CIVED Journal of Civil Engineering and Vocational Education

EISSN: 2622-6774
Vol. 12 No.2 June 2025
http://cived.ppj.unp.ac.id/index.php/CIVED

Stabilization of Clay Soil in Relation to CBR Value using Palm Oil Fuel Ash (POFA) in Flood-Prone Areas

Akbar Kurnia[1*], Fithriyah Patriotika[2], Rizka Joniva Sari[3], Majid Maulana[4]
[1,2,3,4] Civil Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
*Corresponding Author, e-mail: akbarkurnia2929@gmail.com

Received 6th April 2025; Revision 26th May 2025; Accepted 15th June 2025

ABSTRACT

Oil is a crucial element in supporting the structural integrity of buildings. However, the rapid development of infrastructure has led to a reduction in the availability of land with favorable soil conditions, forcing many constructions to be built on less stable soils. The clay soil in Tunggul Hitam, Padang City, has a low bearing capacity, exhibits high shrink-swell behavior, and loses stiffness when wet, which may result in damage to roads and foundation structures. To address this issue, chemical stabilization was carried out using palm shell ash as an additive. This research aims to analyze the California Bearing Ratio (CBR) value of clay soil in the Tunggul Hitam area of Padang City by incorporating palm shell ash in varying proportions of 0%, 4%, 8%, 12%, and 16%. The soil types used in this study were Organic Clayey Silt and Silty Clay (OL). The tests included determining the physical and mechanical properties of the soil, such as sieve analysis, specific gravity, plastic limit, liquid limit, and CBR value. The CBR tests were conducted after soaking the samples for four days. The results showed that the CBR value of the untreated soil (soaked, 65 blows) was 6.1%, which increased to 31.512% at a 16% mixture ratio. This 25% improvement in CBR value indicates that palm shell ash is effective as a stabilizing agent for enhancing the engineering properties of clay soil in the study area.

Keywords: *Clay soil; Palm shell ash; Soil stabilization; California Bearing Ratio; Tunggul Hitam.*

Copyright © Akbar Kurnia, Fithriyah Patriotika, Rizka Joniva Sari, Majid Maulana
This is an open access article under:https://creativecommons.org/licenses/by/4.0/
DOI: https://doi.org/10.24036/qm4b1057

INTRODUCTION

Soil is a material composed of solid mineral grains that are not chemically bonded, along with organic particles produced by weathering. The voids between soil particles are generally filled with fluids and gases [1–3]. The bearing capacity of soil must be sufficient to safely sustain the loads imposed by superstructures. Nevertheless, field investigations frequently indicate that many soils exhibit inadequate bearing capacity, which poses a potential risk to the structural performance and overall safety of the constructed facilities. [4–6].

Soils characterized by soft to very soft consistency, high moisture content, low shear strength, high compressibility, and low bearing capacity are classified as soft soils. [7]. This soil is classified as cohesive, consisting predominantly of very fine-grained particles, either clay or silt. The typical characteristics of soft soils commonly encountered at construction sites may lead to reduced shear strength, excessive deformation, and structural instability if not properly addressed. [8].

Clay soil is composed of particles ranging from macroscopic to microscopic size, formed through the weathering of the chemical constituents of parent rock. This soil exhibits a desiccated and hard consistency in a dry state, demonstrates cohesive and plastic behavior at intermediate moisture content, and attains a very soft consistency under high water content conditions. This clay soil exhibits a relatively high susceptibility to mechanical weakness. It demonstrates a significant swelling potential during the wet season and pronounced shrinkage behavior during the dry season. Moreover, if the movement and settlement of the structure occur non-uniformly across the entire construction, it may result in cracking and potential subsidence hazards in the structures built on such soil [9,10].

One of the areas in Padang City underlain predominantly by clay or silt deposits is the Dadok Tunggul Hitam Subdistrict. Preliminary investigations indicate that the soils in this area have very low bearing capacity, exhibit a significant reduction in stiffness under wet conditions, and exhibit a high swelling–shrinkage potential in response to changes in moisture content. In addition, Tunggul Hitam is considered a flood-prone area due to its topographical and hydrological characteristics [11]. Therefore, to mitigate the adverse effects associated with these soil characteristics, soil stabilization or ground improvement measures are necessary to enhance soil bearing capacity.

The bearing capacity of soil can be enhanced through ground improvement using either mechanical or chemical soil stabilization methods. Soil stabilization is the process of mixing and manipulating soil, with or without additives. Mechanical stabilization is achieved by blending two or more soil types to produce a stronger material that meets the requirements for construction materials or subgrade layers. In practice, the soil can be mixed on-site, at a plant, or at a material collection location, and then simultaneously spread and compacted at the project site. In contrast, chemical stabilization involves the addition of supplementary materials such as cement, fly ash, lime, Portland cement, Palm Oil Fuel Ash, and others. [12,13]. In this study, chemical stabilization was carried out using Palm Oil Fuel Ash (POFA).

Palm Oil Fuel Ash (POFA) is a by-product obtained from the combustion of palm waste in boilers at temperatures of 700 °C–800 °C and possesses a chemical composition similar to that of cement, consisting of silica (SiO_2), alumina (Al_2O_3), potassium (K_2O), calcium (CaO), magnesium (MgO), iron (Fe_2O_3), and sulfur (SO_3). This similarity in chemical composition allows POFA to bind soil water, thereby strengthening the cohesion between soil particles. As the proportion of POFA increases, the soil's moisture content decreases, resulting in a lower liquid limit. [14]. The fine particle size of POFA enables it to fill air voids in soil, thereby enhancing the shear strength between soil particles [8].

The increase in the proportion of POFA used also affects the CBR value of the soil. The CBR test on the soaked natural soil yielded a value of 8.98%, whereas the addition of 16% POFA combined with 5% lime resulted in a CBR value of 47.887% [12]. This finding is consistent with several other studies which report that an increase in the proportion of POFA leads to a corresponding increase in the soil's CBR value. [13,15,16]. Several previous studies employing POFA as a soil stabilization additive have demonstrated a positive trend. Accordingly, this study applies a similar approach using clay soil sourced from a flood-prone area.

CIVED
Journal of Civil Engineering and Vocational Education

EISSN: 2622-6774
Vol. 12 No.2 June 2025
http://cived.ppj.unp.ac.id/index.php/CIVED

METHOD

The soil sample used was disturbed clay soil collected from the Tunggul Hitam area.

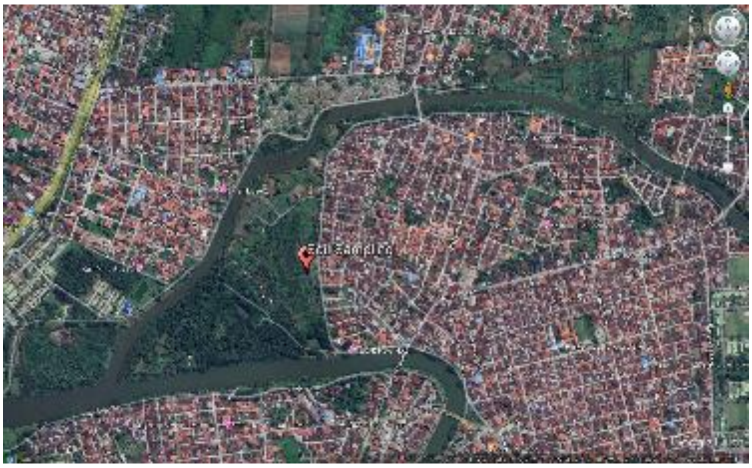
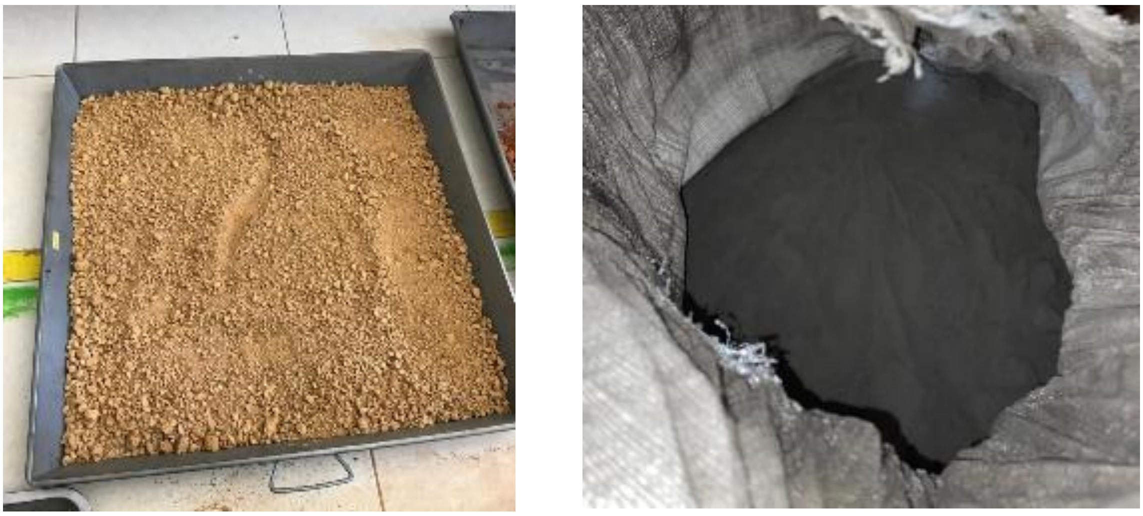


Figure 1. Soil sampling location

The stabilizing material used in this study was POFA that had passed a No. 200 sieve. The research comprised preliminary tests aimed at determining the physical characteristics of the clay soil, including specific gravity, Atterberg limits, soil classification, and soil density. Subsequent testing was conducted by incorporating POFA into the natural soil. The proportions of POFA used were 4%, 8%, 12%, and 16% of the total mixture weight. The samples were cured for four days soaked conditions. Thereafter, the California Bearing Ratio (CBR) test was performed on each mixture to determine both the CBR value and the design CBR.

Table 1. Variation of the research sample

Sample	Specimen for CBR testing
Original Soil	3
Soil 96% + POFA 4%	3
Soil 92% + POFA 8%	3
Soil 88% + POFA 12%	3
Soil 79% + POFA 16%	3



(b)

EISSN: 2622-6774
Vol. 12 No.2 June 2025
http://cived.ppj.unp.ac.id/index.php/CIVED

(a)

Figure 2. (a) Original Soil, (b) Palm Oil Fuel Ash (POFA)

According to SNI 1744:2012, the CBR value selected from laboratory testing is the value at 0.1-inch penetration. If the test results indicate that the CBR value at 0.2-inch penetration is greater than that at 0.1-inch, the test must be repeated. Should the repeated test still show a higher CBR value at 0.2-inch penetration, the CBR value at 0.2-inch penetration shall be adopted [18].

$$\text{CBR value at 0.1-inch penetration} = \frac{X}{6{,}9\ Mpa} \times 100\% \quad (1)$$

$$\text{CBR value at 0.2-inch penetration} = \frac{y}{6{,}9\ Mpa} \times 100\% \quad (2)$$

With,

X = Corrected load reading (MPa) at 0.1-inch penetration on the load-penetration curve.

Y = Corrected load reading (MPa) at 0.2-inch penetration on the load-penetration curve

The design CBR value is determined at the required percentage of maximum dry density, typically at the minimum percentage specified in the standards (95%). The test data obtained using three types of compaction for each soil sample are presented in the form of curves. These curves illustrate the soil's response over a specified range of moisture content. For reporting purposes, the lowest CBR value corresponding to the determined dry density and the achieved compaction dry density is selected. The design CBR value is then derived from the curve relating dry density to the corrected CBR.

Material

Laboratory CBR testing is conducted in accordance with SNI 1744:2012, following these steps:

1. Preparation of equipment and materials:
    a. Cylindrical CBR mold
    b. Compaction tool
    c. Water content measuring device
    d. Load and penetration measuring apparatus
    e. Soil sample
2. Preparation of test sample:
    a. Collect a representative soil sample from the site.
    b. Mix the soil with water until it reaches the optimum moisture content (OMC).
    c. Place the moist soil into the CBR mold and compact it in accordance with the specified standard procedure.
3. Determination of wet mass and moisture content of test sample:
    a. Weigh the CBR mold containing the compacted wet soil.
    b. Take a representative portion of the soil from the mold to determine its moisture content.
    c. Calculate the dry mass of soil using the formula: Dry mass = Wet mass - (Moisture content x Wet mass)
4. Soaking: For soaked condition, submerge the CBR mold containing the compacted soil in water for four days.
5. Penetration test:
    a. After soaking, place the CBR mold on the penetration testing machine.
    b. Apply penetration load gradually at a rate of 1.27 mm/min.
    c. Record the load and penetration at each specified interval.

6. Depiction of relationship curve between load and penetration: Plot the relationship curve between load and penetration on a semi-logarithmic graph.
7. Determination of CBR value: Read the CBR value on the relationship curve between load and penetration at a penetration of 2.54 mm.

RESULTS AND DISCUSSION

Laboratory testing was conducted in a structured manner to obtain data on the properties of the natural soil, which serves as the basis for planning stabilization measures. The tests included determination of natural moisture content, soil specific gravity, Atterberg limits, particle size distribution, and the CBR value, which are required for evaluation prior to improvement. The results of the soil properties tests are presented in Table 2 below.

Table 2. Soil Properties Test Results

No	Testing	Result
1	Water content, w (%)	14,24
2	Volume weight, (gr/cm^3)	1,87
3	Specific gravity, G	2,38
4	Pass sieved no. 200 (%)	63,38
5	Atterberg Limit	
	• LL, Liquid Limit (%)	44,76
	• PL, Plastic Limit (%)	26,59
	• PI, Plasticity (%)	18,17
6	Maximum dry unit weight (gr/cm^3)	1,54
7	CBR original soil, soaked (%)	4,1

The laboratory test results of the soil properties indicated a moisture content of 14.24%. The soil's bulk density and specific gravity were 1.87 g/cm^3 and 2.38, respectively. The percentage of soil passing the No. 200 sieve was 63.38%, and the maximum dry density of the soil was 1.54 g/cm^3. The Atterberg limits were determined as follows: liquid limit (LL) = 44.76%, plastic limit (PL) = 26.59%, and plasticity index (PI) = 18.17%. Meanwhile, the CBR value of the natural soil obtained from laboratory testing was 4.1%.

The California Bearing Ratio (CBR) test was developed to evaluate the bearing capacity of soils as well as their ability to support applied loads, such as those from pavement structures. CBR testing is employed to evaluate the potential strength of subgrade soils, subbase layers, and foundation materials. The CBR value of the soil plays a significant role in determining the bearing capacity of the subgrade. The correlation between the bearing capacity curve and the CBR value is used to determine the subgrade strength. In road construction, the higher the CBR value of the subgrade soil, the greater the bearing capacity of the pavement. A high CBR value allows for a thinner pavement layer, thereby reducing construction costs; conversely, a low CBR value results in an unstable pavement, requiring a thicker pavement layer. Table 3 illustrates the increase in CBR values resulting from the addition of rice husk ash (POFA) to clay soil.

Table 3. CBR value of clay due addition of POFA

Sample	CBR Soaked (%)
Original Soil	6,1
Soil 96% + POFA 4%	2,6
Soil 92% + POFA 8%	4,5
Soil 88% + POFA 12%	24,7

Soil 79% + POFA 16%	31,5

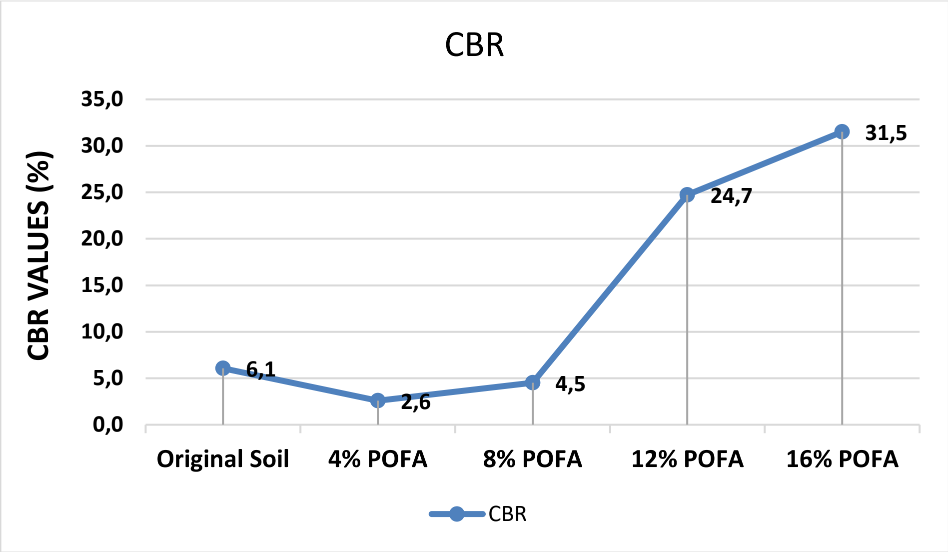


Figure 3 CBR value of clay due addition of POFA

The design CBR value is determined from the soaked CBR test results. The soaked CBR values and the maximum dry density of the soil are plotted to form a curve, which is correlated with the number of blows applied to each layer of the test sample. Table 4 presents the results of the CBR values per compaction blow.

Table 4. CBR Value Based on Number of Blows

Frequency of impact	CBR Soaked (%)	Maximum dry unit weight (gr/cm$^{3)}$
10	2,91	1,27
30	4,4	1,31
65	6,1	1,37

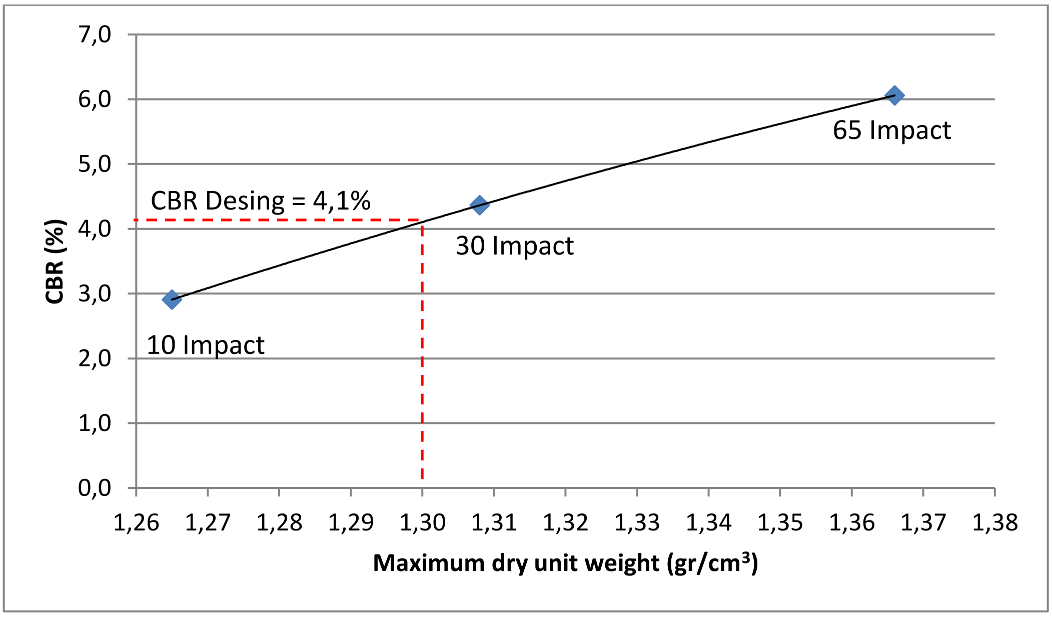


Figure 4. Relationship curve between CBR value, maximum dry soil weight and number of impacts

Based on the soaked CBR values mentioned above, the design CBR can be calculated as follows:

95% of the maximum dry density of the soil (1.37 g/cm³) = 1.30 g/cm³
The CBR value at a dry density of 1.30 g/cm³ is 4.1%

Table 5 presents the design CBR values resulting from the addition of rice husk ash (POFA) to the clay soil.

Table 5 CBR design value of clay due addition of POFA

Sample	CBR Soaked (%)
Original Soil	4,1
Soil 96% + POFA 4%	1
Soil 92% + POFA 8%	3,9
Soil 88% + POFA 12%	20
Soil 79% + POFA 16%	30

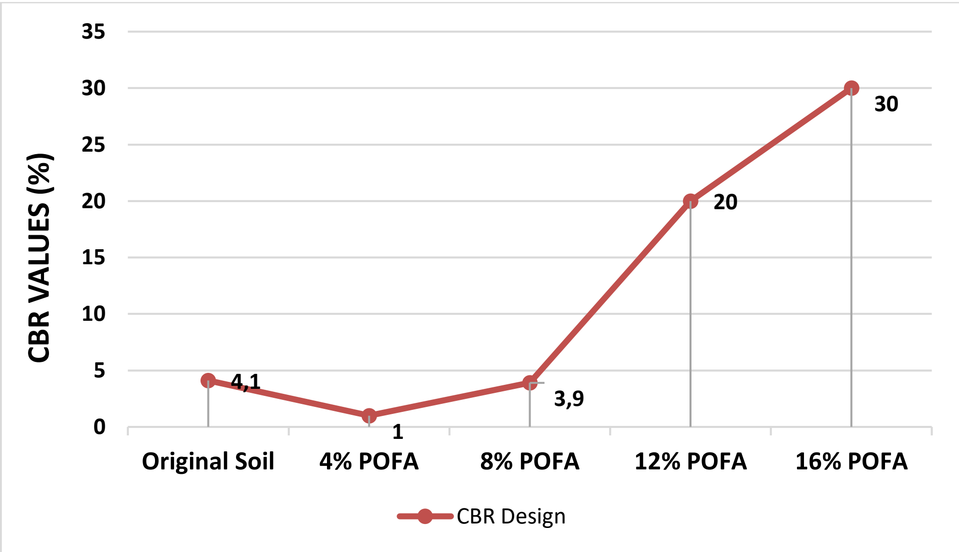


Figure 5 CBR design value of clay due addition of POFA'

DISCUSSION

The sieve analysis results indicate that 63.38% of the soil particles pass the No. 200 sieve (>50%), classifying the soil as fine-grained. The Atterberg limits tests yielded a liquid limit (LL) of 44.76%, a plastic limit (PL) of 26.59%, and a plasticity index (PI) of 18.17%. A plasticity index greater than 17 indicates high-plasticity clay. Soils with high plasticity are prone to deformation without a corresponding change in volume; the higher the plasticity, the greater the potential for swelling and shrinkage, which may cause damage to structures built on them.

Based on its properties, this soil falls into the A-7-6 category, which is considered unsuitable for use as a subgrade according to the American Association of State Highway and Transportation Officials (AASHTO). According to the Unified Soil Classification System (USCS), the soil is classified as OH, representing fine-grained organic clay with medium to high plasticity. Therefore, soil stabilization is required to enhance its bearing capacity, enabling its use as a subgrade material.

The CBR and design CBR values of the natural soil soaked conditions were 6.1% and 4.1%, respectively. These values fall within the poor to fair category [17], indicating that improvement is necessary if the soil is to be used for construction. The addition of POFA to the soil produced varying CBR values. At proportions of 4% and 8%, a decrease in CBR was observed. This is attributed to the low content of silica (SiO_2) and alumina (Al_2O_3) in POFA at these levels, which is insufficient to fully react with the soil, thereby disturbing the soil's natural bonding and affecting its bearing capacity.

In contrast, the samples containing 12% and 16% POFA exhibited a different behavior. Under these conditions, the chemical compounds present in POFA reacted effectively with the soil. This reaction strengthened the bonds between soil particles, thereby increasing the soil's bearing capacity and resulting in higher CBR values. The highest CBR value was observed at 16% POFA, with a CBR of 31.5% and a design CBR of 30%. These results indicate that the addition of POFA at certain proportions as a stabilizing additive can effectively enhance the CBR of clay soil.

CONCLUSION

Based on the USCS classification, the soil is identified as clay with medium to high plasticity (OH) and classified as A-7-6 according to AASHTO. This indicates a high susceptibility to water influence. Therefore, soil stabilization is required to enhance its bearing capacity. The addition of POFA to clay soil can enhance its density. Incorporating 16% POFA into the clay soil resulted in a CBR value of 31.5%, representing a 25% increase compared to the CBR of the soil without POFA.

REFERENCE

[1] Yulianti D, Firda A, Djohan B, Fuad IS. Stabilitas Tanah Lempung Menggunakan Kapur Dan Fly Ash Dengan Pengujian CBR. Jurnal Teknik Sipil Lateral 2023;1:47–53.

[2] Aryanto M, Suhendra S, Amalia KR. Stabilisasi Tanah Lempung Ekspansif Menggunakan Kapur Tohor. Jurnal Talenta Sipil 2021;4:38. https://doi.org/10.33087/talentasipil.v4i1.47.

[3] Sitinjak J, Sarie F, Hendri DO. Stabilisasi Tanah Lempung Menggunakan Pasir Pantai Terhadap Nilai Cbr. Jurnal Kacapuri 2021;4:265–75.

[4] Pristianto H, Rokhman I. Studi Daya Dukung Stabilisasi Tanah Lempung Menggunakan Campuran Abu Kayu. Jurnal Momen 2022;05:62–6.

[5] Zahara Y, Gusrizal, Reza M. Pengaruh Penambahan Pofa Dengan Tanah Lempung Untuk Meningkatkan Daya Dukung Tanah Berdasarkan Nilai California Bearing Ratio. Jurnal Sipil Sains Terapan 2024;07:61–7.

[6] Hakam A, Srihandayani S, Ismail FA, Asmirza MS, Hape MM. Environmentally Friendly Foundation For The Sustainability Development Of Infrastructures In Swamp Area. IOP Conf Ser Mater Sci Eng, vol. 615, Institute of Physics Publishing; 2019. https://doi.org/10.1088/1757-899X/615/1/012068.

[7] Waruwu A, Zega O, Rano D, Maureent B, Panjaitan T, Harefa S. Kajian Nilai California Bearing Ratio (CBR) Pada Tanah Lempung Lunak Dengan Variasi Tebal Stabilisasi Menggun Vulkanik. Jurnal Rekayasa Sipil (JRS-Unand) 2021;17:116–30. https://doi.org/10.25077/jrs.17.2.116-130.2021.

[8] Jufrimal F, Muharani IF, Ultari M, Maghensky R, Jody NS, Kushandayani A. Pengaruh Penambahan Abu Cangkang Kelapa Sawit Palm Oil Fuel Ash (POFA) terhadap Nilai Kuat Geser Tanah Lempung. Akselerasi: Jurnal Ilmiah Teknik Sipil 2025;6:25–31.

[9] Harahap MPS, Nasution DW, Hastuty IP, Roesyanto R, Nuraliman A. Pengaruh Penambahan Abu Tandan Sawit dan 12% Serbuk Cangkang Telur Terhadap Stabilisasi

Tanah Lempung Ditinjau Dari Nilai CBR dan UCT. Blend Sains Jurnal Teknik 2023;2:156–67. https://doi.org/10.56211/blendsains.v2i2.328.

[10] Aziz UA, Riyanto E, Mustofa B. Pengaruh Penambahan Serbuk Bata Merah Dan Garam Dapur Terhadap Nilai CBR Pada Stabilisasi Tanah Lempung. Jurnal Surya Beton 2022;6:64–73.

[11] Darmawan Y, Mashuri I, Jumansa MA, Alam FM, Azzahra A. Analisis Daerah Rawan Banjir dengan Metode Composite Mapping Analysis (CMA) di Kota Padang (Flood Vulnerability Analysis using Composite Mapping Analysis (CMA) in Padang City). Jurnal Ilmiah Geomatika 2023;29:89–98.

[12] Andriani, Putra HG, Yuliet R, Maulana R, Marel SP. Analysis of clay improvement as subgrade using Palm Oil Fuel Ash (Pofa). IOP Conf Ser Earth Environ Sci, vol. 1173, Institute of Physics; 2023. https://doi.org/10.1088/1755-1315/1173/1/012024.

[13] Fitriani ARS, Oktarise Dwina D, Alfernando O. Use Of A Mixture Of Pofa (Palm Oil Fuel Ash) And Gypsum As A Peat Soil Stabilization Viewed From The CBR Value (California Bearing Ratio). Jurnal Teknika Sains 2023;08:73–83.

[14] Tasya Clara Putri N, Oktarise Dwina D, Kumalasari D. Stabilisasi Tanah Gambut Dengan Penambahan POFA (Palm Oil Fuel Ash) Dan Semen Terhadap Indeks Properti Tanah. Jurnal Teknologi Dan Inovasi Industri 2022;03:1–8.

[15] Toyeb M, Hakam A, Andriani. The strength and economic benefit of soil stabilization with Palm Oil Fuel Ash (POFA) as agro-waste. E3S Web of Conferences, vol. 464, EDP Sciences; 2023. https://doi.org/10.1051/e3sconf/202346411001.

[16] Oktarise Dwina D, Alfernando O, Kumalasari D, Nofrina T. Pengolahan Pofa (Palm Oil Fuel Ash) Dan Semen Sebagai Material Alternatif Timbunan Pilihan Jalan Untuk Perbaikan Infrastruktur Jalan. Jurnal Teknik Sipil 2022;11.

[17] J. E. Bowles, *Engineering Properties of Soil and Their Measurement.* New York: McGraw-Hill Book Company Limited. 1992.

[18] SNI 1744:2012 (2012), Metode Uji CBR Laboratorium