INVOTEK
Jurnal Inovasi Vokasional dan Teknologi
http://invotek.ppj.unp.ac.id/index.php/invotek
Vol. 26, No. 1, Feb 2026
ISSN: 1411 – 3411 (p)
ISSN: 2549 – 9815 (e)

Application of Calcined Green Mussel Shell Powder to Increase Peat Soil Stability Against CBR Values as a Road Pavement Subgrade

Nadhifah Alifia Dewayanti Retnaningrum[1], Latif Budi Suparma[1 *], Suryo Hapsoro Tri Utomo[1]

[1] Master Programme in Transportation Systems and Engineering, Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta
Jl. Grafika No. 2, Kampus UGM, Yogyakarta-55281

**Corresponding author: lbsuparma@ugm.ac.id* Doi: https://doi.org/10.24036/invotek.v26i1.1350

Abstract

Peat soil has compressible properties, high water content, and low bearing capacity, so it needs to be stabilized to increase its strength as a road pavement subgrade. Peat soil is commonly found in South Sumatra, especially in the Banyuasin II District, Banyuasin Regency, South Sumatera. This study added green mussel shell powder ($CaCO_3$) and calcined mussel shell powder (CaO) as stabilizers with the CBR (California Bearing Ratio) testing method. This test was carried out with variations in the mixture of mussel shell powder (0%, 10%, 20%, 30%) and curing time (0, 3, 7 days), as well as testing physical and mechanical properties such as atterberg limits, specific gravity, sieve analysis, soaked CBR, and unsoaked CBR. Samples with optimal CBR values will be added with CaO (calcined mussel shell powder) 10% to see its effect. Based on the test results, the original peat soil has an unsoaked CBR of 0.65% and a soaked CBR of 0.65%. After the stabilizer was mixed, the optimal variation was found in a mixture of peat soil plus 30% shell powder with 7 days of curing at 13.7%, while for soaked CBR, with a variation of 30% soaking for 4 days at 8.5%. Furthermore, this variation was mixed with calcined shell powder (10%) to see its effect. The test results showed a significant change, the values of unsoaked CBR 35% and soaked CBR 45%.

Keywords: Peat Soil, Green Mussel Shell Powder, Calcination, Soaked CBR, Unsoaked CBR.

1. Introduction

The subgrade is the foundation that determines the longevity of a road because it supports the weight of passing vehicles. Peat soil is a type of soil that is poorly rated as a road subgrade because it contains a lot of water and is wet, making it unable to support maximum vehicle loads. Peat soil is easily compressed or deformed (compressible), contains organic material, and consistently undergoes changes or decay, which can cause slow land subsidence over the long term [1]. The results of research on peat soil stabilization prove that the use of chemicals such as cement or lime as stabilizers is proven to be effective in increasing the compressive strength of peat soil [2].

Green mussel shells are often found in coastal areas and constitute non-biodegradable waste. Mountains of green mussel shell waste have polluted the Cilincing River, causing the area to become shallow and polluted, disrupting the marine ecosystem and the activities of residents [3]. Shell waste contains the main compound $CaCO_3$, which, if heated at high temperatures (calcination), will become CaO (calcium oxide) [4]. Quoted from research on the physical properties of peat soil [5], CaO is a compound similar to cement, which binds water. Therefore, researchers wanted to analyze the effect of adding green mussel shell waste as a mixture for subgrade stabilization [6].

In this study, peat soil stabilization will be carried out using pure mussel shell powder (MSP) (0%, 10%, 20%, 30%) and with curing period of 0, 3, and 7 days with variations of blows of 10, 35, and 65. Other study reported that the addition of bagasse ash (3%, 6%, 12%) with 8% lime to peat, with curing for 3 days and 5 days, increased cohesion and internal friction angle compared to native peat.

Received date 20/05/2026, Revised date 16/06/2026, Accepted date 19/06/2026

P-ISSN: 1411-3414
E-ISSN: 2549-9815

The highest increase was achieved in the combination of 8% lime + 12% bagasse ash with curing for 5. This shows that the effect of 5 days of curing is more beneficial than 3 days on the same variety [7]. Stabilization of peat soil with the addition of 10% lime and 5–15% rice husk ash with curing times of 0, 4, and 7 days. It was found that the unconfined compressive strength and cohesion increased with curing time up to 7 days, especially in the mixture of 10% lime + 15% rice husk ash and curing for 7 days [8].

Then, further testing of the sample with the best CBR value was carried out, which added 10% calcined green mussel shell powder, and then the CBR was tested again. In the study of clay soil stabilization [9]. The best CBR value was obtained from a mixture of clay soil with a variation of 30% shells. Furthermore, other research on peat soil stabilization using a mixture of shell powder and fly ash showed that the mixture was able to increase the pH and improve the bearing capacity of the peat soil [10].

The combination of sawdust ash and shell powder for soft soil stabilization can increase the CBR value and reduce peat soil moisture [11]. Varying immersion factors also affect the quality of stabilization results. This research will contribute to a broader understanding of the effect of time and the addition of calcined green mussel shells on soil stabilization. Thus, it is important to consider the optimal proportion of green mussel shell powder and the most effective and efficient curing time in this study. The mixture of peat soil and mussel shell powder was tested for soil bearing strength and expansion using CBR testing, and this research method is based on SNI 1744:2012 [12]. The expected results in this study are that the use of green mussel shell powder as a mixture of peat soil can increase the CBR value to strengthen the subgrade and increase the CBR value of the base soil, so that it can withstand the load of vehicles that will pass.

2. Method

This research method uses a laboratory experimental approach to determine the effect of adding green mussel shell powder ($CaCO_3$) and calcined green mussel shell powder (CaO) on the strength of peat soil as a road pavement subgrade. The soil used for this study was peat soil from Muara Sugihan, Banyuasin Regency, South Sumatra. The soil condition used was disturbed soil at a depth of 0.5-1.0 m from the ground surface. The stabilizing material used is green mussel shells from Kalibaru, Cilincing, North Jakarta.

2.1 Preparation of Green Mussel Shells

The green mussel shells are washed until clean, then dried and ground by pounding and filtering using a sieve number 20, hereinafter referred to as MSP. The additional stabilizing material is green mussel shells that have been ground (200 mesh) and then heated using a furnace at a temperature of 800°C for 6 hours (calcination) to form CaO.

2.2 Sample Characterization

Peat soil, MSP and calcined MSP (CaO) were characterized using X-Ray Diffraction (XRD) to determine their crystallinity and composition.

2.3 Preparation of Test Samples

The test samples in this study were made from peat soil varied with MSP and CaO, as shown in Table 1.

Table 1. Composition of Peat Soil, MSP and CaO Mixture Test Samples

No.	% Peat Soil	% MSP	% CaO
1	100	0	0
2	90	10	0
3	80	20	0
4	70	30	0
5	63	27	10

P-ISSN: 1411-3414
E-ISSN: 2549-9815

2.4 Soil Physical Properties Test

Physical properties tests were carried out on peat soil with the aim of identifying the type of soil being tested, including water content tests, specific gravity tests, sieve analysis tests, Atterberg Limits tests and standard Proctor tests.

2.4.1 Water Content

Soil water content testing is carried out to determine how much water is contained in a soil sample using the gravimetric method [13], [14]. This water content test is important because it affects the physical properties of the soil, such as its strength, density, and bearing capacity.

2.4.2 Specific Gravity

The soil specific gravity test is a laboratory test used to compare the volume weight of solid soil particles with the volume weight of distilled water according to SNI 1964:2008 [15] and ASTM D854 [16]. This test is important for determining physical soil properties such as porosity, density, and mineral composition, which influence how the soil responds to loads and environmental changes. Specific gravity tests are performed using a pycnometer. Specific gravity values help classify soil types and more accurately determine their mechanical characteristics.

2.4.3 Sieve Analysis

Sieve distribution test (sieve analysis) is carried out by filtering dry soil samples through a series of sieves of different sizes in stages, starting from sieves with large holes to small ones (9.525 - 0.075 mm). After filtering, the weight of the soil retained on each sieve is measured, and its percentage of the total sample weight is calculated according to SNI 3423:2008 [17] and ASTM D6913 [18].

The hydrometer test is used to measure the size distribution of fine soil particles, particularly those smaller than 0.075 mm (clay and silt). This method is based on the principle of particle sedimentation in aqueous solution, by observing the turbidity of the soil suspension using a hydrometer at a specific time (ASTM D7928) [19]. Particle settling velocity is related to grain size using the Stokes formula. The hydrometer test provides data on the distribution of fine particles that are difficult to measure using the sieve method.

2.4.4 Atterberg Limits

Test Atterberg Limits is a laboratory test used to determine the water content limits of fine-grained soils. This test measures the change in soil consistency from solid to plastic, then to liquid. There are three main limits: Liquid Limit (LL) is the water content when the soil changes from plastic to liquid. Plastic Limit (PL) is the water content when the soil changes from solid to plastic. From the results of this measurement, we can also calculate the Plasticity Index (PI), which is the difference between LL and PL, which indicates the range of water content in which the soil is plastic according to SNI [20], [21] and ASTM D4318 [22].

2.4.5 Proctor Standard

Proctor Standard is a laboratory testing method used to determine the relationship between water content and soil density, which can be achieved through compaction with a certain energy in accordance with SNI 1742:2008 [23] and ASTM D698 [24]. The main purpose of this test is to determine the optimum water content so that the soil can be compacted optimally to reach maximum dry density, which is very important in construction to ensure the stability and strength of the soil as a foundation for buildings or roads. The Proctor Standard test was carried out on all test samples, namely peat soil, a mixture of peat soil and MSP (10, 20 and 30%), a mixture of peat soil, MSP (30%) and CaO (10%).

2.5 Mechanical Properties Test

Soil mechanical property testing aims to determine the soil's response to external loads. In this study, soil mechanical property testing uses the California Bearing Ratio (CBR), a testing method used to assess the bearing capacity of soil or subgrade material in road construction and other structures. This

P-ISSN: 1411-3414
E-ISSN: 2549-9815

test measures the ratio of the pressure required to penetrate a soil sample to the standard pressure required to penetrate standard crushed rock. The higher the CBR value, the stronger and more capable the soil is of supporting the load. The CBR test process includes compacting the soil sample in a cylindrical mold, soaking it in water for 4 days for testing soaked, and piston penetration testing at constant speed in accordance with SNI 1744:2012 [12] and ASTM D1883 [25].

2.6 Data Analysis

Based on CBR testing, soaked and then CBR Unsoaked, optimum values were obtained from various variations and curing times. These variations will be retested by adding 10% CaO to determine the extent of CaO's influence in increasing the bearing capacity of the subgrade.

3. Result and Discussion

3.1 MSP Calcination Results

MSP with a size of 200 mesh is a greyish-white powder. MSP has the main content of the $CaCO_3$ compound as much as 95.69 – 99.5%. After the calcination process at 800°C for 6 hours, the color changes to bone white, since the compound $CaCO_3$ has been converted into CaO compounds, and the organic compounds contained in MSP have evaporated. The calcination reaction that occurs according to reaction (1) [26]–[28]:

$$CaCO_{3\,(s)} \rightarrow CaO_{(s)} + CO_{2\,(g)} \quad (1)$$

After calcination, in addition to the color change in MSP, there was also a 44% weight loss due to the release of CO_2 gas into the air.

3.2 XRD Characterization Results

The diffractogram of the XRD analysis results is shown in Figure 1. Figure 1 shows that the peat soil used in this study contains organic compounds, as indicated by the presence of several $CaCO_3$ peaks and peak C. From Figure 1, it can be seen that the peat soil used contains the minerals Si, Mg, Na and Al. The diffractogram results show that MSP has a main content of the compound $CaCO_3$. Meanwhile, the diffractogram of calcined MSP shows the formation of CaO compounds.

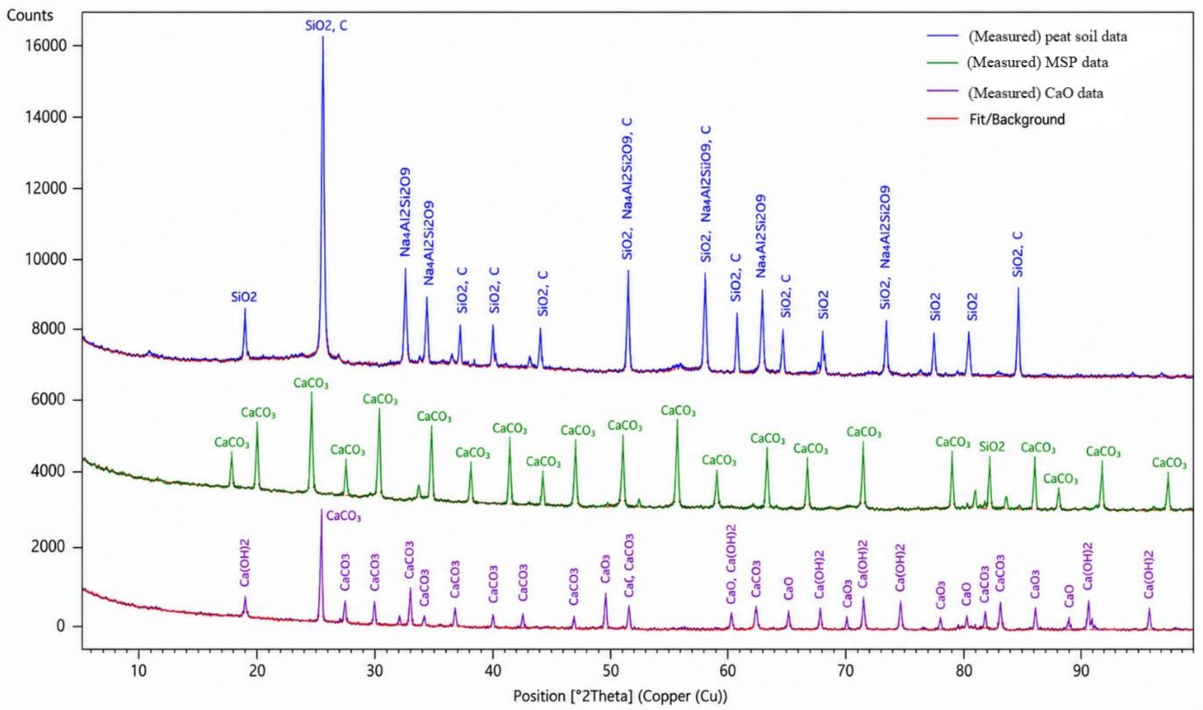

Figure 1. Diffractogram of XRD Analysis Results of Peat Soil, MSP ($CaCO_3$) and Calcined MSP (CaO)

P-ISSN: 1411-3414
E-ISSN: 2549-9815

In addition, there are $Ca(OH)_2$ compounds, which are compounds formed as a result of the absorption of water vapor by CaO during storage, according to reaction (2):

$$CaO_{(s)} + H_2O_{(g)} \rightarrow Ca(OH)_{2\,(s)} \quad (2)$$

The calcination process carried out in this study has not changed all the $CaCO_3$ compounds from MSP to CaO; this can be seen in the diffractogram, which still shows the presence of peaks of the $CaCO_3$ compound.

3.3 Results of Soil Physical Properties

Prior to conducting the CBR test, material testing was performed to ensure the material's physical condition. The results of several laboratory tests are presented in Table 2 and Table 3 below.

Table 2. Results of Testing the Physical Properties of Peat Soil

No.	Testing	Results
1	Water Content (%)	63.058
2	Specific Gravity	1.700
3	Atterberg Limits	
	a. Liquid Limit LL (%)	53.290
	b. Plastic Limit PL (%)	46.500
	c. Plasticity Index PI (%)	6.790
4	Sieve Analysis	
	a. Sieve No. 200 (%)	82.002
	b. Sieve No. 40 (%)	16.214
	c. Sieve No. 10 (%)	1.784

Table 3. Test Results Proctor Standard Peat Soil and MSP Mixture in Various Variations

Variation	Maximum Dry Density MDD (g/cm^3)	Optimum Moisture Content OMC (%)
Peat soil	1.125	42.5
Peat soil + 10% MSP	1.280	34.0
Peat soil + 20% MSP	1.320	30.5
Peat soil + 30% MSP	1.400	27.0
Peat soil + 30% MSP + 10% CaO	1.525	20.0

Description: MDD: Maximum Dry Density, OMC: Optimum Moisture Content, MSP: Mussel Shell Powder

Based on the results of the peat soil specific gravity test, it is 1.70. A specific gravity value of 1.70 falls into the peat soil category [29]. According to the Atterberg limits value, the classification based on AASHTO [30], the peat soil used in this study is classified as class A-5, which is not good for use as subgrade. Based on USCS [31], the peat soil used is classified as an OH soil type, namely organic clay soil with medium to high plasticity.

In Table 3, it can be seen that from the results of the density test or Proctor Standard, the maximum dry weight and optimum water content were obtained, which varied for each variation of the test specimen. Based on Table 3, the higher the percentage of added material (MSP), the greater the MDD value produced, and the lower the OMC value.

3.4 CBR Soaked and CBR Unsoaked Test Results

The total sample size in this study was 54, divided into several groups based on the length of fermentation and soaking time. Table 4 displays the CBR values. Unsoaked at 0 days of curing, Table 5 displays the CBR value. Unsoaked at 3 days of curing, Table 6 displays the CBR value. Unsoaked at 7

P-ISSN: 1411-3414
E-ISSN: 2549-9815

days of curing, Table 7 displays the Soaked CBR value at 4 days of immersion, and Table 8 shows the CBR soaked and CBR unsoaked values with the best variation, namely 30% MSP + 10% CaO.

Table 4. 0-Day Unsoaked CBR Test Results

MSP Percentage	Number of Blows			CBR Value (%)
	10	35	65	
0%	0.237	0.503	0.773	0.650
10%	1.292	2.745	4.216	3.700
20%	4.532	5.034	9.672	6.100
30%	3.035	6.381	9.837	9.500

Table 5. 3-Day Unsoaked CBR Test Results

MSP Percentage	Number of Blows			CBR Value (%)
	10	35	65	
0%	0.495	1.052	1.616	1.300
10%	1.938	4.117	6.324	5.800
20%	2.906	6.175	9.486	8.300
30%	3.875	8.234	12.648	12.000

Table 6. 7-Day Unsoaked CBR Test Results

MSP Percentage	Number of Blows			CBR Value (%)
	10	35	65	
0%	0.710	1.578	2.459	1.900
10%	2.583	5.489	8.432	8.000
20%	3.681	7.753	11.945	10.500
30%	4.736	10.063	15.459	13.700

Table 7. 4-Day Soaked CBR Test Results

MSP Percentage	Number of Blows			CBR Value (%)
	10	35	65	
0%	0.316	0.463	0.893	0.650
10%	2.846	3.125	5.952	5.100
20%	4.532	5.034	9.672	8.000
30%	2.899	4.774	8.928	8.500

Table 8. Test Results of Soaked CBR and Unsoaked CBR 30% MSP + 10% CaO

CBR	Number of Blows			CBR Value (%)
	10	35	65	
Unsoaked 7 days	11.625	24.701	37.944	35.000
Soaked for 4 days	16.864	27.776	47.616	45.000

Tables 4 through 6 demonstrate that the addition of MSP consistently increases the CBR value in proportion to the percentage of MSP added. This result can be seen in the graph in Figure 2:

P-ISSN: 1411-3414
E-ISSN: 2549-9815

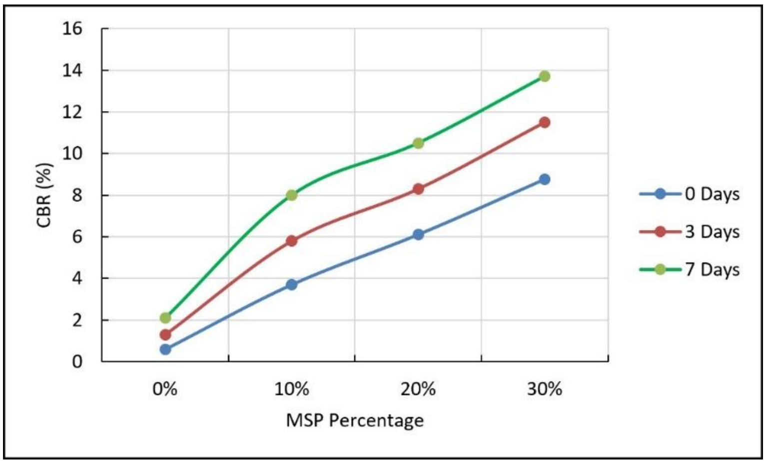

Figure 2. Graph of Increase in Unsoaked CBR Values in Peat Soil + MSP Variations

The addition of MSP to peat soil also increases the soaked CBR value, but not as high as the unsoaked CBR value. The graph can be seen in Figure 3.

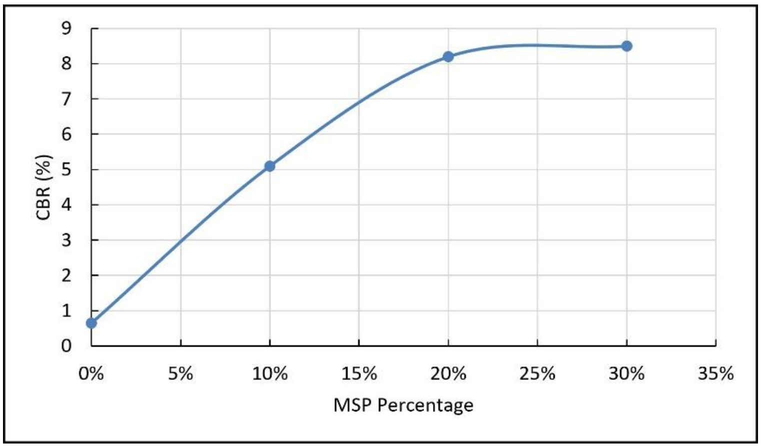

Figure 3. Graph of Increase in Soaked CBR Values in Peat Soil + MSP Variations

Table 8 shows that adding 10% CaO to the 30% MSP sample variation resulted in a significant increase in the CBR value, up to 549%. This condition occurs due to the CaO's ability to bind other compounds when exposed to water [5]. The comparison of values can be seen clearly in the graphs of Figure 4.

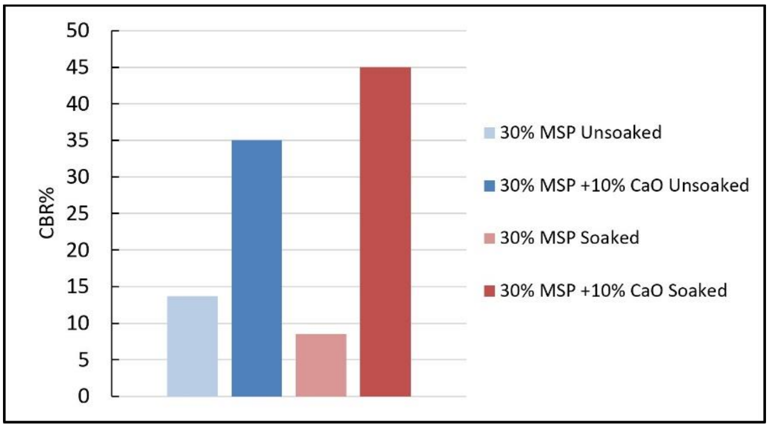

Figure 4. The Effect of Adding CaO on The CBR Value

It is also proven in the graphs in Figure 5 and Table 9 that the greater the number of blows, the denser and higher the unsoaked CBR value produced.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

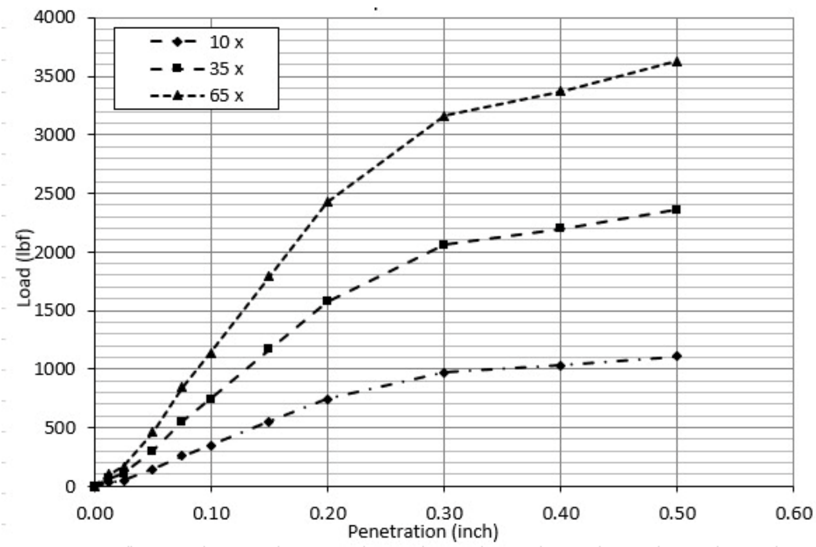

Figure 5. Graph of Unsoaked CBR Value of Peat Soil + 30% MSP + 10% CaO

Table 9. Test Value Results of Unsoaked CBR 30% MSP + 10% CaO

	Blows	CBR Value (%)
Penetration 0.100 inch	10x	11.630
	35x	24.700
	65x	37.940
Penetration 0.200 inch	10x	16.500
	35x	35.070
	65x	53.870

Same as unsoaked CBR, the graphs in Figure 6 and Table 10 show that the greater the number of blows, the denser and higher the Soaked CBR value produced.

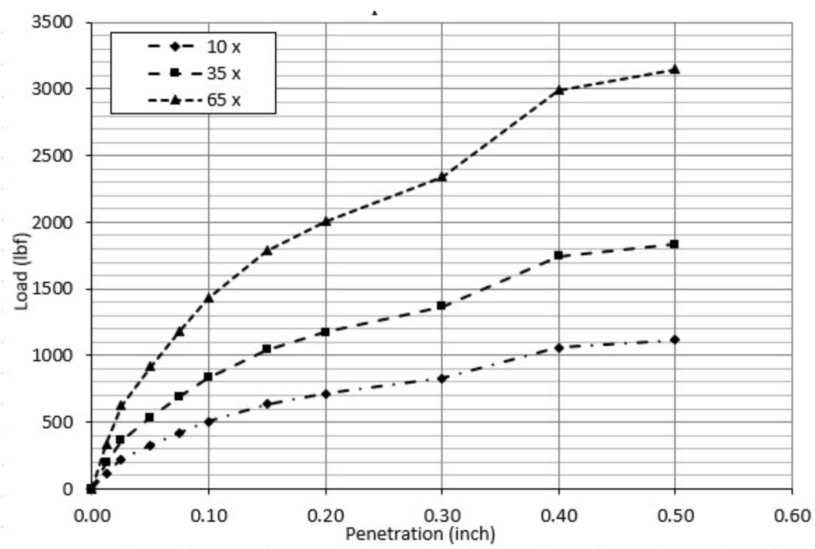

Figure 6. Graph of CBR Value of Soaked Peat Soil + 30% MSP + 10% CaO

Table 10. Test Value Results of Soaked CBR 30% MSP + 10% CaO

	Blows	CBR Value (%)
Penetration 0.100 inch	10x	16.860

P-ISSN: 1411-3414
E-ISSN: 2549-9815

	35x	27.780
	65x	47.620
Penetration 0.200 inch	10x	15.810
	35x	26.040
	65x	44.640

4. Conclusion

Based on the AASHTO classification results, the peat soil in this study is categorized as A-5 soil (silt soil with low to moderate plastic properties) where the level of soil usability for subgrade is classified as poor. The minimum CBR value of the soil for the needs of subgrade namely 6%, while the CBR value of the original peat soil 0.650%. After peat soil stabilization using MSP and CaO, the optimal CBR value is at 30% MSP + 10% CaO. This result proves that the addition of MSP and CaO stabiliser materials has a significant effect and increases the soaked CBR value from 0.65% to 45% while the unsoaked CBR is from 0.65% to 35%. It is proven that MSP and CaO are able to increase the CBR value of peat soil, especially if CaO is mixed in.

References

[1] M. K. H. Radwan, F. W. Lee, Y. B. Woon, M. K. Yew, K. H. Mo, and S. H. Wai, "*A study of the strength performance of peat soil: A modified cement-based stabilization agent using fly ash and polypropylene fiber*," *Polymers (Basel)*, vol. 13, no. 23, Dec. 2021, doi: 10.1051/e3sconf/20183401034.

[2] N. Mohd Zambri and Z. Md Ghazaly, "*Peat Soil Stabilization using Lime and Cement*," in *E3S Web of Conferences*, EDP Sciences, Mar. 2018. doi: 10.1051/e3sconf/20183401034.

[3] R. Fauzia, "Gunungan Limbah Cangkang Kerang Cemari Kalibaru Cilincing ," detikNews. Accessed: May 16, 2026. [Online]. Available: https://news.detik.com/foto-news/d-8125346/gunungan-limbah-cangkang-kerang-cemari-kalibaru-cilincing

[4] D. Fajar Fitriyana *et al.*, "Pengaruh Perlakuan Microwave terhadap Struktur Kristal dan Gugus Fungsional $CACO_3$ dari Cangkang Kerang Hijau," vol. 16, no. 2, pp. 291–297, 2025, doi: 10.55679/djitm.v16i2.5.

[5] F. E. Yulianto, N. E. Mochtar, and M. Ma'ruf Afif, "*Physical and Engineering Properties of Peat Soil Stabilized with the Admixture of $CaCO_3$+Rice Husk Ash Due to Water Infiltration from Surrounding Areas*," *Journal of Applied Engineering Science*, vol. 20, no. 1, pp. 276–284, 2022, doi: 10.5937/jaes0-32003.

[6] A. J. Choobbasti *et al.*, "Influence of using rice husk ash in soil stabilization method with lime," *Frontiers of Earth Science in China*, vol. 4, no. 4, pp. 471–480, 2010, doi: 10.1007/s11707-010-0138-x.

[7] B. B. Pratama, O. Hendri, and F. Sarie, "Analisis Peningkatan Niali Kuat Geser Tanah Gambut dengan Bahan Stabilisasi Abu Ampas Tebu dan Kapur," 2021, doi: https://doi.org/10.31602/jk.v4i2.6420.

[8] A. Gazali, R. Adawiyah, M. G. Perdana, Hairunisa, and A. A. Yuanda, "Stabilisasi Tanah Gambut menggunakan Penambahan Kapur dan Abu Sekam Padi Ditinjau terhadap Nilai Kuat Tekan dan Kuat Geser," 2022, doi: https: https://doi.org/10.31602/jk.v5i2.9487.

[9] M. Anggraini, P. E. Saputra, and G. Yanti, "Stabilisasi Tanah Lempung Menggunakan Serbuk Cangkang Kerang Ditinjau dari Nilai CBR," Inersia: Jurnal Teknik Sipil, vol. 15, no. 1, pp. 47–56, Apr. 2023, doi: 10.33369/ijts.15.1.47-56.

[10] T. Sartika, U. Sepani, S. A. Putri, and Y. Apriyanti, "Satbilisasi Tnaha Gambut Menggunakan Campuran Serbuk Cangkang Kerang dan Fly Ash Ditunjau dari Nilai CBR Tanah dan Tingkat Keasaman Tanah." doi: 10.35313/potensi.v24i1.3613.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

[11] Irvan Ustuchri *et al.*, "Pemanfaatan abu serbuk kayu dan serbuk cangkang kerang sebagai material stabilisasi tanah lunak," PADURAKSA: Jurnal Teknik Sipil Universitas Warmadewa, vol. 12, no. 2, pp. 166–171, Dec. 2023, doi: 10.22225/pd.12.2.6602.166-171.

[12] SNI 1744:2012, Metode uji CBR laboratorium Badan Standardisasi Nasional. 2012. [Online]. Available: www.bsn.go.id

[13] ASTM D2216-10, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, 2019.

[14] SNI 1965:2008, Standar Nasional Indonesia Cara uji penentuan kadar air untuk tanah dan batuan di laboratorium.

[15] SNI 1964:2008, Standar Nasional Indonesia Cara Uji Berat Jenis Tanah.

[16] ASTM D854, *Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*. West Conshohocken, PA: ASTM International, 2023. doi: 10.1520/D0854-23.

[17] SNI 3423:2008, Standar Nasional Indonesia Cara uji Analisis Ukuran Butir Tanah.

[18] ASTM D6913, *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis 1*. doi: 10.1520/D6913-17.

[19] ASTM D7928, *Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*. West Conshohocken, PA: ASTM *International*, 2021. doi: 10.1520/D7928-21E01.

[20] SNI 1966:2008, Standar Nasional Indonesia Cara uji penentuan batas plastis dan indeks plastisitas tanah. 2008.

[21] SNI 1967:2008, Standar Nasional Indonesia Cara uji penentuan batas cair tanah Kembali ke daftar.

[22] ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils 1*. 2017. [Online]. Available: www.astm.org,

[23] SNI 1742:2008, *Standar Nasional Indonesia Cara uji kepadatan ringan untuk tanah*.

[24] ASTM D698, *Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3))*. West Conshohocken, PA: ASTM International, 2008. doi: 10.1520/D0698-12R21.

[25] ASTM D1883, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils 1*.

[26] W. Purwaningrum, Y. Fany Claudia Manurung, F. Fatma, and A. Mara, "*Modification of CaO from Quail Egg Shells with Sodium Dodecyl Sulfate through Extraction and Precipitation Method as Adsorbent for Methylene Blue Dyes*," *Indonesian Journal of Fundamental and Applied Chemistry*, vol. 9, no. 3, pp. 155–162, Oct. 2024, doi: 10.24845/ijfac.v9.i3.155.

[27] A. Aridhani, N. Kurnyawaty, and S. Oko, Pemanfaatan Cangkang Kerang Hijau Sebagai Adsorben untuk Menurunkan Kadar Besi (Fe 2+) dalam Air. 2024.

[28] S. Suhaera *et al.*, "Pemanfaatan Kalsium dari Limbah Cangkang Kerang Hijau (Perna viridis) Sebagai Zat Aktif pada Sediaan Pasta Gigi," *Jurnal Surya Medika*, vol. 10, no. 1, pp. 354–361, Apr. 2024, doi: 10.33084/jsm.v10i1.7237.

[29] H. C. Hardiyatmo, *Mekanika Tanah I*. 1992.

[30] ASTM D3282-15, *Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*. West Conshohocken, PA: ASTM International, 2015. doi: 10.1520/D3282-15.

[31] ASTM D2487-17, *Standard Classification of Soil for Engineering Purposes (Unified Soil Classification System)*. 2017.