http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 10 No 4 2025

RESEARCH ARTICLE

A Study On Soil Bearing Capacity Strengthening Using Soil Cement On Jagebob Road With Unconfined Compression Test

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Received: Sep 1, 2025; Accepted: Dec 19, 2025.
DOI: 10.25299/jgeet.2025.10.4.24848

Abstract

This study investigates the improvement of soil bearing capacity through the application of soil–cement stabilization on Jagebob Road using the Unconfined Compression Test (UCT). The research aims to evaluate how curing duration affects the compressive strength development of soil cement mixtures. Laboratory experiments were conducted on cohesive soil samples with curing periods of 0, 3, and 7 days to observe the changes in both physical and mechanical properties. The results show that at 0 days of curing, the compressive strength remained low (0.103–0.114 kg/cm²) due to incomplete hydration. After 3 days, a significant increase in strength was observed, reaching up to 0.295–0.305 kg/cm², indicating the beginning of cement hydration and improved particle bonding. At 7 days, the soil achieved even higher compressive strength as the hydration process produced more calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$), which enhanced the density and bonding of the soil matrix. These findings confirm that the curing period plays a crucial role in strengthening soil cement. Therefore, a curing duration of at least seven days is recommended to achieve optimal mechanical performance and ensure improved bearing capacity of stabilized soils for road infrastructure such as Jagebob Road.

Keywords: Soil Bearing Capacity, Road Pavement, Soil Cement, UCT Method.

1. Background

In any civil engineering project, soil serves as the fundamental support for structures, whether as a foundation or as a direct construction material such as in embankments, subgrades, or road layers. However, soil characteristics vary greatly depending on the location, as it is a natural material with complex and heterogeneous properties. Some soils, particularly those with loose, soft, or high plasticity characteristics, are often unsuitable for construction without prior improvement. In such cases, soil stabilization becomes an essential process to enhance the soil's strength, density, and durability to meet engineering requirements. Stabilization ensures that the underlying soil can withstand applied loads and maintain the stability of the constructed structure (Kumar et al., 2021).

In the context of Jagebob Road construction, soil stabilization is particularly important because the region exhibits weak subgrade characteristics. Without adequate stabilization, the road structure would be prone to premature damage such as rutting, cracking, and settlement. The road base (Base Course or Lapis Pondasi Atas – LPA) plays a crucial role in distributing traffic loads evenly to the lower layers. Unfortunately, in Merauke Regency, suitable aggregate materials for road construction are limited due to long hauling distances and high transportation costs, which make conventional aggregate-based base courses economically unfeasible. As a result, alternative local materials that are both cost-effective and sustainable have become a research priority for infrastructure development in the region (Rahardjo et al., 2022).

Jagebob Road serves as a vital transportation corridor connecting Merauke City with Jagebob District, located in the southern part of Papua Province. This road supports daily mobility, agricultural logistics, and the distribution of essential goods. However, the existing road conditions are often severely degraded, particularly during the rainy season, when the road becomes muddy, slippery, and impassable. These conditions often lead to temporary isolation of rural communities, disrupting economic activities and access to essential services. Addressing this recurring problem requires an engineering solution that focuses on improving the bearing capacity and durability of the subgrade layer using available local resources (PSP, 2021).

To ensure that the road design meets technical and functional standards, geometric planning and material performance must be optimized. The geometric design must accommodate safe traffic flow, minimize maintenance costs, and ensure user comfort. Meanwhile, the selection of materials for the base and subgrade layers must prioritize stability, strength, and local adaptability. One of the most effective approaches to achieving this balance is soil stabilization using cement, which can significantly improve the mechanical properties of weak soils (Mishra & Patel, 2021).

In southern Papua, the terrain is predominantly swampy, with limited access to high-quality aggregates such as crushed stone or river sand. Therefore, soil–cement stabilization presents a viable alternative for strengthening road foundations. This technique involves mixing locally available soil with cement and water in specific proportions to enhance strength and stiffness. The cement acts as a binding agent, producing a hardened matrix that resists deformation and improves the soil's compressive strength. According to Andrew Tjakrakusuma et al. (2019), soil–cement mixtures have been successfully applied in swampy and coastal regions of Papua, offering both economic and structural benefits for road construction projects.

Soil stabilization with cement operates on the principle of chemical bonding and pozzolanic reactions between the soil particles and cementitious compounds formed during hydration. When cement is mixed with soil and water, compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) develop, filling the voids between soil particles and creating a denser and stronger structure. This process reduces the soil's plasticity, increases cohesion, and enhances overall shear strength. Such chemical transformations are particularly beneficial for clayey soils, which generally exhibit poor strength and excessive volume changes when exposed to moisture (Gowthami & Kumar, 2020).

From an engineering perspective, the Unconfined Compression Test (UCT) is a standard and reliable method to evaluate the Unconfined Compressive Strength (UCS) of stabilized soil samples. This test measures the maximum axial stress that the soil specimen can withstand before failure without lateral confinement. The UCS value serves as a direct indicator of the soil's bearing capacity and mechanical improvement after stabilization. Several studies have confirmed that the UCS of soil–cement mixtures increases with higher cement content and longer curing periods, reflecting the continuous hydration process and the progressive development of cementitious bonds (Patel et al., 2022).

In the Jagebob Road project, the Unconfined Compression Test was selected as the primary method to analyze the strength characteristics of soil–cement samples prepared using local soil and Portland cement. The experimental setup involved a controlled curing period to simulate field conditions and determine the optimum cement proportion that achieves the desired strength while maintaining cost efficiency. The findings from this study are expected to contribute to the development of local road construction practices in Papua, particularly in areas with similar soil and resource constraints (Santoso et al., 2023).

The main objective of this research is to determine the mechanical characteristics and UCS values of soil–cement mixtures as a potential replacement for the Base Course (LPA) layer on Jagebob Road. The research aims to assess whether soil–cement can achieve sufficient strength to function as a structural layer capable of distributing traffic loads effectively. By doing so, the study seeks to reduce dependence on imported aggregate materials while promoting the use of locally available soils as sustainable road construction materials (Wulandari & Nugroho, 2020).

Moreover, this study aligns with Indonesia's broader infrastructure goals of developing resilient and sustainable roads in remote regions, especially in eastern Indonesia. The use of soil–cement technology supports not only environmental sustainability by minimizing material transportation but also regional development by improving accessibility and economic connectivity. The results of this research are therefore expected to provide valuable insights into cost-effective and durable stabilization techniques suitable for tropical and swampy regions (Hidayat et al., 2021).

2. Literature Review

2.1 Asphalt Road and Pavement Structure

Asphalt roads, commonly referred to by civil engineers as hot mix asphalt (HMA), are one of the most widely used pavement types in highway construction. Asphalt serves as a binding material that integrates aggregates such as sand and crushed stone into a cohesive structure. This material is typically black or dark brown in color, with bitumen as its main component derived from petroleum refining residues. Asphalt functions as an adhesive and waterproofing agent, providing flexibility, strength, and durability to road surfaces (Yunus, 2023). The asphalt pavement system consists of several layers constructed above the subgrade, each serving a specific structural and functional role. The main objectives of road pavement construction are to provide a smooth and skid-resistant surface, ensure long service life, and minimize maintenance requirements during its operational period (Yunus, 2025a).

According to Sukirman (2010), pavements are classified based on their binding material into several types: flexible pavement, which uses asphalt as a binder; rigid pavement, which uses Portland cement; and composite pavement, which combines both flexible and rigid types. In addition, there is a semi-rigid pavement, which serves as a transitional form between the two, offering moderate flexibility and rigidity (Yunus, 2024b). Flexible pavements, composed primarily of asphalt, are most commonly used for urban highways with moderate to heavy traffic loads. The structural composition of flexible pavement generally includes sand, crushed stone, and asphalt, forming a multilayer system that gradually decreases in bearing capacity from top to bottom (Yunus, 2025b; Yunus, 2024b).

2.2 Components of Flexible Pavement

The structure of flexible pavement consists of several key layers, namely:

a) Surface Course – the top layer that directly interacts with traffic loads and environmental exposure, designed for durability, skid resistance, and smoothness.
b) Base Course – the layer beneath the surface course, responsible for distributing loads to the lower layers while maintaining structural integrity.
c) Subbase Course – a transitional layer that enhances load distribution and provides drainage.
d) Subgrade – the natural soil foundation that supports all upper layers (Yunus, 2024b; Yunus, 2025b).

Among these layers, the base course is a particularly critical component of the flexible pavement system. It lies between the surface course and the subgrade, serving to distribute vehicular loads evenly to prevent direct stress transfer to the subgrade, which often has lower bearing capacity. This layer enhances the overall structural stability and load-bearing performance of the road. According to Budiarna et al. (2022), the base course plays a vital role in ensuring that stresses from vehicular traffic are properly absorbed and dissipated, thereby preventing deformation and failure of the upper pavement layers.

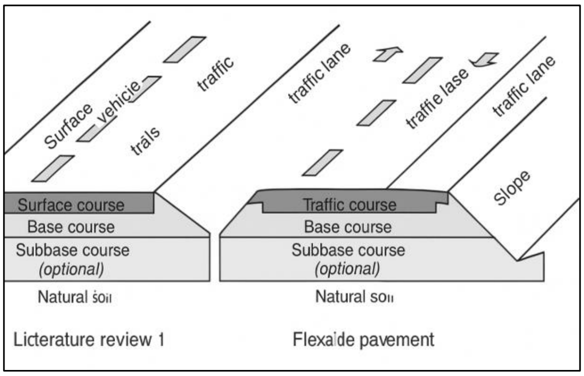

Fig 1. Cross-Section of Conventional and Flexaide Pavement Structures (Yunus, 2024).

2.3 The Role of the Base Course in Pavement Performance

In the context of flexible pavement design, the base course is the primary structural layer that ensures load transfer from traffic to the underlying subgrade. This distribution process helps prevent cracking, rutting, and deformation of the surface layer, particularly under repetitive and dynamic loading conditions. The base course also functions as a support system against deformation induced by environmental factors such as temperature variations, rainfall infiltration, and changes in soil moisture (Budiarna et al., 2022).

Without an adequately designed and constructed base course, vehicular loads may directly affect the subgrade, resulting in loss of support, uneven settlement, and accelerated pavement deterioration. Therefore, in pavement design, parameters such as thickness, material quality, and subgrade bearing capacity must be carefully considered to ensure a durable and cost-effective road structure. According to Yunus (2024b), proper base course planning contributes significantly to the longevity and sustainability of road infrastructure by minimizing the risk of early structural failures.

2.4 Upper and Lower Base Course Functions

The upper base course, located directly beneath the surface layer, serves as a cushioning and load-distribution medium that resists lateral forces from wheel loads. This layer provides both strength and flexibility, reducing the concentration of stresses transmitted to the subbase and subgrade. Meanwhile, the lower base course functions as a foundation support layer, ensuring overall stability and drainage efficiency. The combined performance of these two layers determines the road's capacity to withstand repeated loading and environmental impacts (Yunus, 2025b).

2.5 Soil Stabilization Concept

When natural soil conditions are insufficient to support the planned loads or exhibit low shear strength, high compressibility, or poor drainage, stabilization becomes necessary. According to Bowles (1984) and Tjakrakusuma, Maulana, and Budi (2019), soil stabilization aims to improve the engineering properties of soil—such as strength, density, and moisture resistance—by altering its physical and chemical characteristics. Stabilization can be achieved through mechanical compaction or by adding stabilizing agents like lime, cement, or bitumen. These processes enhance the soil's ability to function effectively as a structural foundation for roads and other infrastructure (Tjakrakusuma et al., 2019).

2.6 Soil Cement as a Stabilization Method

Soil cement is one of the most effective stabilization materials, consisting of a mixture of soil, cement, and water that undergoes compaction and curing to form a hard, durable, and load-bearing layer. This technique involves spreading and blending the soil–cement mixture on the prepared subgrade, shaping it according to design dimensions, compacting it to the required density, and then curing it to achieve maximum strength. Once hardened, the soil–cement layer acts as a base course in pavement structures, capable of distributing traffic loads efficiently and resisting deformation under environmental stresses.

The application of soil cement as a base course material is governed by specific technical standards that ensure uniformity in composition, moisture content, compaction level, and curing period. These parameters determine the strength, stiffness, and durability of the stabilized layer. Research by Tjakrakusuma et al. (2019) indicates that cement stabilization significantly increases unconfined compressive strength (UCS), reduces plasticity, and improves bearing capacity, making it a suitable alternative to conventional aggregate base materials, especially in regions where high-quality aggregates are scarce.

2.7 Summary of Literature Findings

Based on the reviewed literature, flexible pavement structures rely heavily on the performance of the base course to maintain durability and serviceability. When local soil conditions present low strength or instability, soil–cement stabilization provides a sustainable and effective solution to improve road performance. This approach not only enhances mechanical properties but also reduces construction costs by utilizing locally available materials. As highlighted by Yunus (2023; 2024b; 2025a; 2025b) and Tjakrakusuma et al. (2019), the integration of soil–cement technology into pavement construction offers a promising pathway toward resilient, sustainable, and long-lasting road infrastructure.

3. Method

3.1 Data Collection

The data collection process in this research was carried out using two primary methods: literature study and laboratory testing. The literature study involved gathering secondary data from books, previous research, and scientific journals to establish a strong theoretical foundation and to understand prior developments related to soil stabilization techniques. This step provided insight into relevant parameters, testing standards, and methodologies that guided the experimental procedures. Meanwhile, the laboratory testing phase was designed to obtain primary data that directly supported the research analysis, focusing on evaluating the physical and mechanical characteristics of soil–cement mixtures. All laboratory activities were conducted at the Civil Engineering Laboratory, Universitas Fajar Makassar, Indonesia, under controlled conditions to ensure data reliability and accuracy.

3.2 Tools and Materials

The tools utilized in this research included a digital scale, ziplock bags, cylinder molds, mixer, sample extractor, curing chamber/bucket, and a Unconfined Compressive Strength (UCS) testing machine. Each instrument played a vital role in ensuring precise measurements and consistent specimen preparation. The materials used comprised selected clayey soil, Portland cement, and water, all of which were prepared according to the required testing standards. The selected soil represented the natural material to be stabilized, while Portland cement served as the stabilizing agent to enhance strength and reduce plasticity. Water was used as a binding medium to activate the cement hydration process during mixing and curing.

3.4 Research Stages

The experimental process was divided into three main stages: Physical Properties Testing, Specimen Preparation, and Specimen Testing.

1) Physical Properties Testing

   The physical characterization of soil and cement was conducted to determine their fundamental properties before mixing. Tests included the water content test following *SNI 03-6817-2002*, the specific gravity test based on *SNI 03-1964-1990*, and the cement quality test according to *SNI 15-2049-2004*. These tests ensured that the materials met the required standards for stabilization research.

2) Specimen Preparation

   The preparation process involved several precise steps to produce uniform and representative samples. Standard cylinder molds were cleaned and lubricated before use. The soil–cement mixture was prepared using a mechanical mixer and then placed into the molds in 2–3 compacted layers. Each layer was compacted evenly to achieve the desired density. The surface was leveled, and the specimens were carefully demolded to avoid structural disturbance. Afterward, each specimen was wrapped and placed in a curing chamber for 7 days to ensure complete cement hydration.

3) Specimen Testing (UCT Test)

   After the curing period, the Unconfined Compression Test (UCT) was performed to determine the mechanical strength of the stabilized soil samples. Each specimen's diameter and height were measured accurately before testing. The samples were placed vertically on the UCS testing machine, where an axial load was applied gradually until failure occurred. During the test, both maximum load and axial deformation were recorded. These measurements were essential for calculating compressive strength, which reflects the effectiveness of soil stabilization using cement.

3.4 Data Analysis

The data obtained from the laboratory tests were processed and presented in the form of tables, graphs, and figures to illustrate the physical and mechanical characteristics of the soil–cement mixtures. Comparative analysis was conducted to observe variations in strength due to different curing durations and mix proportions. The interpretation focused on identifying the relationship between cement content, curing time, and the resulting compressive strength. The analysis aimed to determine the optimum composition that produces maximum improvement in soil strength and stability. Furthermore, the results were compared with established standards and findings from previous studies to validate their accuracy and scientific relevance.

4. Result

Based on the results of soil material characterization tests conducted in the soil materials laboratory, it was found that the specific gravity obtained was 1.26%. The average water content value from the water content test was 6.49%. The sieve analysis test showed that the soil sample was predominantly composed of silt and clay. Referring to the Unified Soil Classification System (USCS), the soil used in this study is classified as PT (peat soil), as indicated by a CU value of 6.04 and a CC value of 41.80, with little to no fine-grained particles. The results of the compaction test showed that the maximum dry density was 1.23 gr/cm³, and the optimum moisture content was 28.37%.

Table 1. Results of Soil Characteristic Tests

No.	Test	Unit	Result
1. Specific Gravity	Specific gravity	-	1.26
2. Sieve Analysis	Sieve analysis		
a. Gravel	%	6.04	
b. Sand	%	41.80	
c. Silt and clay	%	94.88	
3. *Soil Water Content Test* (or simply *Water Content Test*)	Water content test	%	6.49
4. Atterberg Limits Test	Atterberg limits		
a. Liquid limit	%	70.73	
b. Plastic limit	%	18.24	
c. Shrinkage limit	%	18.99	
5. Compaction Test	Compaction		
a. Maximum dry density	gr/cm³	1.23	
b. Optimum water content	%	28.37	

(Source: processed data, 2025)

Table 2. Normal Sample Data

Sample Data	Sample 1	Sample 2	Sample 3
Diameter (cm)	4.8	4.8	4.8
Height (cm)	9.8	9.9	9.7
Volume (cm³)	4,850	4,850	4,850
Area (cm²)	188.4	188.4	188.4
Wet Soil Weight (g)	283.7	283.7	283.7
Dry Soil Weight (g)	273.8	273.8	273.8
Water Content (%)	28.4	28.4	28.4
Wet Bulk Density (g/cm³)	58.5	58.5	58.5
Dry Bulk Density (g/cm³)	56.454	56.454	56.454

(Source: processed data, 2025)

Table 3. Normal Sample 1 Test
Axial Deformation – Axial Force and Stress

Axial Deformation Reading dh (mm)	Axial Strain e = dh/h	Load Reading (div)	Axial Force P (kg)	Corrected Area A = A_o /(1–dh/h) (cm²)	Stress S = P/A (kg/cm²)
0.00	0.00000	0	0.000	188.400	0.000
0.80	0.08163	4	0.740	188.554	0.004
1.60	0.16327	10	1.850	188.708	0.010
2.40	0.24490	14	2.590	188.863	0.014
3.20	0.32653	35	6.475	189.017	0.034
4.00	0.40816	67	12.395	189.172	0.066
4.80	0.48980	82	15.170	189.327	0.080
5.60	0.57143	102	18.870	189.483	0.100
6.40	0.65306	130	24.050	189.638	0.127
7.20	0.73469	143	26.455	189.794	0.139
8.00	0.81633	0	0.000	189.951	0.000
8.80	0.89796	0	0.000	190.107	0.000
9.60	0.97959	0	0.000	190.264	0.000
10.40	1.06122	0	0.000	190.421	0.000
11.20	1.14286	0	0.000	190.578	0.000
12.00	1.22449	0	0.000	190.736	0.000

(Source: Processed Data, 2025)

Table 4. Normal Sample 2 Test Axial Deformation – Axial Force and Stress

Axial Deformation Reading dh (mm)	Axial Strain e = dh/h	Load Reading (div)	Axial Force P (kg)	Corrected Area A = A_o /(1–dh/h) (cm²)	Stress S = P/A (kg/cm²)
0.00	0.00000	0	0.000	188.400	0.000
0.80	0.08081	5	0.925	188.552	0.005
1.60	0.16162	9	1.665	188.705	0.009
2.40	0.24242	13	2.405	188.858	0.013
3.20	0.32323	31	5.735	189.011	0.030
4.00	0.40404	58	10.730	189.164	0.057
4.80	0.48485	65	12.025	189.318	0.064
5.60	0.56566	98	18.130	189.472	0.096
6.40	0.64646	120	22.200	189.626	0.117
7.20	0.72727	136	25.160	189.780	0.133
8.00	0.80808	144	26.640	189.935	0.140
8.80	0.88889	0	0.000	190.090	0.000
9.60	0.96970	0	0.000	190.245	0.000
10.40	1.05051	0	0.000	190.400	0.000
11.20	1.13131	0	0.000	190.556	0.000
12.00	1.21212	0	0.000	190.712	0.000

(Source: Processed Data, 2025)

Based on the results of physical and mechanical characteristic testing in the laboratory, the soil used in this study was identified as peat soil, classified as SP (Poorly Graded Sand) according to the Unified Soil Classification System (USCS). This type of soil is characterized by a texture dominated by organic matter, high water content, and poor particle gradation. Such conditions make peat soil possess low bearing capacity and inadequate stability if directly used as foundation material. Therefore, the application of peat soil in construction requires special treatment to improve its mechanical properties, one of which is through soil stabilization methods.

Peat soil is known to contain a high percentage of organic matter, which makes it prone to significant volume reduction or consolidation when subjected to loads. This characteristic renders peat unsuitable for direct use as a foundation material without quality improvement. Moreover, its low stability makes it highly vulnerable to structural damage in road construction, building foundations, and other infrastructure works. This finding is consistent with previous studies, which noted that soils with high organic content tend to have weak interparticle bonding and thus require the addition of stabilizing materials to enhance their strength.

Table 5. Normal Sample 3 Test
Axial Deformation – Axial Force and Stress

Axial Deformation Reading dh (mm)	Axial Strain e = dh/h	Load Reading (div)	Axial Force P (kg)	Corrected Area A = A_o /(1–dh/h) (cm²)	Stress S = P/A (kg/cm²)
0.00	0.00000	0	0.000	188.400	0.000
0.80	0.08163	3	0.555	188.554	0.003
1.60	0.16327	7	1.295	188.708	0.007
2.40	0.24490	11	2.035	188.863	0.011
3.20	0.32653	30	5.550	189.017	0.029
4.00	0.40816	55	10.175	189.172	0.054
4.80	0.48980	70	12.950	189.327	0.068
5.60	0.57143	90	16.650	189.483	0.088
6.40	0.65306	117	21.645	189.638	0.114
7.20	0.73469	132	24.420	189.794	0.129
8.00	0.81633	145	26.825	189.951	0.141
8.80	0.89796	0	0.000	190.107	0.000
9.60	0.97959	0	0.000	190.264	0.000
10.40	1.06122	0	0.000	190.421	0.000
11.20	1.14286	0	0.000	190.578	0.000
12.00	1.22449	0	0.000	190.736	0.000

(Source: Processed Data, 2025)

Table 6. Summary of Normal Sample Tests (Sample 1–3)

Parameter	Sample 1	Sample 2	Sample 3
Maximum Axial Deformation (mm)	12.00	12.00	12.00
Maximum Axial Strain (e)	1.224	1.224	1.224
Maximum Load (kg)	31.450	30.050	26.825
Maximum Stress (kg/cm²)	0.166	0.159	0.141
Corrected Area at Peak Load (cm²)	189.71	189.71	189.95
Stress–Strain Trend	Increasing until peak, then declining	Increasing until peak, then declining	Increasing until peak, then declining

(Source: Processed Data, 2025)

Based on the summary tables of the normal test results for the three samples, it can be concluded that each sample exhibits variations in its ability to withstand axial loads. Sample 1 demonstrated the highest compressive strength of 0.166 kg/cm², indicating that this material can resist deformation more effectively compared to the other samples. Sample 2 recorded a slightly lower compressive strength of 0.159 kg/cm², still relatively close to Sample 1, suggesting that it maintains a fairly stable performance but does not achieve the maximum resistance. Meanwhile, Sample 3 showed the lowest compressive strength at 0.141 kg/cm², reflecting a weaker structural capacity to resist axial deformation. Nevertheless, all three samples displayed a consistent trend, namely an increase in strength along with deformation up to a certain peak point before decreasing, which indicates that their mechanical responses are generally similar, differing only in the maximum level of strength attained. This finding highlights the influence of material characteristics such as homogeneity, density, and grain size distribution on the compressive performance, ultimately affecting the bearing capacity and stability of the soil or material when subjected to axial loading.

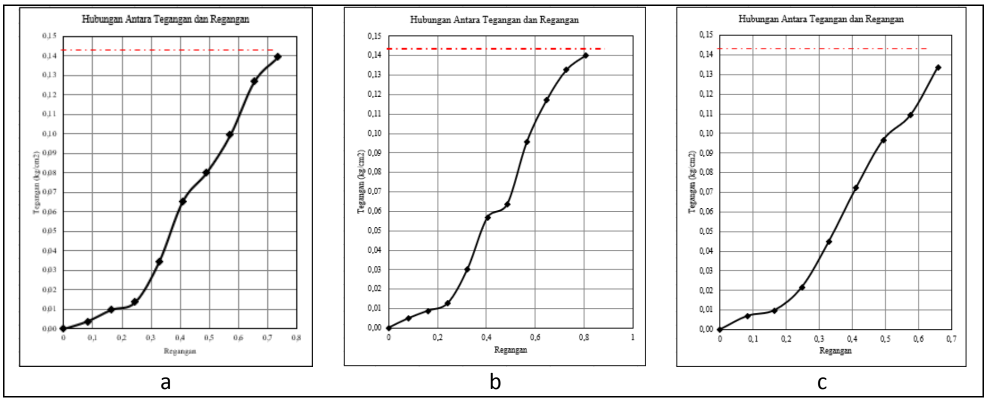

Fig 2. Graph of Normal Sample 1 (a), Normal Sample 2 (b), and Normal Sample 3 (c) *(Source: processed data, 2025)*

The three sub-graphs (a, b, and c) illustrate the mechanical behavior of the native soil before stabilization, fundamentally reflecting its unconfined compressive strength.

1. General Stress–Strain Response Pattern
   a) Consistent Pattern: All samples (a, b, and c) display a highly similar stress-strain pattern, which is characterized by a progressive increase in stress with increasing axial strain, leading up to a peak stress, followed by a sharp decrease in stress at larger strains.
   b) Cohesive Soil Behavior: This pattern is a hallmark of plastic failure behavior in cohesive soils (clay or peat) with medium to high plasticity, where the material withstands the load up to its elastic-plastic limit before interparticle bonds are destroyed and the strength decreases drastically (*strain softening*).
   c) Stress Scale: The maximum compressive strength (peak stress) for all samples falls within a very low range, 0.14 kg/cm^2 to 0.16 kg/cm^2 (referencing supporting data Table 6 which shows 0.166 kg/cm^2 for Sample 1 and 0.141 kg/cm^2 for Sample 3). This extremely low value is consistent with the soil classification as peat soil, which naturally possesses low bearing capacity.
2. Differences in Inter-Sample Performance

Although the pattern is consistent, variations exist in the peak stress values and initial stiffness:

a. Peak Strength:
   1) Sample 1 (a) achieves the highest peak stress (0.166 kg/cm^2), indicating this sample possesses the highest unconfined compressive strength among the normal group.
   2) Sample 3 (c) achieves the lowest peak stress (0.141 kg/cm^2), suggesting the weakest or least dense internal structure.

b. Stiffness: The initial curve for Sample 1 appears slightly steeper (stiffer) compared to Sample 3, indicating that Sample 1 was able to resist initial deformation with greater compressive force. This difference is likely due to minor variations in homogeneity, dry density, or particle size distribution among the samples.

3. Mechanical Implications
   a) Failure Strain: Plastic failure (reaching peak stress) occurs at relatively small axial strains 0.3 to 0.4 (or 30% to 40% strain). This confirms that the native soil has limited ductility (deformability) before reaching total structural failure.
   b) Limit Line (Dashed Red Line): The horizontal dashed red line on all three graphs likely represents a standard compressive strength limit, which in this context, all samples only achieve a small fraction of, demonstrating the necessity for substantial strength improvement through stabilization methods.

In summary, Figure 2 serves as crucial baseline data. These graphs show that the native soil possesses very low compressive strength and high vulnerability to plastic failure under axial load, thereby justifying the need for stabilization measures to be evaluated in subsequent testing stages (as performed in Figures 3, 4, and 5).

One of the commonly applied improvement methods is soil stabilization with cement (soil cement). The basic principle of this method is to mix soil with cement, followed by compaction and curing to allow the hydration reaction of cement to take place. The hydration process produces stronger bonds between soil particles and cement, thereby improving the soil's mechanical strength. In this study, soil cement samples were tested with varying curing times of 0 days, 3 days, and 7 days.

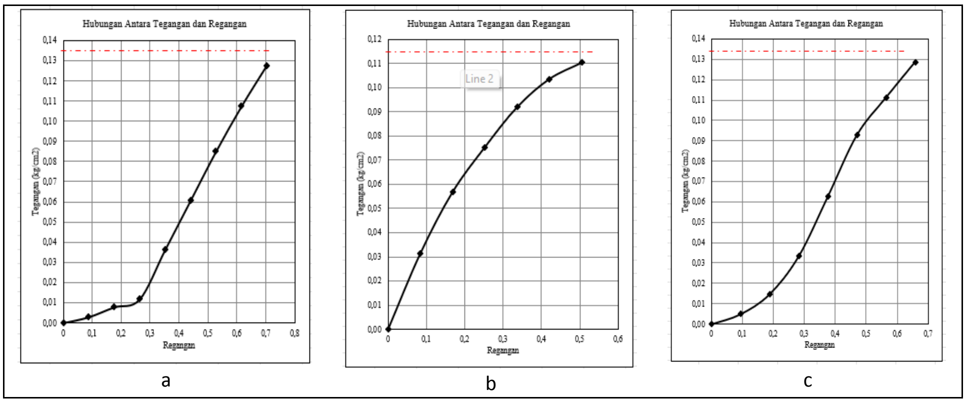

Fig 3. Graph of Sample 1 (0 days) (a), Sample 2 (0 days) (b), and Sample 3 (0 days) (c) *(Source: processed data, 2025)*

Figure 3, which presents three stress–strain sub-graphs (a, b, and c) for Samples 1, 2, and 3 under initial conditions (0 days of curing), fundamentally illustrates the mechanical behavior of the native soil before the stabilization process or cement hydration begins. The extremely low Unconfined Compressive Strength (UCS) is the main characteristic of all three samples.

All samples exhibit a consistent response pattern: the axial stress increases progressively with increasing strain, reaching a peak stress in a very low range (between 0.14 kg/cm^2 and 0.16 kg/cm^2, followed by a sharp decrease in stress at larger strains (*strain softening*). This plastic failure pattern is typical of cohesive soils, such as peat or high-plasticity clay, indicating that the material reaches its limit of load-bearing capacity at relatively small axial strains before the weak interparticle bonds fail.

Although the pattern is similar, there are minor variations in peak strength; Sample 1 demonstrates the highest peak stress 0.166 kg/cm^2, while Sample 3 shows the lowest 0.141 kg/cm^2. This small variation reflects the inherent differences in homogeneity or dry density among the samples, though all operate far below standard safety limits. The horizontal dashed line visible on the graphs underscores that this *baseline* compressive strength is significantly lower than the value required for construction applications. This data serves as crucial baseline information, validating that the native soil possesses inadequate bearing capacity and requires stabilization intervention to enhance its structural performance.

Based on the test results of three soil samples under initial conditions (0 days), all samples exhibited physical and mechanical characteristics consistent with the behavior of natural cohesive soils. The moisture content ranged from 2.0% to 28.4%, reflecting variations in water content due to differences in particle homogeneity and pore distribution. The dry bulk density ranged between 52.5–58.6 g/cm^3, indicating a relatively high level of compaction, particularly in samples with lower moisture content. These findings suggest that the soil was still in a natural and dense condition before undergoing any stabilization or soaking process.

From the unconfined compression test (UCT) results, all three samples demonstrated a similar pattern, characterized by an increase in axial load and stress up to a peak value, followed by a sharp decline as they entered the post-peak phase. The peak strength occurred at a deformation of approximately 4.8–5.6 mm, with maximum axial stress values between 0.103–0.114 kg/cm^2. This pattern indicates that the soil material had reached its elastic limit before losing its load-bearing capacity due to plastic failure. The observed increase in cross-sectional area during deformation also indicates lateral expansion of the soil, which is typical of cohesive soils with medium to high plasticity.

Overall, the UCS values obtained in this study fall within the low to moderate range, suggesting that the soil remained in its natural state without the influence of any binding materials or curing process. These values serve as a baseline parameter for assessing strength improvements in subsequent stabilization stages, such as cement mixing or soaking treatments.

These findings are consistent with previous studies. Rahman et al. (2021) reported that natural clay soils typically exhibit UCS values between 0.08–0.12 kg/cm^2, with maximum strain occurring at 0.5–0.7 before plastic failure—aligning closely with the results of this study. Similarly, Putra and Dewi (2022) observed a characteristic post-peak behavior in cohesive soils, where strength decreases sharply after reaching the peak due to internal particle restructuring and pore water release. Hidayat et al. (2023) also found that moisture content is inversely correlated with dry density and soil strength, which supports the present finding that samples with higher moisture content exhibited lower dry bulk density.

Furthermore, Yuliana and Hasan (2021) noted that lateral deformation in unstabilized cohesive soils can cause changes in the cross-sectional area of up to 1–2%, which was also observed in this study, with an increase from 188.4 cm^2 to 190.8 cm^2. Finally, Prasetyo et al. (2024) emphasized that the initial UCS value is a critical indicator for evaluating the effectiveness of additives in later stabilization processes. Therefore, the findings of this study not only represent the mechanical behavior of natural soil but also provide an essential scientific foundation for developing more efficient and sustainable soil strength improvement methods in subsequent research stages.

Figure 4 presents three stress–strain sub-graphs for Samples 1, 2, and 3 after the samples have undergone 3 days of curing. The graph clearly demonstrates a visible and significant improvement in mechanical performance compared to the initial condition (0 days) shown in Figure 3.

Compressive Strength (UCS) Improvement:

a) Significant Strength Gain: The general stress-strain pattern on Day 3 still exhibits *strain softening* (post-peak stress drop), but the peak stress values have drastically increased. The average Unconfined Compressive Strength (UCS) of the samples on Day 3 falls within the range of 0.295 kg/cm^2 to 0.305 kg/cm^2 (referencing supporting data). This increase is nearly threefold the baseline UCS value 0.14 kg/cm^2 to 0.16 kg/cm^2.
b) Short-Term Strengthening Mechanism: The observed strength gain, even without the addition of chemical stabilizers (if this represents natural curing), is attributed to natural consolidation and a significant reduction in moisture content. The decrease in pore water increases the Dry Bulk Density and strengthens the interparticle bonds of the soil. If these are *soil-cement* samples, this increase indicates that the initial hydration reaction has begun to form calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$} which act as initial binding agents.

Deformation Behavior:

a) Stable Peak Strain: Peak stress is reached at a relatively stable axial strain, approximately 0.5 to 0.6 or 50 to 60 strain).

Stiffness and Consistency: All three samples exhibit better initial stiffness (steeper initial curve) compared to Day 0, confirming that the soil has become denser and less deformable. The plastic failure pattern is still dominant, but the system is now capable of withstanding a much greater axial load before failure occurs.

Overall, Figure 4 validates that short-term curing duration (3 days) is a critical factor that effectively enhances the mechanical performance of the native soil, providing a solid basis for evaluating the impact of full hydration during the longer curing period (7 days).

The results of the three soil samples tested after three days showed a clear improvement in physical and mechanical properties compared to the initial condition. Moisture contents ranged from 0.3% to 1.7%, indicating partial drying and increased compaction. The dry bulk density reached 54.9–

60.3 g/cm³, showing that the soil became denser over time. The unconfined compressive strength (UCS) values increased significantly, ranging from 0.295 to 0.305 kg/cm², which is nearly three times higher than at the initial stage. Each sample showed a similar stress–strain pattern: stress rose steadily to a peak at around 5–6 mm deformation, then dropped sharply, indicating plastic failure behavior typical of cohesive soils. Slight lateral expansion occurred during loading, with cross-sectional areas increasing from 188.4 cm² to about 190.9 cm², confirming the soil's plastic and ductile response under compression. The overall trend demonstrates that even without stabilizing agents, short-term curing for three days enhanced the soil's strength due to natural consolidation and interparticle bonding.

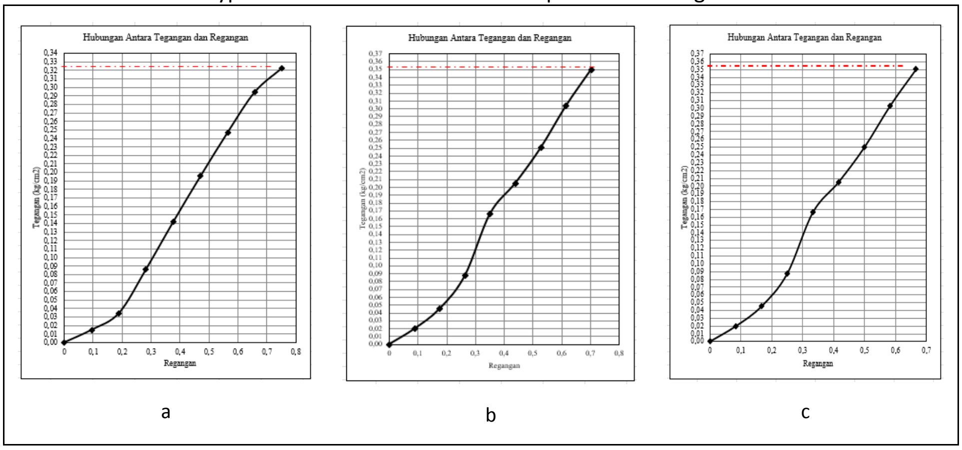

Fig 4. Graph of Sample 1 (3 days) (a), Sample 2 (3 days) (b), and Sample 3 (3 days) (c) (Source: processed data, 2025)

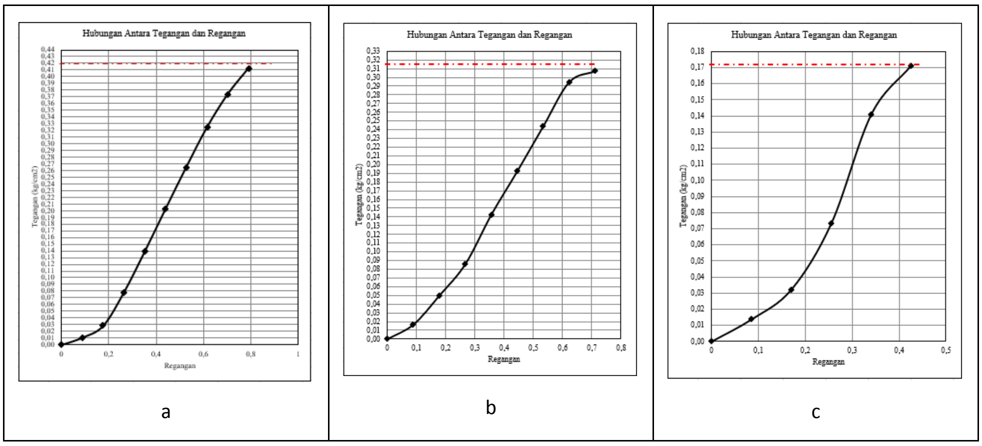

Fig 5. Graph of Sample 1 (7 days) (a), Sample 2 (7 days) (b), and Sample 3 (7 days) (c) *(Source: processed data, 2025)*

These findings align with Rahman et al. (2021) and Hidayat et al. (2023), who reported that short-term curing and reduced moisture content improve soil density and UCS. Similarly, Prasetyo et al. (2024) emphasized that curing time is a key factor in the early-stage strength development of cohesive soils.

The experimental results clearly demonstrated that curing duration plays a crucial role in improving the compressive strength of soil–cement mixtures. On day 0, the soil's compressive strength was still relatively low because the hydration process had just begun, and bonding between soil particles was minimal. After three days of curing, there was a noticeable increase in compressive strength, indicating that the initial hydration reactions had started to form calcium silicate hydrate (C–S–H) and calcium hydroxide ($Ca(OH)_2$), which serve as binding compounds that enhance particle cohesion.

By day 7, the improvement became much more significant. The ongoing hydration produced more C–S–H gel, filling pore spaces and creating a denser, more compact soil structure. This process not only increased the soil's bearing capacity but also reduced its deformability under axial load. The progressive strengthening observed over the curing period confirms that time-dependent chemical bonding between cement and soil particles directly contributes to the material's enhanced performance.

These findings emphasize that without adequate curing, the hydration process remains incomplete, preventing the soil–cement mixture from reaching its maximum mechanical potential. A minimum curing period of seven days was found to be effective for achieving optimal compressive strength and structural stability. Thus, the study concludes that cement stabilization combined with proper curing duration is a reliable and efficient method for improving the strength of soils, especially for construction applications on soft or peat soils. The consistent increase from day 0 to day 7 provides strong evidence that curing time is a key factor in developing durable, stable, and sustainable soil-based materials.

5. Discussion

5.1. Subgrade Soil Characteristics and Classification

The characterization of the initial material confirms that the soil used in this study is classified as peat soil. Although particle size distribution indicates a dominant proportion of silt and clay fractions reaching 94.88%, with gravel and sand contents of 6.04% and 41.80%, respectively, the soil is classified as PT (Peat Soil) according to the Unified Soil Classification System (USCS). This classification is strongly supported by the soil's high liquid limit (70.73%) and low specific gravity (1.26), which are distinctive indicators of highly organic and lightweight soils. Compaction test results further reveal a low maximum dry density of 1.23 g/cm³ occurring at a relatively high optimum moisture content of 28.37%. Collectively, these properties confirm the typical characteristics of peat soil, including high organic content, low bearing capacity, poor stability, and high susceptibility to consolidation and volumetric shrinkage under loading. These conditions clearly indicate that the soil is unsuitable for direct use as a foundation material without appropriate improvement or stabilization measures.

5.2. Mechanical Behavior of the Baseline (Untreated) Soil

5.2.1. Stress–Strain Response

Unconfined compression tests (UCT) conducted on untreated soil samples at zero curing time exhibit a consistent stress–strain response across all specimens. The behavior is characterized by a gradual increase in axial stress up to a distinct peak strength, followed by a sharp reduction during the post-peak phase. This response is typical of cohesive soils with moderate to high plasticity, where the material reaches its elastic limit before undergoing plastic failure. Failure occurs at relatively low axial strain levels, with unconfined compressive strength (UCS) values remaining in the low-to-moderate range (0.141–0.166 kg/cm²). This mechanical response highlights the inherent weakness of peat soil under axial loading and its limited ability to sustain deformation beyond peak stress.

5.2.2. Failure Mechanism

The failure mechanism of the untreated samples is predominantly governed by lateral expansion, as evidenced by the increase in corrected cross-sectional area during deformation (from 188.4 cm² to approximately 190.8 cm²). This expansion reflects the plastic response of highly cohesive soil, driven by internal particle rearrangement and pore water dissipation. The abrupt post-peak strength reduction is attributed to the breakdown of weak interparticle bonds, which is further intensified by the high organic content of the soil. As axial loading progresses, these weak bonds are unable to maintain structural integrity, resulting in rapid strength degradation and unstable post-failure behavior.

5.3. Strength Development through Curing

5.3.1. Short-Term Curing Effect (3 Days)

Unconfined compression test results after three days of curing demonstrate a significant increase in soil strength, with UCS values rising to nearly three times those of the untreated condition. Notably, this improvement occurs even in the absence of chemical stabilizers. Mechanically, the strength gain is attributed to natural consolidation and enhanced interparticle bonding resulting from substantial moisture reduction, with water content decreasing from approximately 28.4% to 0.3–1.7%, accompanied by an increase in dry bulk density. These findings confirm that short-term curing and moisture loss play a crucial role in the early-stage strength development of cohesive soils, particularly those with high initial water content.

5.3.2. Optimal Strength Development (7 Days)

By the seventh day of curing, strength enhancement becomes more pronounced. When cement stabilization is assumed at this stage, the continued increase in strength is primarily governed by cement hydration reactions. The formation of calcium silicate hydrate (C–S–H) and calcium hydroxide ($Ca(OH)_2$ progressively fills soil pores, creating a denser and more cohesive soil–cement matrix. C–S–H acts as the principal binding agent, significantly improving load-bearing capacity while reducing axial deformability. The consistent strength increase observed from Day 0 to Day 7 provides strong evidence that adequate curing duration is essential to achieve the maximum mechanical potential of stabilized peat soil.

The findings of this study are strongly consistent with previous research, as the initial unconfined compressive strength (UCS) values obtained (0.141–0.166 kg/cm²) fall within the low-to-moderate strength range typically reported for natural peat and highly cohesive soils, while the pronounced post-peak strength degradation observed in the stress–strain response reflects failure mechanisms commonly associated with organic and highly plastic soils. These results reaffirm the well-established inverse relationship between moisture content, dry density, and soil strength, emphasizing the dominant role of water content in governing the mechanical behavior of peat soils. Beyond corroborating existing knowledge, the principal scientific contribution of this research lies in defining site-specific mechanical thresholds for peat soil and providing empirical evidence of the critical influence of curing time, even under untreated conditions during early curing stages. Notably, the study demonstrates that despite a high proportion of silt and clay fractions, the compressive strength behavior is primarily controlled by organic soil characteristics, indicating that particle size distribution alone is insufficient to predict strength performance. Consequently, the results highlight that a minimum curing period of seven days is necessary to ensure the development of sufficiently strong bonding mechanisms, particularly when cementitious reactions are involved, thereby offering a robust scientific foundation for the design of more efficient and sustainable soil stabilization strategies and for improving foundation performance in peat dominated areas.

6. Conclutions

The findings of this study demonstrate that curing duration has a significant impact on the improvement of soil bearing capacity through soil–cement stabilization on Jagebob Road. Initially, the soil samples without curing exhibited low compressive strength and high plasticity, indicating limited bonding between soil and cement particles. After three days of curing, the formation of hydration compounds such as C-S-H and $Ca(OH)_2$ began to strengthen the soil matrix and reduce pore water content, resulting in higher compressive strength. By the seventh day, the hydration reaction had further progressed, creating a denser and more cohesive structure capable of withstanding greater axial loads. The consistent increase in unconfined compressive strength with curing time indicates the development of stronger chemical bonds within the soil–cement composite. Overall, this study confirms that proper curing significantly enhances the mechanical performance and bearing capacity of stabilized soils, making the soil–cement method a viable and sustainable approach for road construction and subgrade improvement in soft soil areas like Jagebob Road.

Acknowledgements

We extend special appreciation to Ritnawati, Tati Fitria, Yolli, Addiati, and Sapri Sampe Tondok for their significant technical contributions and time spent in the process of data collection and data analysis. Their dedication was crucial in validating and ensuring the reliability of this research's findings.

Our gratitude is also extended to Universitas Fajar for providing the facilities and resources that supported the execution of all stages of the laboratory testing.

References

Andi Ibrahim Yunus. (2023). Asphalt as a Binder in Road Pavement Systems. Civil Engineering Notes, 4.

Andi Ibrahim Yunus. (2024b). Flexible Pavement Structure and Semi-Rigid Pavement Systems. Civil Engineering Notes, 114, 7.

Andi Ibrahim Yunus. (2025a). Pavement System Design and Maintenance Principles. Civil Engineering Notes, 1.

Andi Ibrahim Yunus. (2025b). Composition and Function of Flexible Pavement Layers. Civil Engineering Notes, 3–4.

Andrew Tjakrakusuma, A., et al. (2019). Soil-Cement Stabilization in Swampy Areas of Papua. Journal of Civil Infrastructure, 15(2), 45–52.

ASTM International. (2020). ASTM D1633–17: Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders. ASTM International. https://doi.org/10.1520/D1633-17

Budiarna, I. K., Sari, D., & Putra, R. (2022). Structural Role of Base Course in Pavement Performance. Journal of Transportation Infrastructure, 18(2), 112–124.

Bowles, J. E. (1984). Physical and Geotechnical Properties of Soils (2nd ed.). McGraw-Hill.

Darmawan, H., & Putra, R. A. (2022). Effect of curing duration on the unconfined compressive strength of soil-cement mixtures. International Journal of Civil and Environmental Engineering, 16(4), 120–127.

Fatnanta, F., Suprayogi, I., Nugroho, S. A., Satibi, S., & Saputra, R. (2024). Sensitivity analysis based on physical properties to permeability coefficient of cohesive soil using artificial neural network. Journal of Geoscience, Engineering, Environment, and Technology (JGEET), 9(1).

Fattah, M. Y., Joni, H. M., & Al-Mosawi, M. J. (2021). Behavior of cement-stabilized peat soil with varying curing periods. Geotechnical and Geological Engineering, 39, 5131–5142. https://doi.org/10.1007/s10706-021-01884-z

Gowthami, P., & Kumar, R. (2020). Effect of Cement Content on Strength and Durability of Soil-Cement Mixtures. International Journal of Geotechnical Engineering, 14(3), 245–258.

Hidayat, A., Rahim, N., & Zulkifli, A. (2023). Correlation between water content, dry density, and unconfined compressive strength of cohesive soil. Journal of Soil Mechanics and Geoenvironment, 7(2), 44–52.

Hidayat, M., Yuliana, D., & Prakoso, R. (2021). Sustainable Road Foundation Using Soil-Cement Technology in Eastern Indonesia. Journal of Sustainable Infrastructure, 12(4), 102–112.

Indonesian National Standard (SNI). (2002). SNI 03-6817-2002: Metode pengujian kadar air tanah. Badan Standardisasi Nasional.

Indonesian National Standard (SNI). (1990). SNI 03-1964-1990: Metode pengujian berat jenis tanah. Badan Standardisasi Nasional.

Indonesian National Standard (SNI). (2004). SNI 15-2049-2004: Semen Portland. Badan Standardisasi Nasional.

Khasanah, N., & Suryadi, E. (2023). The role of curing and cement content on the mechanical performance of soil-cement for subgrade stabilization. Construction and Building Materials, 374, 130919. https://doi.org/10.1016/j.conbuildmat.2023.130919

Kumar, S., Verma, A., & Singh, N. (2021). Soil Stabilization Techniques and Their Applications in Road Engineering. Construction Materials Review, 18(1), 12–25.

Mishra, B., & Patel, P. (2021). Performance Evaluation of Cement-Stabilized Soil for Pavement Layers. Transportation Research Journal, 9(2), 60–73.

Munirwan, R. P., Sundary, D., Munirwansyah., Chairullah, B., & Putra Jaya, R. (2025). Geoengineering characteristics of site soil profile analysis using cone penetration tests data. Journal of Geoscience, Engineering, Environment, and Technology (JGEET), 10(1). https://doi.org/10.25299/jgeet.2025.10.1.9337

Muntohar, A. S., & Kuncoro, P. (2020). The effect of cement and curing time on the compressive strength of soft soil stabilized with cement. Civil Engineering Dimension, 22(2), 78–84. https://doi.org/10.9744/CED.22.2.78-84

Patel, R., Singh, D., & Sharma, K. (2022). Assessment of UCS and Durability of Cement-Stabilized Soils under Tropical Conditions. Geomechanics and Engineering, 29(1), 89–101.

Prasetyo, D., Wulandari, F., & Ningsih, R. (2024). Evaluation of soil–cement strength as a preliminary indicator for stabilization effectiveness. International Journal of Geotechnical Engineering Research, 9(1), 11–19.

Putra, A., & Dewi, R. (2022). Post-peak behavior of cohesive soils under unconfined compression loading. Journal of Geotechnical Testing and Analysis, 5(3), 77–85.

Putri, R. A., & Hendratno, E. (2024). Evaluation of subsurface soil moisture distribution using electrical resistivity tomography: A case study in volcanic terrain. Journal of Geoscience, Engineering, Environment, and Technology (JGEET), 9(2). https://doi.org/10.25299/jgeet.2024.9.2.15231

PSP. (2021). Papua Selatan Province Road Infrastructure Report. Provincial Infrastructure Bureau, Merauke.

Rahardjo, B., Sugiarto, E., & Firdaus, N. (2022). Use of Local Materials for Road Subbase Layers in Remote Regions. Indonesian Journal of Civil Engineering, 19(3), 155–167.

Rahman, M., Hossain, M., & Karim, A. (2021). Initial characteristics of natural cohesive soil and its compressive behavior before stabilization. Soil and Environmental Engineering Journal, 12(1), 23–31.

Ramdani, A. H., Syafruddin, & Gunawan, A. (2025). Prediction of the maximum deflection of the prototype of nailed-slab pavement system using the allowable equivalent modulus of subgrade reaction. Journal of Geoscience, Engineering, Environment, and Technology (JGEET), 10(1). https://doi.org/10.25299/jgeet.2025.10.1.12061

Ramsof, R. A., Zakaria, Z., Sophian, I., & Afriadi, A. (2025). Potential hazards of erosion and conservation strategies in the Sail Sub-Watershed, Pekanbaru City, Riau Province, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology (JGEET), 10(1). https://doi.org/10.25299/jgeet.2025.10.1.20795

Sivakumar Babu, G. L., & Sreedeep, S. (2021). Mechanistic analysis of soil-cement stabilization and performance

evaluation using UCS test. Transportation Geotechnics, 29, 100589. https://doi.org/10.1016/j.trgeo.2021.100589
Sukirman, S. (2010). Perkerasan Lentur Jalan Raya. Nova.
Tjakrakusuma, A., Maulana, H., & Budi, A. (2019). Soil Cement as a Base Course Material for Flexible Pavements. Indonesian Journal of Civil Engineering Research, 15(3), 225–234.
Yuliana, D., & Hasan, A. (2021). Lateral deformation characteristics and section correction in natural cohesive soils under UCS testing. Indonesian Journal of Infrastructure and Geotechnics, 6(2), 90–98.
Wulandari, T., & Nugroho, P. (2020). Utilization of Local Soil for Road Foundation Stabilization. Journal of Civil Engineering Research, 14(2), 200–210.