the recapitulation of the average value of cohesion ($c$, kPa), the internal friction angle ($\phi$, °), and the shear strength ($\tau$, kPa). Based on the table, it can be seen that the highest cohesion value ($c$, kPa) is found in the WPG 15 sample (15 % mix of gypsum plafond waste). As for the value of the internal friction angle ($\phi$, °), the largest value is in the 5 % mixture of gypsum plafond waste (WPG 5) of 16.36. For soil shear strength parameters ($\tau$, kPa), the largest value is found in the 15 % gypsum plafond waste mixture (WPG 15) of 26.57. Recapitulation graph of the mean values of $c$, $\phi$, and $\tau$ shown in Figure 6.
Table 2. Recapitulation of cohesion value (C) and internal friction angle (ϕ)

| Code | Cohesion (c, kPa) | Internal Friction Angle (ϕ, °) |
|------|-------------------|-------------------------------|
|      | Location 1 | Location 2 | Location 3 | Location 1 | Location 2 | Location 3 |
| WPG 0 | 13.00 | 15.95 | 14.72 | 13.90 | 16.05 | 15.38 |
| WPG 5 | 14.71 | 14.96 | 14.89 | 16.03 | 16.14 | 16.92 |
| WPG 10 | 22.67 | 23.87 | 24.34 | 15.42 | 15.66 | 15.10 |
| WPG 15 | 23.64 | 24.33 | 24.65 | 15.21 | 15.32 | 14.94 |
| WPG 20 | 23.29 | 23.74 | 23.87 | 13.06 | 13.13 | 13.36 |
| WPG 25 | 21.34 | 21.56 | 21.47 | 10.92 | 11.08 | 11.42 |

Table 3. Recapitulation of shear strength value (τ)

| Code | Shear Strength (τ) |
|------|-------------------|
|      | Location 1 | Location 2 | Location 3 |
| WPG 0 | 14.92 | 17.72 | 16.62 |
| WPG 5 | 16.67 | 17.25 | 16.34 |
| WPG 10 | 25.92 | 24.19 | 26.90 |
| WPG 15 | 26.50 | 27.16 | 26.06 |
| WPG 20 | 20.86 | 21.22 | 21.37 |
| WPG 25 | 21.01 | 21.16 | 19.78 |

Based on the results of soft clay soil testing in the Pakjo area of Palembang, it can be seen that the shear strength of soft clay which is given a gypsum plafond waste has increased. Shear strength value (τ) of soft clay soil before gypsum plafond waste mixture is given 16.42 kPa. After being given a mixture of gypsum plafond waste, soft clay soil shear strength increased at a percentage of 5 %, 10 %, and 15 % at 16.75 kPa, 25.67 kPa, and 26.57 kPa.

Figure 6 above shows that the cohesion value (c) in the mixture of 5%-15% gypsum plafond waste has increased, while in the mixture of gypsum plafond waste 20%-25% has decreased. The value of the internal friction angle in (ϕ) in Figure 6 shows that the mixture of 5%-25% gypsum plafond waste has decreased, it happens because the soil has a slight shift due to the high cohesion value of the soil because the particles between the soil grains are very strong. In Figure 6 also shows that the mixture of 5%-15% gypsum plafond waste increases, this increase occurs because gypsum contains calcium which binds the soil to organic matter to clay. Whereas the mixture of gypsum plafond waste 20%-25% has decreased. The results of [6] described that the mixture of gypsum and NaCl can increase chemical content and unconfined compressive strength of the soil.

Table 4. Recapitulation of Average Value from Cohesion (c), internal friction angle (ϕ) and Shear Strength (τ) of Soft Clay Soil

| Code | Cohesion (c, kPa) | Internal Friction Angle (ϕ, °) | Shear Strength (τ, kPa) |
|------|-------------------|-------------------------------|------------------------|
| WPG 0 | 14.55 | 15.11 | 16.42 |
| WPG 5 | 14.85 | 16.36 | 16.75 |
| WPG 10 | 23.62 | 15.39 | 25.67 |
| WPG 15 | 24.20 | 15.15 | 26.57 |
| WPG 20 | 23.63 | 13.18 | 21.15 |
| WPG 25 | 21.45 | 11.14 | 20.65 |
Figure 5. The results of direct shear test

Figure 6. Recapitulation graph of the average value results of direct shear test
3.3. SEM-EDX test results

Soil soft clay in the Pakjo area of Palembang, South Sumatra Province generally has a slightly reddish brown color. To be able to see the texture of the soil, an SEM (Scanning Electron Microscope) analysis is performed. To find out the quantitative data, the elements contained in soft clay soil are analyzed using EDX (Energy Dispersive X-Ray). SEM analysis and SEM-EDS were conducted at the Palembang Branch Forensic Laboratory. The soil sample used for SEM-EDX analysis is in the form of soft clay soil samples from the disrect shear test with the maximum value. The results of SEM (Scanning Electron Microscope) analysis can be seen in Figure 7.

In Figure 7a is an image resulting from SEM 5000x magnification soft soil. While Figure 7b is an image resulting from a 10000x magnification soft soil SEM. From Figure 7a, the pore is seen from the soft clay soil with a pore size of 41.5 \( \mu m \). For Figure 7b, the soil pore size is 20.8 \( \mu m \). From the results of the SEM test, it was seen that gypsum plafond waste affected the soft soil pore size. The results of EDX (Energy Dispersive X-Ray) from soft clay soil samples in this study are presented in Figure 8. Based on the results of the analysis of the elements contained in peat soil through EDX analysis, it can be seen that in soft clay soils many element such as: aluminum, oxygen, carbon, silicon, iron. The largest element content of soft clay soil is the element O (Oxygen) with a percentage value contained of 45.21 % and 50.231 %.

![Figure 7. The Results of SEM](image)

![Figure 8. The Results of EDX](image)
4. Conclusion
The results of the properties index showed that the red soil/soft clay soil in the Pakjo area of Palembang based on the USCS classification system was clay or CH, whereas based on the AASHTO classification system was A-7-6. Plasticity Index (IP) of 40.87 %, Liquid Limit (LL) of 66.00 % and Plasticity Limit (PL) of 35.13%. The optimum moisture content (w_{opt}) based on the results of standard soil compaction testing obtained optimum moisture content of 22 % with a maximum dry weight (\(\gamma_{dmax}\)) of 1.74 gr/cm³. The results of direct shear test obtained the value of cohesion (c), the value of the inner shear angle (\(\phi\)) and the shear strength value (\(\tau\)), namely: Cohesion value (c) maximum occurs in the mixture of gypsum plafond waste percentage of 15 % that is 24.20 kPa. The maximum shear angle value in (\(\phi\)) in the mixture of 15 % gypsum plafond waste is 15.15°. The maximum shear strength value (\(\tau\)) occurs in the mixture of gypsum plafond waste with a percentage of 15 %, which is 26.57 kPa.

Acknowledgment
This research is part of PDD 2017.

References
[1] Rustam, R.K., dan Amiwarti. 2017. Karakteristik Kuat Geser Tanah Merah. Prosiding Simposium II-UNIID 2017 e-ISBN: 978-979-587-734-9, 394-399.
[2] Das, B. M., 2010, Principles of Geotechnical Engineering, 7th Edition. Stamford, USA: Cengage Learning.
[3] Dafalla, M. A., 2013, Effects of Clay and Moisture Conteniton Direct Shear Tests for Clay-Sand Mixtures, Hindawi Publishing Corporation, Advances in Materials Science and Engineering, ArticleID562726,8 pages.
[4] Roesyanto, Iskandar, R., Hastuty, I.P., and Dianty, W.O., 2017, Clay Stabilization by using Gypsum and Paddy Husk Ash with Reference to UCT and CBR Value, IOP Conf. Series: Materials Science and Engineering 309 (2018) 012026 doi:10.1088/1757-899X/309/1/012026.
[5] Rahman, Z.A., Lee, J.Y.Y., Rahim, S.A., Lihan, T., and Idris, W.M.R., 2015, Application of Gypsum and Fly Ash as Additives in Stabilization of Tropical Peat Soil, Journal of Applied Sciences 15 (7): 1006-1012, ISSN 1812-5654.
[6] Murthy, GVLN., Kavya, K.B.V. A., Krishna, V.A., Ganesh, B., 2016, Chemical Stabilization of Sub-Grade Soil with Gypsum and Nacl, International Journal of Advances in Engineering & Technology, ISSN: 22311963.
[7] Meliande, A., and Casagrande, M., 2017, Analysis of the Behavior of a Clay Soil Stabilized with Mineral Coal Fly Ash and Lime for Geotechnical Applications, Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul. Pp. 3163-3166.
[8] Kamei, T., Ahmed, A., and Ugai, K. 2013, Durability of Soft Clay Stabilized with Recycled Bassanite and Furnace Cement Mixture, Soil and Foundations, 51(1):155-165.
[9] Vivek S., Kumar, P., Shukla, V., Markal, K., and Mallikarjun, 2018, Stabilization of Expansive Soils Using Construction and Demolition Waste, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 , Volume: 05 Issue: 06.
[10] Ilies, N. M., Circu, A.P., Nagy, A.C., Ciubotaru, V.S., Bak, Z.K., 2017, Comparative Study on Soil Stabilization with Polyethylene Waste Materials and Binders, Procedia Engineering 181, 444-451.
[11] Ahmed, A., and Issa, U.H., 2014. Stability of Soft Clay Soil Stabilised with Recycled Gypsum in a wet Environment, Soil and Foundations, 54(3):405-416.
[12] Sukpunya, A., And Jotisankasa, A., 2016, Large Simple Shear Testing of Soft Bangkok Clay Stabilized with Soil-Cement-Columns and Its Aplication, Soil and Foundations, 56(4):640-651.
[13] Gul, M, and Marri, A., 2018, Difficulties in the Sample Preparation and Testing of Modified Soils, Indian Journal of Science and Technology, Vol 11(14), DOI: 10.17485/ijst/2018/v11i14/121543.

[14] ASTM. 2011. Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions, D, 3080/D,3080M-11. ASTM International, West Conshohocken, PA, USA.

[15] ASTM. 2010. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, D2216-10. ASTM International, West Conshohocken, PA, USA.

[16] ASTM. 2003. Standard Test Method for Laboratory Compaction Characteristics of Soil. ASTM D 698-00., ASTM International, West Conshohocken, PA, USA.