JURNAL ONLINE SKRIPSI
MANAJEMEN REKAYASA KONSTRUKSI POLINEMA

Journal homepage: http://jurnal.polinema.ac.id/ **ISSN: 2722-9203 (media online/daring)**

ADDITION LIME AND FLY ASH AS PEAT SOIL STABILIZATION FOR ROAD SUBGRADE IN EAST KOTAWARINGIN

Nur Anwaril Jamil[1,*], Fuji Asema[2], Nur Laily Lupita Sari[3] , Dandung Novianto[4], Kharisma Nur Cahyani[5]
Civil Engineering Department, Politeknik Negeri Malang[1, 2, 3,4,5]
Koresponden*, Email: *nuranwariljamil22@gmail.com*

ABSTRACT

Peat soil is characterized by high water content and low bearing capacity, making it unsuitable for use as a road subgrade without stabilization treatment. This study aims to analyze the physical characteristics of natural peat soil from Kenan Sandan, East Kotawaringin, and evaluate the California Bearing Ratio (CBR) values after stabilization using lime and fly ash. Laboratory tests included physical properties, Modified Proctor compaction, and soaked CBR tests with lime variations of 10%, 15%, 20%, and combinations of lime (15% and 20%) with 10% fly ash at 1 and 3-day curing periods. The results showed that the peat soil has a moisture content of 97.54%, specific gravity (Gs) of 2.22, liquid limit (LL) of 69.25%, plasticity index (PI) of 38.61%, and pH of 5, classifying it into the A-8 group (organic soil) based on AASHTO M145. The 3-day soaked CBR of natural soil was only 2.26%, failing to meet the minimum 6% requirement of MDPJ 2024. The 10% lime addition was ineffective, yielding a CBR of only 2.44%. However, 15% and 20% lime additions significantly increased CBR values to 20.22% and 22.59%, respectively. The highest performance was achieved by the 20% lime + 10% fly ash combination with a CBR of 27.04% at 3-day curing. Pavement thickness analysis indicated that stabilization with 15% lime or more can reduce the required Class C Aggregate Base (LFA) thickness to 150 mm. In conclusion, the combination of 20% lime and 10% fly ash is the most effective mixture for improving the bearing capacity of peat soil for road subgrades.

Keywords : CBR; fly ash; lime; peat soil; stabilization; subgrade.

1. INTRODUCTION

Road infrastructure development in Indonesia continues to expand to improve regional connectivity and stimulate economic growth. However, in Kalimantan, particularly in East Kotawaringin Regency, Central Kalimantan Province, road construction faces considerable geotechnical challenges due to the widespread distribution of peat soil [1]. Peat soil is an organic soil formed from the accumulation of partially decomposed vegetation under water-saturated conditions. It generally exhibits high water content, high compressibility, low shear strength, and low bearing capacity, making it unsuitable for use as a road subgrade without proper stabilization [2].

The subgrade serves as the foundation of pavement structures by supporting and distributing traffic loads to the underlying ground. Inadequate subgrade strength can cause excessive settlement, cracking, and premature pavement failure. Therefore, improving the engineering properties of peat soil through stabilization has become an important topic in geotechnical engineering [3].

Hydrated lime is one of the most widely used stabilizing agents because it promotes cation exchange and pozzolanic reactions, producing cementitious compounds that improve the strength and stiffness of peat soil [2]. Fly ash has also been extensively utilized as a supplementary stabilizer due to its pozzolanic properties, which contribute to increased bearing capacity while simultaneously promoting the beneficial use of industrial by-products [4], [5].

Several previous studies have demonstrated the effectiveness of chemical stabilization for improving weak soils. Yudhyantoro [9] reported that sufficient lime content is essential to obtain a significant increase in the CBR value of peat soil. Abdelbaset et al. [10] found that the combination of hydrated lime and fly ash considerably enhanced the mechanical properties of stabilized soil. Tastan et al. [12] showed that fly ash effectively improved the engineering characteristics of organic soils through pozzolanic reactions. Likewise, Wulandari and Surbakti [13] observed a substantial increase in soaked CBR after lime stabilization of peat soil.

Recent studies have further confirmed the benefits of combining lime and fly ash. Sambre et al. [16] concluded that lime–fly ash mixtures provide a sustainable alternative for improving subgrade performance. Dwina et al. [17] reported that adding lime and fly ash significantly increased the bearing capacity of peat soil for road applications. Mohd Zambri and Ghazaly [18] demonstrated that lime treatment effectively improves the engineering behavior of tropical peat soils. Furthermore, Sutarno and Mohamad [20] found that pozzolanic materials modified the compaction characteristics and physicochemical properties of peat soil, while Utkarsh [22] highlighted that lime–fly ash stabilization effectively increases soil strength and reduces swelling.

Although previous studies have confirmed the effectiveness of lime and fly ash in improving peat soil properties, most investigations have focused primarily on the increase in engineering characteristics without evaluating their implications for pavement design. Limited studies have examined peat soil stabilized with lime contents of 10%, 15%, and 20%, combined with 10% Class F fly ash under short curing periods of 1 and 3 days. Furthermore, the stabilized CBR values have rarely been evaluated in relation to pavement thickness requirements based on the Manual Desain Perkerasan Jalan 2024 (MDPJ 2024).

2. METHODS

2.1 Study Location and Soil Sampling

This study was conducted at the Soil Mechanics Laboratory, Politeknik Negeri Malang, with peat soil samples collected from Jalan Kenan Sandan, Kotawaringin Timur Regency, Central Kalimantan Province, at coordinates 2°30'51.7"S 112°57'32.6"E (-2.514349, 112.959047). The research was carried out over a period of four months, covering the preparation and soil sampling stage, laboratory testing for the characterization of both natural soil and soil stabilized with a combination of lime and fly ash, data analysis of the test results, and preparation of the research report.

Soil sampling was conducted by excavating the soil to a depth of 100 cm. Undisturbed soil samples were obtained in the form of blocks measuring 10 × 10 × 10 cm, while disturbed samples were collected for laboratory testing of physical properties, compaction, and CBR.

2.2 Materials

The main materials used in this study consist of:

1. Peat soil collected directly from the research site at Jalan Kenan Sandan, Kotawaringin Timur Regency, Central Kalimantan.
2. Hydrated lime ($Ca(OH)_2$) obtained from a construction material supplier providing industry-standard quality products, used at fixed percentages of 10%, 15%, and 20% of the dry weight of the soil.
3. Class F fly ash obtained from a coal-fired power plant (PLTU) and complying with ASTM C618 specifications for Class F fly ash ($SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$), used at 10% of the dry weight of the soil.

2.3 Mix Variations and Laboratory Testing Program

The study used variations in the percentage of lime (10%, 15%, 20%) and fly ash (10%) as the main variables in the soil stabilization process. The mix variations evaluated were: natural soil, 10% lime, 15% lime, 20% lime, and 15% lime + 10% fly ash. All mixtures were tested under curing periods of 1 day and 3 days.

Laboratory testing included: (1) soil physical properties testing (water content, specific gravity, Atterberg limits, unit weight, particle size distribution, and pH) in accordance with ASTM standards; (2) Modified Proctor compaction test (ASTM D1557) to determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC); and (3) soaked California Bearing Ratio (CBR) test (ASTM D1883) with soaking periods of 1 day and 3 days to simulate saturated field conditions.

2.4 Curing Periods and Specimen Preparation

The mixing process was carried out gradually and thoroughly until a homogeneous mixture of soil, lime, and fly ash was obtained. The soil mixture was then fed into the mold for the formation of the test specimen in accordance with compaction and CBR testing standards. The test specimen was then treated (curing) in the mold with curing periods of 1 day and 3 days before testing to allow for initial reaction between peat soil, lime, and fly ash.

2.5 Pavement Thickness Analysis

Pavement thickness analysis was conducted based on the Road Pavement Design Manual 2024 (Manual Desain Perkerasan Jalan 2024) [6]. The analysis referred to Design Chart-3B, which relates the CBR value of the subgrade to the required thickness of selected fill or Class C aggregate base layer. Subgrade soil with a CBR value of 6–10% requires a selected fill thickness of 200 mm, while a CBR value of 10–30% requires 150 mm, and CBR ≥ 30% requires no additional layer.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Peat Soil

The physical properties testing of natural peat soil from Kenan Sandan, East Kotawaringin, revealed typical geotechnical characteristics of organic soils. The results are summarized in Table 1.

Table 1. Physical Properties of Natural Soil

Testing Parameters	Value	Units
Water Content (w)	97.54	%

Specific Gravity (Gs)	2.22	gram
Weight of Wet Contents (γwet)	1.85	$gram/cm^3$
Dry Fill Weight (γdry)	0.94	$gram/cm^3$
Liquid Limit (LL)	69.25	%
Plastic Limit (PL)	30.64	%
Plasticity Index (PI)	38.61	%
Soil pH	5	-
Pass the Filter No. 10	2	%
Pass the Filter No. 40	26	%
Pass the Filter No. 200	13	%
Classification ASHTO	A-8	-

Source: Test Result

The natural moisture content of 97.54% indicates soil conditions with a very high level of saturation, reflecting the ability of the soil to store large amounts of water due to its porous structure and dominant organic matter content. The dry unit weight of 0.94 g/cm³ indicates very low density compared to mineral soils. The liquid limit of 69.25% and plasticity index of 38.61% indicate high plasticity, suggesting significant deformation ability before failure. The soil pH of 5 indicates acidic conditions, which is common in peat soils due to the dominance of organic acids from the decomposition process of vegetation material. This acidic environment can affect the effectiveness of chemical reactions in stabilization processes, particularly those involving calcium-based materials such as lime.

Based on the AASHTO M145 classification system, peat soil from the study site was classified into Group A-8 (organic soil), which is considered unsuitable for use as road subgrade material without prior stabilization treatment [7]. This classification is based on visual identification and physical characteristics according to Note 8 of AASHTO M145, supported by all parameters consistently showing the characteristics of organic soil.

3.2 Modified Proctor Test Results

The Modified Proctor compaction test was conducted to determine the relationship between moisture content and soil dry density at a given compaction energy, in order to obtain Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values [8]. The compaction test results for all mix variations are summarized in Table 2.

Table 2. Modified Proctor Test Results

Mix Variation	Curing (day)	OMC (%)	MDD (g/cm^3)
Peat soil	1	26.00	1.342
Peat soil	3	28.30	1.350
Lime 10%	1	24.00	1.396
Lime 10%	3	22.00	1.385
Lime 15%	1	18.50	1.440
Lime 15%	3	22.00	1.449
Lime 20%	1	16.00	1.457
Lime 20%	3	12.00	1.474
Lime 15% + FA 10%	1	17.50	1.485
Lime 15% + FA 10%	3	21.00	1.500
Lime 20% + FA 10%	1	18.00	1.524
Lime 20% + FA 10%	3	19.00	1.566

Source: Test Result

The natural peat soil at 1-day curing demonstrated an OMC of 26.00% and MDD of 1.342 g/cm³. The addition of 10% lime improved compaction characteristics, increasing the MDD to 1.396 g/cm³ and reducing the OMC to 24.00% at 1-day curing. Increasing the lime content to 15% and 20% further enhanced the dry density, reaching 1.440 g/cm³ and 1.457 g/cm³ respectively, while the OMC continued to decrease to 16.00% for the 20% lime mixture. Unlike the initial draft, the thesis data shows that higher lime dosages consistently improve density at the 1-day stage without a reversal in trend.

Extended curing to 3 days generally showed continued improvement in soil stability. For the 20% lime mixture, the OMC dropped significantly to 12.00%, accompanied by an MDD increase to 1.474 g/cm³. The most significant density improvements were observed in the lime-fly ash combinations. The mixture of 20% lime + 10% fly ash achieved the highest compaction efficiency among all treatments, reaching an MDD of 1.566 g/cm³ with an OMC of 19.00% at 3-day curing. This indicates that the combination of maximum lime dosage and fly ash, supported by extended curing, allows for the most complete development of pozzolanic reactions and particle bonding.

3.2 Soaked CBR Results

Soaked CBR testing was performed to evaluate bearing capacity under saturated conditions, representing the most critical field scenario for road subgrades. The results for all mix variations under 1-day and 3-day curing periods are presented in Table 3 and Table 4, respectively.

Table 3. Soaked CBR and Swelling Values (1-Day Curing)

Mix Variation	CBR (%)	Swelling (mm)
Peat soil	5.07	9.99
Lime 10%	11.78	10.29
Lime 15%	13.75	2.00
Lime 20%	17.63	1.77
Lime 15% + FA 10%	18.15	0.01
Lime 20% + FA 10%	19.43	0.01

Source: Test Result

Table 4. Soaked CBR and Swelling Values (3-Day Curing)

Mix Variation	CBR (%)	Swelling (mm)
Peat soil	2.26	14.30
Lime 10%	2.44	7.75
Lime 15%	20.22	0.19
Lime 20%	22.59	0.11
Lime 15% + FA 10%	24.70	0.09
Lime 20% + FA 10%	27.04	0.01

Source: Test Result

The natural peat soil demonstrated a soaked CBR value of 5.07% at 1-day curing, which significantly decreased to 2.26% at 3-day curing. Both values remain well below the minimum requirement of 6% specified in MDPJ 2024. This reduction, accompanied by an increase in swelling from 8.243% to 11.799%, highlights the severe degradation of peat soil strength and volumetric stability under prolonged saturated conditions.

The addition of 10% lime proved insufficient for effective stabilization, yielding CBR values of 1.78% (1-day) and 2.44% (3-day). These values are notably lower than the natural soil's initial strength and fail to meet the 6% requirement. This suggests that a 10% lime dosage is inadequate to initiate the necessary pozzolanic reactions required to bind peat particles[9].

In contrast, the 15% lime treatment achieved a substantial improvement, with soaked CBR values rising from 13.75% at 1-day to 20.22% at 3-day curing. The swelling was also effectively controlled, decreasing from 1.630% (1-day) to 1.453% (3-day). Similarly, the 20% lime dosage produced higher strengths of 17.63% and 22.59% for the respective curing periods, with swelling further reduced to 0.089%. These results indicate that lime dosages of 15% and above successfully transform peat into a competent subgrade material.

The most effective stabilization was achieved through the lime-fly ash combinations. Unlike the initial draft's findings, the addition of fly ash consistently improved early-stage bearing capacity; the 15% lime + 10% fly ash mixture reached 18.15% at 1-day and 24.70% at 3-day curing. The ultimate performance was recorded for the 20% lime + 10% fly ash variation, which achieved the highest soaked CBR value of 27.04% at 3-day curing. This confirms that the synergy between maximum lime dosage and fly ash, supported by extended curing, maximizes the formation of cementitious compounds (C-S-H and C-A-H) and provides the best bearing capacity for road subgrades[4].

Figure 2. Comparison of Swelling Values for All Mix Variations (1-Day and 3-Day Curing)

The CBR improvement trends indicate that higher lime content contributes to improved bearing capacity, but the relationship is not linear and depends significantly on curing time. The influence of curing period is particularly pronounced for the lime-fly ash combination, where 3-day curing more than doubled the CBR value compared to 1-day curing. This phenomenon suggests that fly ash requires longer curing time for the pozzolanic reaction to occur optimally, producing cementation compounds that increase bonds between soil particles [5]. In contrast, the stabilization using lime alone showed a more rapid improvement in bearing capacity due to the immediate occurrence of cation exchange and flocculation-agglomeration processes, which modify the soil structure and reduce plasticity characteristics. However, the long-term strength development is still influenced by the formation of calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) compounds resulting from the pozzolanic reaction between calcium hydroxide from lime and reactive silica or alumina contained in the stabilizing materials. Therefore, the increase in curing duration provides additional time for these reactions to develop, resulting in stronger interparticle bonding and improved resistance against deformation under applied loads [5].

The analysis of road foundation requirements was conducted to evaluate the effect of CBR improvement due to stabilization on the required selected embankment thickness, based on Design Chart-3B of MDPJ 2024 [6]. The results are presented in Table 5.

Table 5. Road Subgrade Requirements Evaluation Based on MDPJ 2024

Mix Variation	CBR 1-day (%)	CBR 3-day (%)	Thickness 1-day (mm)	Thickness 3-day (mm)
Peat soil	5.07	2.26	-	-
Lime 10%	1.78	2.44	-	-
Lime 15%	13.75	20.22	150	150
Lime 20%	17.63	22.59	150	150
Lime 15% + FA 10%	18.15	24.70	150	150
Lime 15% + FA 10%	19.43	27.04	150	150

Source : Test Result

Natural peat soil and soil stabilized with 10% lime failed to meet the minimum soaked CBR requirement of 6%, with values ranging from 1.78% to 5.07%, thus requiring special treatment beyond standard provisions. Stabilization with 15% and 20% lime successfully increased the subgrade bearing capacity to a range of 13.75%–22.59%. This improvement was sufficient to reduce the required selected fill (LFA Class C) thickness to 150 mm for both 1-day and 3-day curing periods, as these variations fell consistently within the 10–30% CBR range defined by MDPJ 2024.

The lime-fly ash combinations demonstrated even greater efficiency in pavement design. Unlike previous calculations, the 15% lime + 10% fly ash mixture achieved a CBR of 18.15% at 1-day curing, which already qualified for the 150 mm thickness requirement. By 3-day curing, this value improved to 24.70%, maintaining the same thickness classification while providing enhanced structural stability.

Among all evaluated variations, the combination of 20% lime and 10% fly ash with 3-day curing provided the highest soaked CBR value of 27.04%. This mixture was identified as the optimum stabilization solution for improving peat soil subgrade performance in East Kotawaringin, requiring only 150 mm of selected fill thickness compared to the impractical and costly requirements for untreated A-8 organic soil.

4. CONCLUSION

Based on the results of laboratory tests and discussions conducted on peat soil from Kenan Sandan, East Kotawaringin, Central Kalimantan, stabilized using lime and fly ash, the following conclusions are drawn.

1. The peat soil from the study area had a natural water content of 97.54%, specific gravity (Gs) of 2.22, liquid limit (LL) of 69.25%, plasticity index (PI) of 38.61%, and pH of 5. Based on the AASHTO M145 classification system, the soil was classified as A-8 (organic soil), indicating that it is unsuitable for use as a road subgrade without prior stabilization.
2. The soaked California Bearing Ratio (CBR) value of the natural peat soil was 5.07% after 1 day of soaking and decreased to 2.26% after 3 days of soaking. These values are lower than the minimum subgrade requirement of 6% specified in MDPJ 2024, indicating that the natural peat soil does not meet the technical requirements for road subgrade applications.
3. The addition of lime improved the bearing capacity of peat soil. The soaked CBR values after 3 days of curing were 2.44%, 20.22%, and 22.59% for lime contents of 10%, 15%, and 20%, respectively. The results indicate that 10% lime was insufficient to achieve the minimum subgrade requirement specified in MDPJ 2024. In contrast, both 15% and 20% lime successfully increased the soaked CBR values above the required minimum of 6%, with the 20% lime mixture producing the highest bearing capacity.
4. 4. The addition of fly ash further improved the bearing capacity of lime-stabilized peat soil. The soaked CBR values after 3 days of curing reached 24.70% for the 15% lime + 10% fly ash mixture and 27.04% for the 20% lime + 10% fly ash mixture. Both mixtures exceeded the minimum MDPJ 2024 subgrade requirement and produced higher CBR values than the corresponding lime-only mixtures, indicating the positive contribution of fly ash to peat soil stabilization under the conditions of this study.
5. 5. Based on the evaluation of the 2024 MDPJ, the results of stabilization with 15% and 20% lime have met the subgrade bearing capacity requirements (CBR ≥ 6%) and can be used as the basis for evaluating the need for a 150 mm thick lower foundation layer (LFA Class C). This evaluation is limited to assessing the subgrade bearing capacity and does not include a complete structural design calculation for the pavement.

These findings provide a useful reference for the stabilization and utilization of peat soil as a road subgrade material.

REFERENCES

[1] Badan Pusat Statistik Kabupaten Kotawaringin Timur, Kabupaten Kotawaringin Timur Dalam Angka 2025. Sampit: BPS Kabupaten Kotawaringin Timur, 2025.

[2] A. Ahmad et al., "Physio-chemical properties, consolidation, and stabilization of tropical peat soil using traditional soil additives—A state of the art literature review," KSCE Journal of Civil Engineering, vol. 25, no. 10, pp. 3662-3678, 2021.

[3] K. C. Onyelowe et al., "Estimating the strength of soil stabilized with cement and lime at optimal compaction using ensemble-based multiple machine learning," Scientific Reports, vol. 14, no. 1, p. 15308, 2024.

[4] R. Renjith et al., "Optimization of fly ash based soil stabilization using secondary admixtures for sustainable road construction," Journal of Cleaner Production, vol. 294, p. 126264, 2021.

[5] V.-L. Nguyen, V. T.-A. Phan, and H.-B. Tran, "Potential of fly ash, cement, and enzyme stabilized soil for road construction," Transportation Infrastructure Geotechnology, vol. 10, no. 6, pp. 1050-1071, 2023.

[6] Direktorat Jenderal Bina Marga, Manual Desain Perkerasan Jalan No. 03/M/BM/2024. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2024.

[7] American Association of State Highway and Transportation Officials, Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes, 2021.

[8] B. M. Das, Advanced Soil Mechanics. Boca Raton: CRC Press, 2019.

[9] Y. Yudhyantoro, "Pengaruh Penambahan Kapur terhadap Kepadatan dan Nilai CBR Tanah Gambut Abu Tinggi," Jurnal Teknik Sipil, vol. 2, no. 2, pp. 137-146, 2013.

[10] A. M. Abdelbaset et al., "Mechanical properties stabilization of low plasticity Kaolin soil using fly ash and hydrated lime," Case Studies in Construction Materials, vol. 21, p. e03662, 2024.

[11] ASTM International, Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils, 2021.

[12] E. O. Tastan et al., "Stabilization of Organic Soils with Fly Ash," Journal of Geotechnical and Geoenvironmental Engineering, vol. 137, no. 9, pp. 819-833, 2011.

[13] T. E. Wulandari and R. Surbakti, "Stabilisasi Tanah Gambut Menggunakan Kapur dengan Pengujian CBR," Agregat: Jurnal Ilmiah Teknik Sipil, vol. 3, no. 2, pp. 96-103, 2023.

[14] M. K. Muwaffa, "Pengaruh Campuran Kapur terhadap Kepadatan Tanah Lempung dengan Pengujian CBR," Jurnal Tugas Akhir Teknik Sipil, vol. 5, no. 2, pp. 32-41, 2021.

[15] E. Mina, R. I. Kusuma, and Z. I. Sausan, "Pemanfaatan Semen Slag Sebagai Campuran Stabilisasi Tanah dan Pengaruhnya terhadap Nilai CBR Terendam (Soaked California Bearing Ratio)," Jurnal Teknik Sipil, vol. 28, no. 3, 2021.

[16] T. Sambre, M. Endait, and S. Patil, "Sustainable soil stabilization of expansive soil subgrades through lime-fly ash admixture," Discover Civil Engineering, 2024.

[17] D. O. Dwina et al., "Stabilisasi Tanah Gambut Dengan Penambahan Kapur dan Fly Ash Sisa Pembakaran Cangkang Sawit Sebagai Subgrade Jalan," Jurnal Fondasi, vol. 10, no. 1, 2021.

[18] N. Mohd Zambri and Z. Md. Ghazaly, "Peat soil stabilization using lime and cement," in E3S Web of Conferences, 2018.

[19] B. B. K. Huat et al., Geotechnics of Organic Soils and Peat, 1st ed. Boca Raton, Florida: CRC Press, 2014.

[20] M. S. Sutarno and H. M. Mohamad, "Peat soil compaction characteristic and physicochemical changes treated with Eco-Processed Pozzolan (EPP)," Civil Engineering Journal, vol. 9, no. 1, pp. 86-103, 2023.

[21] M. T. Mohamad Zulkifley et al., "Definitions and Engineering Classifications of Tropical Lowland Peats," Bulletin of Engineering Geology and the Environment, vol. 72, no. 3-4, pp. 547-553, 2013.

[22] P. Utkarsh, "Enhancing the properties of swelling soils with lime, fly, ash, and expanded polystyrene—A Review," Heliyon, vol. 10, p. e32908, 2024.