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Stabilization of lateritic soil using cement and lime for road construction

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Abstract: In developing countries, crushed rocks are mainly used in road subbase and base courses for road construction. As a result of extremely high fuel prices and lengthy travel times, particularly from Mokepalin, which is 92 miles from Yangon, the exorbitant costs of crushed rock aggregates for road building in Myanmar have therefore become a major concern. Due to energy consumption and carbon emissions, this dependence on remote sources results in increased building costs, project delays, and environmental destruction. In Yangon, local marginal materials (lateritic soil) are also available in Hmawbi, Hlegu, Taikkyi and Twantay townships. According to the engineering properties of soil in term of CBR, Hmawbi lateritic soil is nearly the same as the Mokepalin. Therefore, lateritic soil from Hmawbi was selected as a case study material for this research in order to reduce costs and to be more economical. To evaluate the engineering properties of soil, laboratory tests including sieve analysis, Atterberg limits, UCS, compaction, and CBR testing were carried out. The purpose of this paper is to stabilize lateritic soils for possible use as materials for road sub base and base to substitute crushed rocks. Results showed that 2% of cement and lime content met subbase course for Unconfined Compressive Strength (UCS) values of 0.75 MPa and 1.75 MPa according to Joint Departments of the Army and Air Force and 16% of cement satisfied for road base course for UCS value of 5.36 MPa. The use soil lime mixture was found to be unsuitable for road base course. Cement stabilized lateritic soil proved to be stronger, durable and better than soil lime mixture for road construction.

Keywords: Lateritic soil; CBR; UCS; Stabilization

1. Introduction

The construction of roads in developing nations sometimes meets major challenges, including large travel distances and increasing fuel expenses. These characteristics raise the cost of transportation, making the use of traditional resources, such as crushed rock, economically demanding. The need for extensive procedures and substantial energy use for crushed rock, typically sourced from distant quarries, increases construction costs and environmental impacts [1]. It has become important to come up with some alternatives that have the qualities similar to the currently used conventional materials [2]. The process of changing or maintaining one or more soil characteristics in order to enhance the soil's engineering qualities and performance is known as soil stabilization [2], [3], [4]. Engineers are very often faced with the problem of constructing road beds on or with soils which do not possess sufficient strength to support wheel loads imposed upon them either during construction or in the service life of pavement [5]. Challenges have been created while trying to construct roads with the uniform manual requirement of natural materials like lateritic soils. To remedy these constraints, some methods like soil enhancement have been tried, and cement and other additives are often used for soil stabilization [6]. The need to improve strength and durability of lateritic soil in recent times has become imperative, this has geared researchers towards using stabilizing materials that can be sourced locally at a very low cost [2]. By modifying the current soil qualities to satisfy design strength and durability, soil stabilization provides an economical alternative [3], [6].

Depending on the type of stabilizer, soil type, amount of stabilizer, and curing conditions, the stabilized soil's engineering qualities improved. A variety of additives and stabilizers, including cement, lime, silica fume (SF), fly ash (FA), rice husk ash (RHA), and ground granulated blast slag (GGBS), can be used to improve the properties of soil [7]. Soil stabilization is being used to construct the entire road in some parts of the world, usually in developing countries but increasingly in developed countries as well. There are two primary techniques for stabilizing soil [7]. There are two types of methods: mechanical and chemical. Currently, one or both of these stabilization techniques are used in every road construction project [8], [9], [10].

The additives which were studied in civil engineering research related to soil stabilization are categorized as traditional and non-traditional additives [11]. Since the development of soil stabilization technology in the 1960s, cement has been the most often used binding agent. Because it can be used alone to produce the necessary stabilizing action, it may be regarded as a primary stabilizing agent or hydraulic binder. The primary function of cement is its reaction with water, which can be present in any soil and is not dependent on soil minerals [9]. This may explain why a variety of soils are stabilized by cement. There are several different kinds of cement on the market, including high alumina cement, sulfate-resistant cement, blast furnace cement, and regular Portland cement. The type of soil to be treated and the required ultimate strength typically determine the cement selection [1], [12]. Lime stabilization represents the oldest form of stabilization [13].One of the economical approaches for soil stabilization is by using lime. Other than the cementation effect from the pozzolanic reaction, the modification due to lime describes an improvement in strength derived due to the cation exchange capacity [14]. Pozzolana minerals react with lime in the presence of water to form cementitious compounds, a process known as "lime stabilization" [10], [15]. In dry soils, where water may be necessary for efficient compaction, slurry lime can also be utilized [8].

A type of residual soil that is common in tropical nations is called lateritic soil [16]. Although laterite soil, which is abundant in tropical and subtropical regions and rich in iron and aluminum oxides, is often unsuitable for heavy building in its natural state because of its high compressibility and low bearing capacity [17]. Laterite soil are commonly used as road pavement materials to provide a better sub base, gravel for roads and base materials [18]. They are also good material for embankment construction. However, when it is in fine-grained form, it requires treatment for transportation infrastructure like road and railway subgrade and embankments [8], [14]. The main composition of lateritic is iron hydroxide, aluminum, and other metal oxides, especially those of manganese and titanium [19]. All laterite soils are identified by their red color, which is a severely used soil that contains secondary oxides of iron, aluminum, and manganese from heavy rainfall. Lateritic soil can vary in depth dep. Stated differently, a variety of factors, including the kind of mother rock, the amount of precipitation, and the rate of weathering, influence the depth of lateritic soil [17], [19].

Lateritic soil can be divided into coarse grain and fine grain. Most residual tropical lateritic soils have a large proportion of fine-grained soil particles, which contributes to their poor engineering qualities. As a result, tropical lateritic soils with fine grains are particularly vulnerable to atmospheric exposure. Marginal soils have been stabilized using a variety of soil stabilizers, both conventional and non-traditional. For instance, the soils have been stabilized using waste materials, lime and cement. However, the most often utilized soil stabilizers are cement and lime [20].

This study discusses a methodical approach to stabilization methods of lateritic soils for road construction in Myanmar and highlights the effects induced by cement and lime as stabilizing agents.

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Based on samples from five different borrow pits, engineering properties of stabilized lateritic soil were evaluated through empirical correlations and laboratory tests to present practical and applicable results for civil engineers and infrastructure planners. Whereas most of the past research had only generally described the stabilization process, this investigation was focused on specific geotechnical characteristics in iron- and aluminum-rich lateritic soil for its stabilization. Its novelty also involves a relative comparison of the effect of cement and lime treatment in the environment for the stabilization approach to enhancement and sustainability performance in pavement works. These results provide the replicable methodology that can be adopted by other tropical countries with rich deposits of laterite to ensure stability in the foundations of roads and cost-effective alternatives to conventional crushed rock. Finally, this study contributes to sustainable infrastructure development by addressing various challenges with lateritic soil, economic growth opportunities, and connectivity improvements in developing regions.

2. Material and methods

This research focuses on evaluating the stabilization of lateritic soils collected from five different borrow pits in Mokepalin, Hlegu, Hmawbi, Taikkyi, and Twantay. The study aims to identify a case study soil with better California Bearing Ratio (CBR) values compared to Mokepalin soil, subsequently stabilizing it using lime and cement. The findings will be discussed to highlight the effectiveness of the stabilization techniques and their suitability for sub-base applications. The research flow chart used in this study is shown in Figure 1.

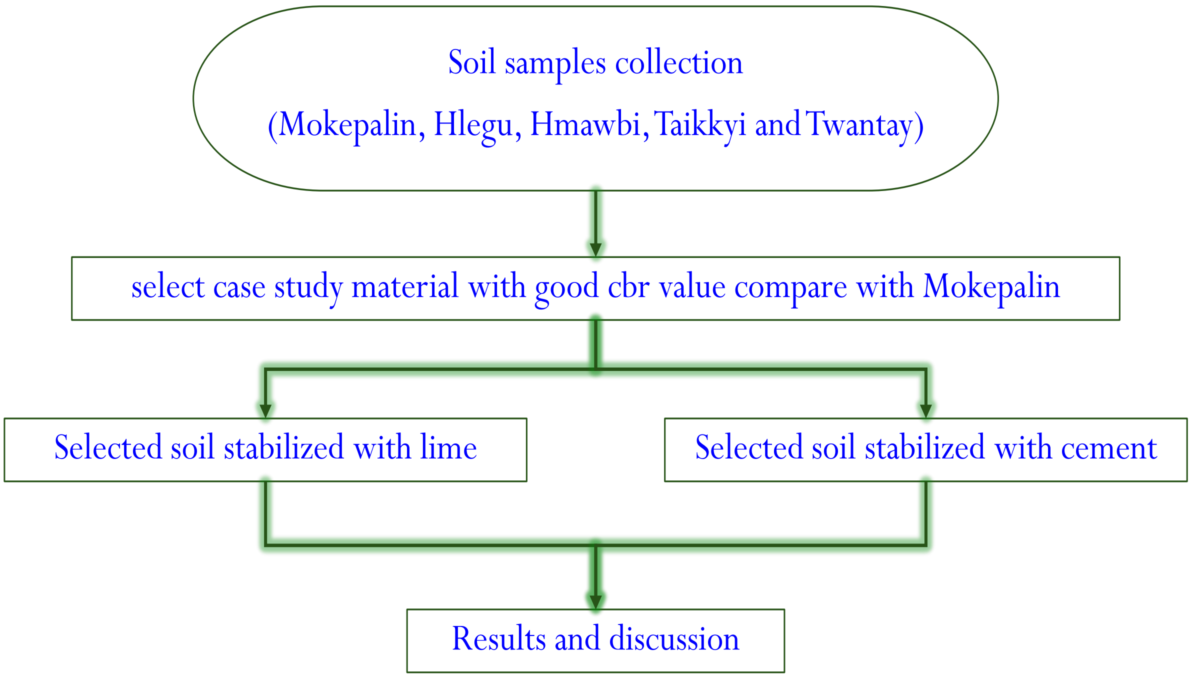

Figure 1. Research flow chart

2.1 Material

The soil in this study was collected from Mokepalin, Hlegu, Hmawbi, Taikkyi, and Twantay. In order to prevent organic topsoil, the soils were collected undisturbed from a depth of about 1 to 2 meters below the current level. Two stabilizers were used consisting of cement and lime.

2.2 Testing program

The testing program consisted of the following tests for unstabilized soil: grain size distribution (ASTM C136), Atterberg limits (ASTM D4318), modified proctor compaction test (ASTM D1557) and soaked CBR test (ASTM D1883). For stabilized soil, the tests included modified proctor compaction (ASTM D1557) and unconfined compressive strength test (ASTM D1633) are as follows.

2.2.1 Preparation of soil mixture

Stabilizers (cement and lime) were added in percentages of 2%, 4%, 6%, 8%, 10%, 12%, 14% and 16% of dry weight of soil respectively. A dry soil sample was mixed with the required amount of stabilizer. To get a uniform color, the stabilizer and soil were thoroughly mixed. Water was added as needed to facilitate the mixing and compaction process.

(a) (b)

Figure 2. Preparation of soil mixtures, (a) Preparation of soil-lime mixture and (b) Preparation of soil-cement mixture

2.2.2 Sieve analysis test

Sieve analysis per ASTM C136 refers to one of the key tests for finding the particle size gradation of a soil or aggregate sample; the result is essential in the classification of soils and for engineering uses. The basic procedure involves taking a representative oven-dried sample of soil and shaking it through a stack of ASTM-standard sieves whose mesh sizes range from 75 mm to 0.075 mm, for 10 to 15 minutes. After sieving, the mass of soil retained on each sieve and in the pan is recorded, and the percentage of material retained and passing through each sieve is calculated. Results are plotted on a grain size distribution curve from which much useful information on soil gradation and texture and suitability for engineering uses can be gleaned. This aspect becomes of particular significance for soil stabilization and pavement design, as particle size distribution influences characteristics such as compaction, permeability, and load-bearing capacity. Proper classification according to the grain size distribution of the soil will enable the engineers to establish the most effective stabilization technique.

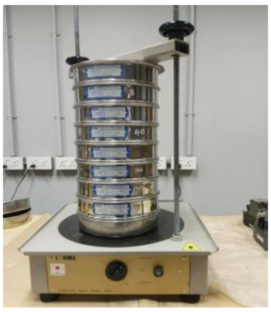

Figure 3. Sieve analysis test

2.2.3 Atterberg's limit test

The Atterberg limits tests for soil determine its plasticity characteristics, which include liquid limit, plastic limit and plasticity index. In the liquid limit test, a sample of soil is mixed with water to form a paste that is placed in a liquid limit device. A paste of the soil is laid in a groove and the gadget dropped repeatedly until the groove closes over some predetermined distance and the moisture content at that time is recorded. In the case of the plastic limit a sample of soil is rolled into a thread until it crumbles at a diameter of 3 mm and the moisture content recorded at this stage. The plasticity index is the difference between the liquid limit and plastic limit. The procedures for these tests follow the ASTM D4318. It helps to classify workability and behavior when subjected to different moisture contents, which is important to ascertain suitability for construction.

(a)

(b)

Figure 4. Atterberg's limit test, (a) Liquid limit test and (b) Plastic limit test

2.2.4 Compaction test

The stabilized soil samples were compacted using the modified Proctor method to determine the optimum moisture content (OMC) and maximum dry density (MDD) follows ASTM D1557. The optimum moisture content is used in preparing samples for UCS and CBR.

Figure 5. Compaction test

2.2.5 California bearing ratio (CBR) test

This test was conducted according to ASTM D1883. The CBR test, initially developed by the California State Highway Department in the United States, is a penetration test under both soaked and unsoaked conditions. This test is used in the bearing capacity evaluation of the test soil, such as subgrade, subbase and base soils for road pavement design. In this study, the tested samples are tested under soaked conditions to withstand environmental condition.

Figure 6. CBR test by using CBR machine

2.2.6 Unconfined compressive strength (UCS) test

The test was conducted using ASTM D1633 for untreated and treated soil samples. It is one of the most popular tests for assessing the strength of stabilized soil and determining the amount of additives for soil stabilization. All the samples are tested in a universal test machine with a loading rate of 0.85 mm/min so that the specimen could fail about 5-6 min before it finally breaks down. UCS specimens were prepared in cylindrical molds, cured for 7, 14, and 28 days in a controlled humidity environment before testing to evaluate strength gain over time. For UCS test, stabilized specimens were compacted, soaked for 2 hours to evaluate strength under wet conditions.

Figure 7. UCS test by soil sample

3. Results and discussion

A series of laboratory tests were conducted to evaluate how effective cement and lime stabilization are in the improvement of engineering properties of lateritic soil. Hence, the results of the compaction characteristics, sieve analysis test, and Unconfined Compressive Strength will be presented in this section. This shall provide insight on the performance of soil at different stabilizer contents. Results shall also be analyzed and compared to previous studies to show how well-stabilized lateritic soil could qualify for road construction applications.

3.1 Basic soil parameters of ifve borrow pits

The engineering properties of lateritic soil vary significantly depending on its source. This study focuses on the geotechnical characterization of lateritic soil obtained from five borrow pits location from Mokepalin, Hmawbi, Hlegu, Taikkyi, and Twantay. These includes fundamental soil properties such as grain size distribution, Atterberg limits, specific gravity, compaction characteristics, and California Bearing Ratio (CBR). These parameters are important for determining the suitability for pavement construction. The basic soil parameters of five borrow pits are compared and shown in the above Table 1.

Table 1. Basic soil parameter of five borrowed pits

Samples	Percent passing through sieve No. 200	Plasticity Index (PI)	OMC (%)	MDD (lb/cuft)	CBR (%)
Mokepalin	23.05	12.11	12.00	122.00	21.00
Hmawbi	32.98	15.01	15.43	115.25	18.28
Taikkyi	37.21	15.21	15.42	112.79	14.10
Hlegu	27.32	13.31	13.88	108.55	11.65
Twantay	47.02	18.08	18.91	108.87	10.40

The results indicate that lateritic soils with greater fines content and corresponding plasticity indices, Twantay and Taikkyi, tend to show higher optimum moisture contents of 18.91% and 15.42%, respectively, and maximum dry densities of 108.87 lb/cuft and 112.78 lb/cuft in that order. Moke Pa Lin lateritic soil with the highest CBR of 21.00%, serves as a reference due to its superior compaction and strength properties. Hmawbi lateritic soil is the one with relatively lower fines content of 32.98%, and a CBR value of 18.28%, nearly the same with Mokepalin lateritic soil. Therefore, Hmawbi lateritic soil was selected as a case study material in this research. These results are consistent with previous research that found lateritic soils with lower plasticity index and moderate fines content perform better mechanically. The detail engineering properties of Hmawbi lateritic soil are shown in the following Table 2.

Table 2. Engineering properties of Hmawbi lateritic soil

Properties	Value
Percent passing through sieve no. 200	32.98%
Liquid Limit	30.05%
Plastic Limit	15.04%
Plasticity Index	15.01%
Optimum Moisture Content	15.43%
Maximum Dry Density	115.25%
California Bearing Ration (4 days soaked)	18.28%
Unconfined Compressive Strength	0.88 MPa
AASHTO Classification	A-2-6

3.2 Sieve analysis test

The composition of the Hmawbi lateritic soil, with 28.4% being gravel, 38.62% being sand, and 32.94% being silt and clay is presented in Figure 8. Liquid limit, plastic limit, and plasticity index are recorded as 30.05%, 15.04%, and 15.01% from the Atterberg limit tests, respectively. The AASHTO classification of soil classified the soil into the group of A-2-6 and recommended the soil for subgrade applications. However, subbase and base courses will need further stabilization measures to meet the engineering requirements for their application. Stabilization with cement, lime, or other agents will probably be necessary to give it the added strength and durability. Improvements in compaction techniques and curing conditions may also be considered based on optimizing its performance in pavement structures. The UCS after stabilization would further be an indication of its suitability for higher-load applications. The addition of cement and lime would improve the engineering properties of the soil, which can be manifested in increased strength, reduced plasticity, and minimized moisture susceptibility.

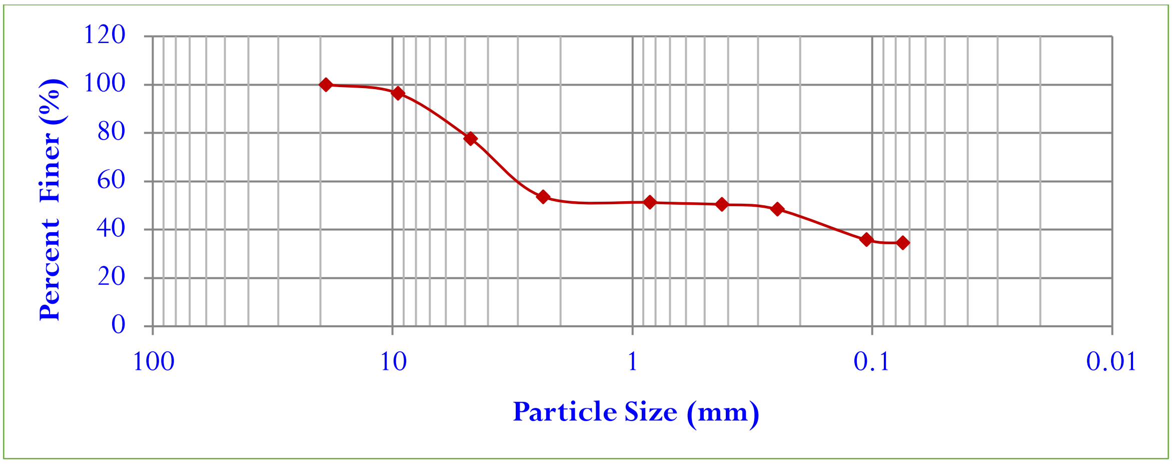

Figure 8. Grain size distribution curve of Hmawbi lateritic soil sample

3.3 Comparison of MDD of cement and lime content

The comparative analysis of the Maximum Dry Density (MDD) for lateritic soil stabilized with varying percentages of cement and lime is illustrated in Figure 9. The maximum dry density for cement stabilization shows a consistent upward trend, increasing from a 115 lb/ft³ at 0% cement content to near 123.5 lb/ft³ at 16%. The more cement content the denser the soil due to the improvement of bonding soil particles and thus reduction of voids in soil matrix. Conversely, the MDD for lime stabilization exhibits a decreasing trend. The MDD decreases from approximately 115 lb/ft³ at 0% lime content to around 105 lb/ft³ at 16% lime content. The reduction in MDD with increasing lime content due to the flocculation and agglomeration of soil particles which increases the void ratio and reduces the overall density of the compacted soil.

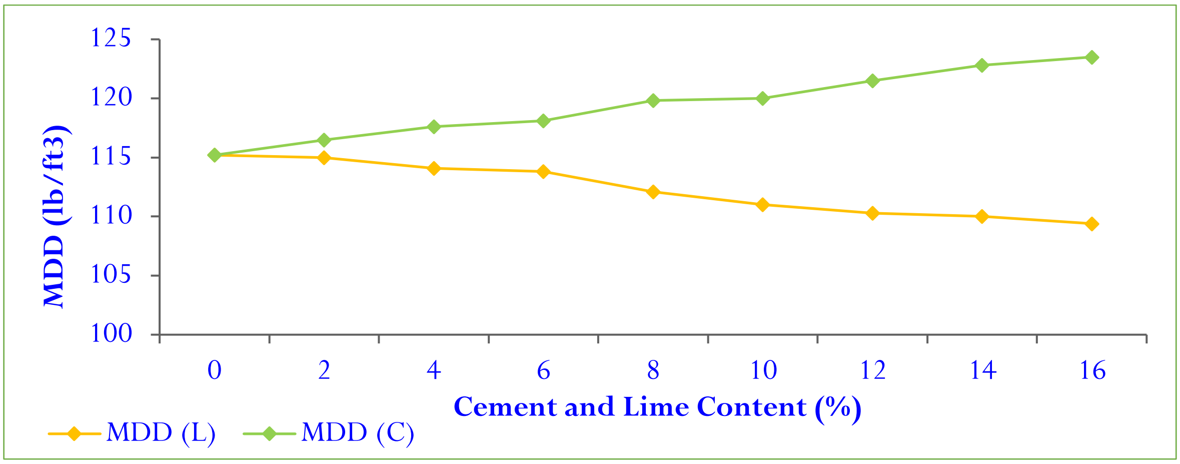

Figure 9. Comparison for MDD of cement and lime content

3.4 Comparison for OMC of cement and lime content

The comparative analysis of the Optimum Moisture Content (OMC) for lateritic soil stabilized with varying percentages of cement and lime is shown in Figure 10. For cement stabilization, the OMC shows a slightly increasing from approximately moisture 14% at 0% cement to 20% moisture content at 16% cement content. This gradual increase is due to the water required for the hydration process of cement and the coating of soil particles with cement paste, which needs more moisture for effective compaction. In the case of lime stabilization, the OMC also exhibits an increasing trend but at a slightly lower than cement stabilization. The OMC rises from 14% to 19% moisture content at 0% to 16% of lime content respectively. This is due to the moisture demand for the chemical reactions between lime and soil, such as cation exchange, flocculation, and pozzolanic reactions, which lead to a modified soil structure. The comparison reveals that the OMC values of cement slightly higher than lime stabilization at same amount of stabilizer contents. This is likely due to the higher hydration of cement compared to the pozzolanic and structural modification effects of lime.

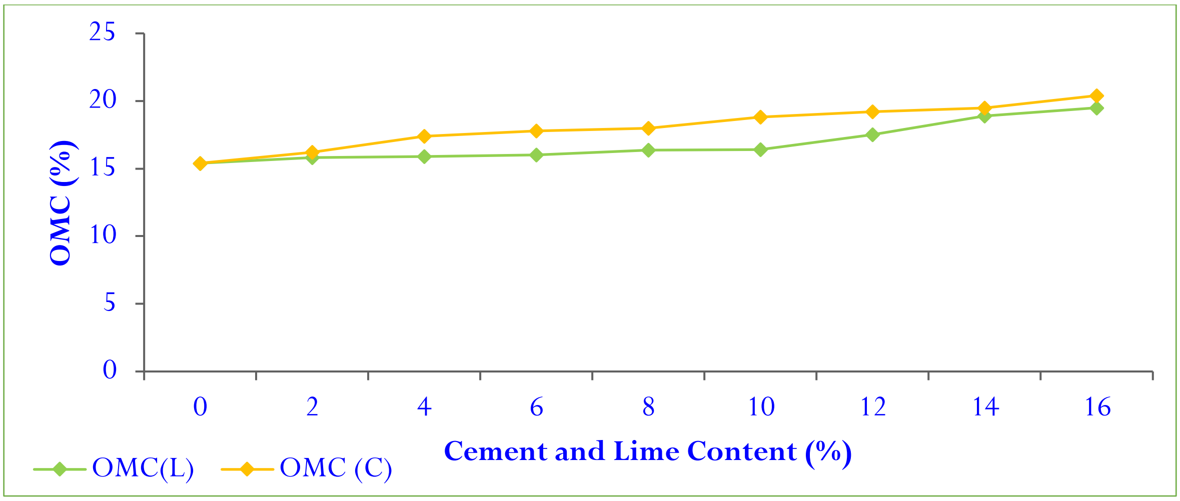

Figure 10. Comparison for OMC of cement and lime content

3.5 Comparison of UCS values of cement stabilized samples

The UCS values of cement-stabilized lateritic soil for varying cement contents at the curing periods of 7, 14, and 28 days are described in Figure 11. At 7 days of curing, the UCS values increase from 2.01 MPa at 2% cement to 3.01 MPa at 10% cement content. For 14 days curing period, the UCS value is 2.01 MPa at 2% cement content and 6.35 MPa at 16% cement content. The UCS strength at 14 days period is greater than 7 days curing period. For 28 days curing, the UCS values is 2.85 MPa and 7.12 MPa at cement content of 2% and 16%. According to the result, the more cement content and the longer curing period, the greater UCS strength.

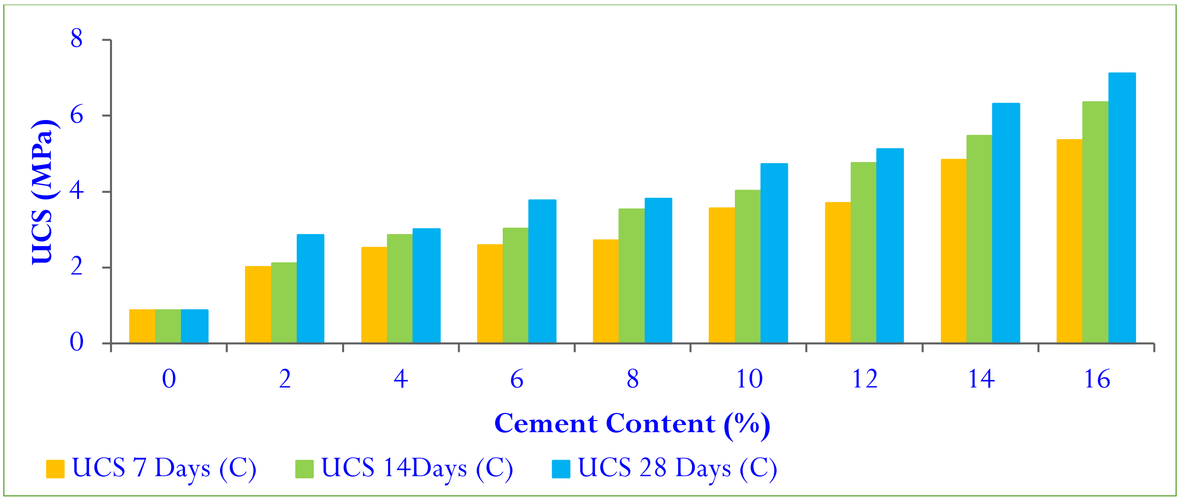

Figure 11. UCS values of cement stabilized test

3.6 Comparison of UCS values of lime stabilized samples

The UCS values of lime-stabilized lateritic soil for different lime contents at the curing times of 7, 14, and 28 days are represented in Figure 12. The UCS values rise from 0.91 MPa at 2% lime to 1.42 MPa at 10% lime after 7 days of curing. The UCS value is 1.41 MPa at 2% cement content and 1.68 MPa at 16% lime content for a 14-day curing time. The UCS value of 14 days strength is higher than the 7-day curing time. For 28 days curing, the UCS values is 1.82 MPa and 2.16 MPa at lime content of 2% and 16%. The results showed that UCS strength increased with lime content and cure period.

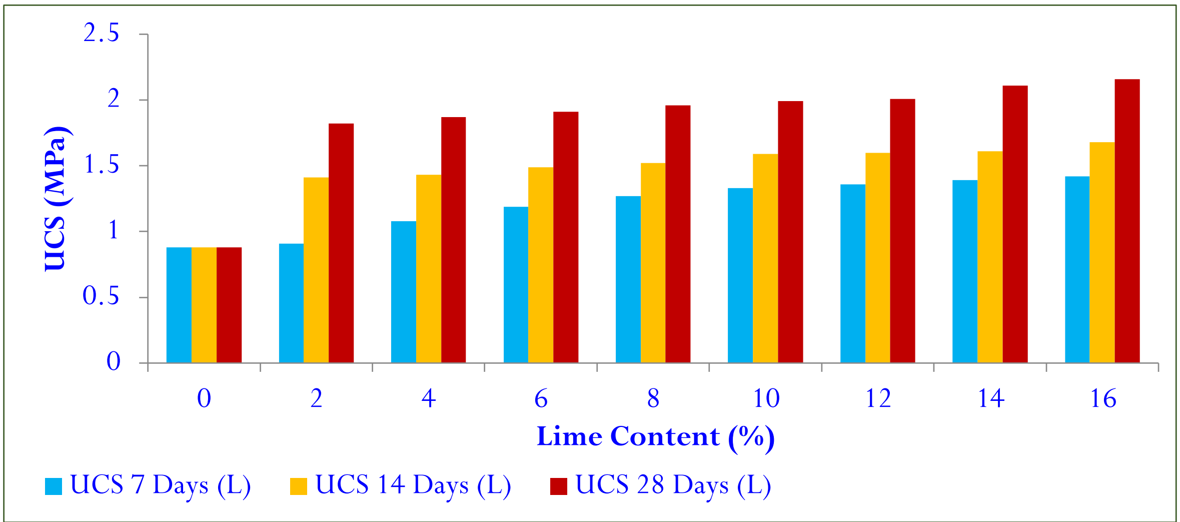

Figure 12. UCS values of lime stabilized test

3.7 Discussion

This study has interesting results confirming stabilization of lateritic soil with lime and cement to enhance its engineering properties for road construction. Before stabilization, the soil CBR value of 18.28% was approaching the value of Mokepalin soil, which is at 21% and hence catch good consideration for the alternative in pavement applications. After stabilization, cement showed a greater gain in strength. The UCS of cement-stabilized soil improved from 2.01 MPa (2% cement) to 7.12 MPa (16% cement) after an interval of 28 days, which was also found to be above the 5.36 MPa specified strength for road base materials. The further strengthening can be attributed to the growing calcium silicate hydrates (CSH) that reinforce the soil structure.

Lime stabilization showed slower strength development, with UCS finally reaching 2.16 MPa at 28 days with 16% lime. While evidence shows improvement at this strength level, the gain is still insufficient to comply with the base course requirements, indicating that lime would be more suitable for subbase layers rather than high-traffic road bases. The compaction results also showed a remarkable trend; the MDD slightly increased with cement while it decreased with lime. This means that cement fills void spaces thus increasing density, while lime causes flocculation resulting in loosening of soil structure.

In comparison with other studies [1] found that adding cement and sand greatly increased the strength of lateritic soil. However, according to the findings presented herein, cement alone would suffice without any aggregates. Likewise, [8] concluded lime stabilization was successful in treating Malaysian lateritic soil, but contrary to this study, the present investigation demonstrated that lime alone was insufficient to impart the required strength in Myanmar's lateritic soils for base layers. This difference accentuates the need to consider regional behavior and soil composition, as the performance of stabilization may vary according to location. In contrast to [2] investigated zeolite-activated lateritic soil stabilization, focusing on stabilizers that are not commonly available, whereas this research focuses on widely available materials that could be practically implemented in the road construction sector of Myanmar. These results indeed verify that cement stabilization is a cost effective alternative to crushed rock thus reducing infrastructure costs while improving road durability in Myanmar.

From the viewpoint of engineering, these results indicate that cement is the best stabilizer for lateritic soil, thereby qualifying it for base course use, while lime would be better utilized in low-traffic roads for subbase layers. This becomes an environmentally friendly and cost-effective alternative to imported crushed rock, thereby helping in reducing the cost of road construction with locally available materials. However, field studies and durability tests over time under real-world traffic conditions need to be further done so that full confirmation of the laboratory results can be done. The findings are directly applicable to Myanmar infrastructure development, particularly in reducing transportation costs associated with crushed rock from Mokepalin. Future research should concentrate on improving alternative stabilizers, including industrial by-products like fly ash and ground granulated blast furnace slag, to optimize their effectiveness in improving the strength, durability, and cost effectiveness of stabilized soils.

4. Conclusion

In this study, it was observed that 2% of lime can be used for road sub base according to the US Army and Air Force specification. Lime can be used only for road sub base construction in low volume roads. For soil cement mixture, cement content of 2% and 16% can be used both road sub base and base construction. It can be seen that cement is more effective than lime. It is possible to use lateritic soil for road construction stabilized with cement or lime. Therefore, upgrading and using lateritic soil should be considered as one of the feasible solution for road pavement construction.

Author's declaration

Author contribution

Htet Okkar Kyaw: Contributed to the conceptualization and methodological framework of the study. Conducted the experimental investigation, analyzed data, and played a key role in writing the manuscript. Participated in the reviewing and editing process to refine the final document. **Nyan Myint Kyaw**: Provided overall guidance and supervision for the research, including conceptualization, development of methodology, and project management. Led the review and editing process to ensure the quality and coherence of the manuscript.

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Conflict of interest

The authors declare that they have no competing interests or conflicts of interest related to this research, its findings, or its publication. There are no financial, professional, or personal affiliations that could have influenced the study, and all results are presented with integrity and objectivity.

Ethical clearance

This research does not involve humans as subjects.

AI statements

The authors have manually rechecked the accuracy and correctness of all content to ensure it aligns with the data and topic of this study. The authors take full responsibility for the content, accuracy, and language used in this article. None of the AI-generated sentences, figures, or tables are included without thorough review and verification.

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