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The Potentials of Lime Stabilization on the Engineering Properties of Lateritic Soil in Osun State, Nigeria.

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Abstract *Lateritic soils are widely used in civil engineering construction due to their abundance and availability; however, their engineering performance is often limited by high plasticity, low bearing capacity, and susceptibility to moisture variations. This study investigated the effect of lime stabilization on the engineering properties of lateritic soil for road construction applications. Laboratory tests were conducted on natural lateritic soil and soil treated with 1.5%, 3%, 4.5%, 6%, 7.5% and 9% lime. The tests performed included grain size distribution, Atterberg limits, compaction, and California Bearing Ratio (CBR) tests. The natural soil was classified as A-2-7 under the AASHTO classification system, with a liquid limit of 43.00%, plasticity index of 23.91%, maximum dry density of 18.65 kN/m³, and CBR value of 9.88%. The results showed that lime stabilization significantly improved the engineering properties of the soil. The plasticity index decreased from 23.91% to 12.74%, while the CBR value increased from 9.88% to 32.50% as the lime content was increased to 7.5%. Although the maximum dry density decreased slightly with increasing lime content, the soil exhibited improved strength, stability, and load-bearing capacity. The study concludes that lime is an effective stabilizing agent for lateritic soil and significantly enhances its suitability for highway subgrade construction. Among the lime contents investigated, 7.5% lime produced the best overall performance and it is therefore recommended for the stabilization of similar lateritic soils.*

Keywords *California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS), Calcium aluminate hydrate (CAH)*

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I. Introduction

Soil is one of the most essential natural materials used in civil engineering for the construction of roads, foundations, embankments, dams, and other infrastructural facilities. It serves as the primary support for structural loads, and its behavior directly influences the stability, safety, and longevity of any engineering structure [1]. Lateritic soil is one of the most widely distributed soil types in tropical and subtropical regions of the world, particularly in countries such as Nigeria, where climatic conditions favor its formation. It is a residual soil formed through prolonged and intense weathering of parent rock materials under conditions of high temperature and heavy rainfall. During laterization, rainwater percolates through the soil profile and dissolves soluble minerals, especially silica, which is then washed away from the soil mass. As silica is progressively removed, there is a relative accumulation of insoluble minerals, particularly iron and aluminum oxides. These oxides are responsible for the distinct reddish-brown, or sometimes yellowish coloration of lateritic soils. The high concentration of iron oxide (Fe_2O_3) not only gives the soil its characteristic color but also contributes to its hardening upon exposure to air [2].

Despite its wide availability and frequent use in construction, lateritic soil often exhibits poor engineering properties that limit its direct application in civil engineering works. One of the major challenges associated with lateritic soil is its relatively high plasticity, which is primarily due to the presence of fine clay particles. Despite their abundance, these soils often possess engineering limitations such as high plasticity, low strength when wet, and susceptibility to volume changes. These properties make them less suitable for direct use in construction without appropriate stabilization measures [3]. In addition, lateritic soils generally have low bearing capacity, particularly when they become saturated with water. The presence of moisture reduces the soil's shear strength and load-carrying ability, thereby increasing the risk of structural failure [4].

Generally, lateritic soils are often considered unsuitable for construction in their natural state. Therefore, it becomes necessary to improve their engineering properties through appropriate soil stabilization techniques before they can be effectively used in applications such as road construction and foundation works [5]. To overcome the challenges associated with weak and unsuitable soils, various soil stabilization techniques are employed to improve their engineering properties and make them fit for construction purposes. This process is essential in geotechnical engineering, as it enables the use of locally available materials that would otherwise be unsuitable, thereby reducing construction costs and improving project sustainability. Stabilization techniques can be broadly classified into mechanical and chemical methods. Mechanical stabilization involves physical processes such as compaction or blending soils of different gradations to achieve better particle distribution and improved strength. On the other hand, chemical stabilization involves the addition of stabilizing agents that react with the soil to bring about long-term improvements in its properties. These agents include cement, bitumen, fly ash, and lime, among others [6].

Lime stabilization is a widely used chemical method for improving the engineering properties of weak soils, particularly clayey and lateritic soils. It involves the addition of lime, either in the form of quicklime (calcium oxide, CaO) or hydrated lime (calcium hydroxide, $Ca(OH)_2$), to soil, which initiates a series of physicochemical reactions that significantly enhance soil performance. Over time, long-term reactions known as pozzolanic reactions take place, in which lime reacts with silica and alumina present in the soil to form cementitious compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds are responsible for the gradual increase in strength, stiffness, and durability of the stabilized soil [7]. The specific objectives of this study are to determine the natural engineering properties of lateritic soil obtained from the study area, evaluate the effects of varying percentages of lime on the geotechnical properties of the soil, assess the strength characteristics of the stabilized soil using laboratory tests such as the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS), and the determination of the optimum lime content required for maximum soil improvement.

II. Materials

The study area for this research is Onibueja area, along Iwo - Osogbo Road. Osogbo, the capital city of Osun State is located in the south- western region of Nigeria. Osogbo lies within the tropical rainforest zone and experiences a humid climate characterized by distinct wet and dry seasons. The wet season typically extends from April to October, while the dry season occurs between November and March. The area receives moderate to high annual rainfall, which significantly influences the weathering processes responsible for the formation of lateritic soils. The combination of high temperature and heavy rainfall promotes intense chemical weathering and leaching, leading to the development of soils rich in iron and aluminum oxides. The lateritic soil used in this study was obtained from a selected borrow pit within the study area. The site was carefully chosen based on the presence of representative lateritic soil commonly used for construction purposes in Osogbo and its surrounding areas. Consideration was also given to accessibility, uniformity of the soil, and absence of contamination. The environmental conditions of the site, including drainage patterns and vegetation cover, were noted as they influence the physical and engineering properties of the soil.

Soil samples were collected at a depth ranging from approximately 1.0m to 1.5m below the ground surface. This depth was selected to avoid the topsoil layer, which typically contains organic matter and other impurities that could affect the accuracy of laboratory test results. The collected samples were carefully placed in airtight, sealed bags to preserve their natural moisture content and prevent contamination during transportation. The samples were then transported to the geotechnical laboratory for preparation and subsequent testing.

2.1. Lateritic Soil

The primary material used in this study was lateritic soil obtained from the selected borrow pit within Osogbo, Osun State. The soil sample represents a typical lateritic deposit commonly used in construction activities in the region, however its engineering properties often require improvement through stabilization. The soil samples were transported, after collection, to the laboratory where they underwent a series of preparation to ensure uniformity and suitability for testing. Initially, the samples were air-dried at room temperature to remove natural moisture content without altering the soil's mineral composition. Air drying is preferred over oven drying for certain tests, as excessive heat may affect the natural properties of clay minerals present in the soil.

The soil was pulverized, after drying manually, using a wooden mallet to break down lumps and achieve a more uniform consistency. Care was taken to avoid crushing individual soil particles, particularly the coarse fractions, in order to maintain the natural gradation of the soil. The pulverized soil was then passed through a 4.75

mm sieve to remove larger particles such as gravel, roots, and other debris. This process ensured that the soil used for testing was free from impurities and met the requirements for standard laboratory procedures. The prepared soil sample was subsequently stored in airtight containers to prevent moisture variation prior to testing. This preparation process is essential for obtaining reliable and reproducible results during laboratory analysis, as it ensures that all tests are conducted on a representative and consistent sample. The physical and engineering properties of the prepared lateritic soil were then determined through a series of standard tests in accordance with established procedures. The representative sample is shown in Figure 1.

Figure 1. A Representative Sample of Raw Laterite

2.2. Lime

Lime was used as the primary stabilizing agent in this study due to its proven effectiveness in improving the engineering properties of fine-grained and lateritic soils. The lime utilized was in the form of either quicklime (calcium oxide, CaO) or hydrated lime (calcium hydroxide, $Ca(OH)_2$), both of which are commonly used in soil stabilization practices. These forms of lime are known for their high reactivity with clay minerals and their ability to initiate chemical processes that enhance soil strength and stability.

The lime was obtained from a reliable commercial supplier to ensure consistency in quality and composition. It was carefully handled and stored in airtight containers under dry conditions to prevent premature reaction with atmospheric moisture and carbon dioxide. Exposure to moisture can cause lime to hydrate or carbonate before use, thereby reducing its effectiveness as a stabilizing agent. Proper storage is therefore essential to maintain its chemical reactivity and ensure accurate experimental results.

In soil stabilization, lime serves as a chemical additive that reacts with the soil through a series of processes, including cation exchange, flocculation, and pozzolanic reactions. These reactions result in a reduction in plasticity, improvement in workability, and gradual development of strength over time. Lime also contributes to the formation of cementitious compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which bind soil particles together and enhance durability.

The quantity of lime used in this study was measured as a percentage of the dry weight of soil, with varying proportions (e.g. 0% 1.5%, 3%, 4.5%, 6%, 7.5% and 9%), used to determine the optimum lime content for stabilization. The selection of these percentages was based on standard practices in soil stabilization studies and previous research findings [8]. The lime was thoroughly mixed with the soil to ensure uniform distribution before the addition of water and subsequent testing. The representative sample of the lime is shown in Figure 2.

Figure 2. Lime (Stabilizing Agent)

2.3. Water

Clean potable water was used throughout this study for the preparation, mixing, and testing of both natural and lime-stabilized soil samples. This is done to ensure that results obtained are not adversely affected by impurities such as salts, organic matter, or chemical contaminants that may be present in non-potable water sources. Such impurities can interfere with soil behavior and alter the chemical reactions involved in stabilization processes.

Water plays a crucial role in soil stabilization, particularly in lime-treated soils, as it facilitates the chemical reactions between the lime and the soil particles. The presence of adequate moisture is necessary for the hydration of quicklime and for the initiation of cation exchange and pozzolanic reactions. These reactions contribute to the formation of cementitious compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are responsible for the improvement in strength and durability of the stabilized soil.

In addition, water is required to achieve proper compaction of soil during laboratory testing. The moisture content of the soil significantly influences its compaction characteristics, particularly the optimum moisture content (OMC) at which maximum dry density (MDD) is achieved. Adequate water content helps to lubricate soil particles, allowing them to rearrange into a denser configuration under compactive effort. Insufficient or excessive moisture can lead to poor compaction and unreliable test results. Therefore, careful control of water content was maintained throughout the experimental process to ensure consistency and accuracy in the results. The quantity of water added to each soil-lime mixture was determined based on standard procedures and compaction requirements.

III. Method

The collected lateritic soil samples were first air-dried at room temperature to remove excess natural moisture. Air drying was carefully carried out to avoid altering the soil's natural structure and mineral composition, which could occur if oven drying at high temperatures were used. After drying, the soil was pulverized manually using a wooden mallet to break down lumps and obtain a more homogeneous sample. The pulverized soil was then passed through a 4.75 mm sieve, in accordance with standard testing procedures, to remove gravel-sized particles, roots, and other unwanted debris. This process ensured that the soil sample used for testing was clean, uniform, and suitable for laboratory analysis.

For the stabilization process, the prepared soil was divided into portions and mixed with varying percentages of lime, typically 0% 1.5%, 3%, 4.5%, 6%, 7.5% and 9% by weight of dry soil. These proportions were selected based on common practice in soil stabilization studies to determine the optimum lime content required for maximum improvement in soil properties. Each soil-lime mixture was prepared by first thoroughly blending the dry soil with the measured quantity of lime to achieve uniform distribution of the stabilizing agent. Subsequently, the required amount of water was added gradually to each mixture to attain the desired moisture content, usually close to the optimum moisture content (OMC) obtained from compaction tests. After the addition of water, the mixtures were thoroughly mixed and kneaded to ensure complete and uniform interaction between the soil, lime, and water.

In some cases, the prepared mixtures were allowed to mellow (rest) for a short period before compaction to facilitate initial reactions such as hydration and cation exchange. The properly prepared samples were then used for various laboratory tests to evaluate the effect of lime stabilization on the engineering properties of the lateritic soil. All preparation procedures were carried out in accordance with standard practices to ensure consistency and accuracy of results.

3.1. Laboratory Test on Natural Soil

The natural (untreated) soil samples collected from the study area were subjected to a series of laboratory tests to determine their fundamental engineering properties. These properties are essential for evaluating the soil's suitability for construction purposes, particularly in pavement and foundation design. The moisture content test was carried out to determine the amount of water present in the soil sample, expressed as a percentage of the dry weight of the soil. This parameter is crucial because it significantly influences the soil's strength, consistency, and compaction characteristics. The test was performed by weighing a wet soil sample, oven-drying it at a standard temperature (usually 105ºC–110°C) for 24 hours, and then reweighing it to determine the loss in weight, which corresponds to the water content.

The Atterberg limits tests were conducted to evaluate the consistency and plasticity characteristics of the soil, which are important for classification and predicting soil behavior under varying moisture conditions. The tests include Liquid limit, Plastic limit, and Shrinkage limit. The compaction test, commonly known as the Proctor test, was conducted to determine the relationship between moisture content and dry density of the soil. The primary objectives of this test are to establish the Optimum Moisture Content (OMC), at which the soil achieves its Maximum Dry Density (MDD). These parameters are vital for ensuring proper compaction in the field, which enhances the strength and stability of the soil when used as a construction material [9]. The test was performed by compacting soil at varying moisture contents using a standard compactive effort.

The California Bearing Ratio (CBR) test was carried out to evaluate the strength and load-bearing capacity of the natural soil. This test is particularly important in road construction, as it helps determine the suitability of the soil as a subgrade material. The test involves measuring the resistance of the soil to penetration under controlled conditions and comparing it to that of a standard crushed rock material. The resulting CBR value provides a basis for pavement thickness design and overall structural performance. The CBR machine used for the test is shown in Figure 3.

Figure 3. CBR Machine

3.2. Stabilization Procedure

The stabilization of the lateritic soil was carried out using lime as an admixture to improve its engineering properties. Different proportions of lime were used to evaluate the effect of lime content on the performance of the soil. The percentages of lime adopted for this study were 0% 1.5%, 3%, 4.5%, 6%, 7.5% and 9% by dry weight of the soil. The required quantity of lime for each mix proportion was carefully measured based on the dry weight of the soil. The dry soil and lime were then thoroughly mixed until a uniform blend was achieved, ensuring even distribution of the stabilizing agent throughout the soil matrix.

After dry mixing, a calculated amount of water was gradually added to each mixture to bring the moisture content close to the Optimum Moisture Content (OMC) previously determined from the compaction test. The mixing process was continued until a homogeneous and workable consistency was obtained. Care was taken to avoid loss of moisture and ensure proper blending. The prepared mixtures were then compacted using the appropriate compactive effort (standard or modified Proctor, depending on the test requirement) to achieve the Maximum Dry Density (MDD). Compaction was carried out in molds corresponding to the specific laboratory tests to be performed, such as California Bearing Ratio (CBR) molds.

The specimens were carefully extruded after compaction and sealed to prevent moisture loss. They were then subjected to curing for specified periods, typically 7, 14, and 28 days. The curing process was conducted under controlled conditions to facilitate the chemical reactions between the lime and the soil minerals. During curing, pozzolanic reactions occur between the calcium from the lime and the silica and alumina present in the soil, leading to the formation of cementitious compounds [7]. These reactions are responsible for improving the strength, stiffness, and durability of the stabilized soil. At the end of each curing period, the specimens were removed and tested to evaluate the improvement in engineering properties resulting from lime stabilization.

3.3. Laboratory Tests on Stabilized soil

To evaluate the effect of lime stabilization on the engineering properties of the lateritic soil, a series of laboratory tests were conducted on the treated samples. These tests were essentially the same as those performed on the natural (untreated) soil, allowing for direct comparison and assessment of improvements resulting from the addition of lime. The Atterberg limits tests were repeated on the stabilized soil samples to determine changes in consistency and plasticity characteristics due to lime treatment. The parameters evaluated were the same for the natural soil.

Addition of lime typically reduces the plasticity of the soil by decreasing the liquid limit and increasing the plastic limit, thereby lowering the plasticity index [10, 11]. This reduction indicates improved workability and decreased susceptibility to shrinkage and swelling. These tests were conducted in accordance with standard procedures after allowing the soil-lime mixtures to equilibrate for a short period. Compaction tests were carried out on each soil-lime mixture to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). These parameters are essential for understanding how the addition of lime affects the compaction characteristics of the soil. Typically, the inclusion of lime results in an increase in OMC and a decrease in MDD due to flocculation and agglomeration of soil particles [12, 13, 14]. The tests were performed using the standard Proctor method, and the results were used to establish appropriate compaction conditions for field application of the stabilized soil.

The California Bearing Ratio (CBR) test was conducted on the stabilized soil samples to assess the improvement in strength and load-bearing capacity. The test was performed on specimens compacted at their respective OMC and MDD values. In many cases, both soaked and unsoaked CBR tests were carried out to simulate field conditions, particularly for road subgrades exposed to moisture. Lime stabilization generally leads to a significant increase in CBR values, indicating enhanced suitability of the soil for pavement construction. The results were compared with those of the natural soil to quantify the degree of improvement.

The data obtained from the laboratory tests were systematically analyzed to evaluate the effect of lime stabilization on the engineering properties of the lateritic soil. The results were presented in the form of tables, graphs, and charts to enhance clarity, facilitate interpretation, and enable meaningful comparisons between untreated and treated soil samples. Descriptive statistical methods were employed to summarize the test results, while graphical representations were used to illustrate trends and relationships between variables such as lime content, moisture content, and strength parameters. The properties of the natural soil were compared directly with those of the stabilized soil at varying lime contents (0%, 1.5%, 3%, 4.5%, 6%, 7.5%, 9%) and curing periods where applicable. The key aspects of the analysis are outlined below:

The California Bearing Ratio (CBR) values obtained for each soil-lime mixture were plotted against the corresponding lime content. This analysis was used to assess the improvement in loadbearing capacity of the soil due to stabilization. Both soaked and unsoaked CBR results, where available, were compared to evaluate performance under different moisture conditions. An increase in CBR values with increasing lime content typically indicates enhanced soil strength and suitability for subgrade applications.

The Plasticity Index (PI) values were analyzed to determine the effect of lime on the soil's plasticity characteristics. Graphs were plotted showing the relationship between PI and lime content. A reduction in PI with increasing lime content reflects improved soil workability and reduced potential for shrinkage and swelling. This parameter is particularly important for assessing the suitability of the soil for construction purposes.

The results of the compaction tests were analyzed by plotting MDD and OMC against lime content. This analysis helps in understanding how lime affects the compaction behavior of the soil. Typically, the addition of lime leads to a decrease in MDD and an increase in OMC due to particle flocculation and changes in soil structure. These trends were carefully evaluated to determine appropriate field compaction requirements. The optimum lime content was determined based on a comprehensive evaluation of all test results, particularly strength parameters such as CBR (and UCS where available), as well as improvements in plasticity and compaction characteristics. The lime content corresponding to the maximum improvement in strength, acceptable plasticity, and favorable compaction properties was selected as the optimum.

In addition, practical considerations such as economic efficiency and ease of application were also taken into account when selecting the optimum lime content. The chosen value represents the most effective proportion of lime that achieves significant improvement in soil performance without unnecessary material usage.

IV. Results and Discussion.

The results obtained from the laboratory tests conducted on both natural and lime-stabilized lateritic soil samples are presented and discussed with reference to the mechanisms of lime stabilization, such as cation exchange, flocculation, and pozzolanic reactions. The findings are also compared with standard highway requirements and previous studies to determine the suitability of the stabilized soil for engineering applications. The engineering properties of natural lateritic soil is presented in Table 1.

Table 1. Engineering Properties of Natural Lateritic Soil

Properties	Values
Grain Size Distribution Coarse (%) Fine (%) Bulk density (KN/m^3)	 90.85 09.15 14.64–29.76
Consistency Limit (%) Liquid Limit Plastic Limit Plasticity Index	 43.00 19.09 23.91
Maximum Dry Density (KN/m^3)	18.65
Optimum Moisture Content (%)	9.15
California Bearing Ratio (%)	9.88
Soil Classification	A-2-7

The grain size distribution indicates that the soil consists predominantly of coarse particles (90.85%) with a relatively low percentage of fines (9.15%), suggesting good drainage characteristics. The bulk density ranges from 14.64 to 29.76 kN/m³, indicating moderate to high compaction potential.

The consistency limits show a liquid limit of 43.00%, plastic limit of 19.09%, and plasticity index of 23.91%, which indicate that the soil possesses moderate plasticity and may exhibit some volume change with variations in moisture content. The maximum dry density of 18.65 kN/m³ and optimum moisture content of 9.15% reflect the moisture condition at which the soil attains its maximum compaction. The California Bearing Ratio (CBR) value of 9.88% indicates relatively low bearing capacity in its natural state, suggesting that the soil may require stabilization before being used as a pavement subgrade or foundation material for engineering works. According to the AASHTO classification system, the soil is classified as A-2-7, which corresponds to a granular soil containing silty or clayey fines with fair to poor subgrade performance. Therefore, the natural lateritic soil exhibits moderate engineering properties but may benefit from stabilization to improve its strength and load-bearing characteristics.

The particle size distribution test was carried out to determine the proportions of gravel, sand, silt, and clay particles present in the soil. The grading curve showed that the soil contained a significant percentage of fine particles passing the No. 200 sieve. According to standard soil classification systems, the soil can be classified as silty-clayey lateritic soil. The dominance of fine particles explains the relatively high plasticity characteristics observed during Atterberg limit testing. Fine-grained soils generally exhibit higher water absorption capacity and lower strength when wet. The result further indicates that stabilization is necessary to improve the soil's engineering performance before its use in pavement construction.

The moisture content characteristics of the natural lateritic soil were evaluated through compaction testing. As presented in Table 1, the soil exhibited an Optimum Moisture Content (OMC) of 9.15%. This value represents the moisture level at which the soil attains its Maximum Dry Density (MDD) of 18.65 kN/m³ under a given compactive effort. The relatively low OMC indicates that the soil requires a small amount of water to achieve effective compaction. This suggests that the soil contains a high proportion of coarse-grained particles, as confirmed by the grain size distribution results, which show 90.85% coarse materials and only 9.15% fines. Coarse-grained soils generally require less water for lubrication between particles during compaction compared to fine-grained soils.

The moisture content plays a significant role in determining the engineering performance of the soil. At moisture contents below the OMC, inadequate water reduces particle lubrication, resulting in lower compaction efficiency. Conversely, moisture contents above the OMC may lead to excess pore water, reducing soil strength and stability. Therefore, maintaining the moisture content close to the optimum value of 9.15% is essential for achieving maximum compaction, improved load-bearing capacity, and enhanced performance of the soil in engineering applications. Therefore, the OMC value obtained indicates that the natural lateritic soil can be compacted effectively with relatively low water demand, making it suitable for construction purposes when properly compacted and moisture-controlled.

The graphical illustration chart for Atterberg Limit test (0% 1.5%, 3%, 4.5%, 6%, 7.5% and 9%) is presented in Figure 4.

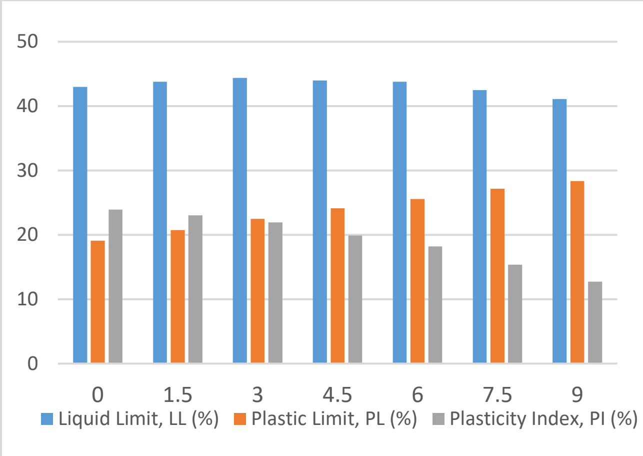

Figure 4. Chart for Atterberg Limit test.

The results obtained showed a Liquid Limit (LL) of 43.00%, a Plastic Limit (PL) of 19.09%, and a Plasticity Index (PI) of 23.91%. The liquid limit represents the moisture content at which the soil changes from a plastic state to a liquid state, while the plastic limit indicates the moisture content at which the soil changes from a semi-solid state to a plastic state. The plasticity index, which is the difference between the liquid limit and plastic limit, reflects the range of moisture contents over which the soil remains plastic. The liquid limit value of 43.00% indicates that the soil has a moderate capacity to retain water before reaching a liquid state. The plastic limit of 19.09% suggests that the soil begins to exhibit plastic behavior at relatively low moisture contents. The plasticity index of 23.91% indicates moderate plasticity, implying that the soil contains a considerable amount of clayey material and may undergo moderate volume changes with fluctuations in moisture content.

The Atterberg limits results suggest that the natural lateritic soil possesses moderate cohesion and plasticity characteristics. Such soils generally exhibit satisfactory engineering behavior when properly compacted; however, excessive moisture may lead to reduced strength and increased compressibility. The moderate plasticity of the soil also indicates a moderate potential for shrinkage and swelling, which should be considered in construction and pavement design applications. Therefore, the Atterberg limits analysis shows that the natural lateritic soil falls within the category of moderately plastic soils and possesses engineering properties suitable for various geotechnical applications, although stabilization may be required where higher strength and durability are desired.

The compaction characteristics of the natural and lime-treated lateritic soil were evaluated by determining the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) at varying lime contents of (0% 1.5%, 3%, 4.5%, 6%, 7.5% and 9%). The results indicate that the addition of lime significantly influenced the compaction behavior of the soil.

The graphical representation chart for the compaction test is presented in Figure 5.

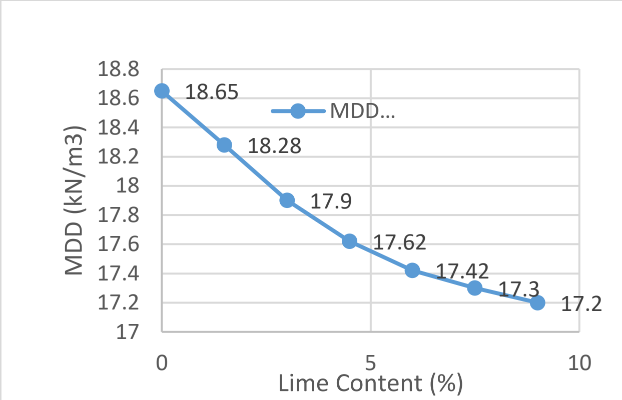

Figure 5. Chart for Compaction test.

The natural soil (0% lime) recorded a Maximum Dry Density (MDD) of 18.65 kN/m³ and an Optimum Moisture Content (OMC) of 9.50%. As 3% lime was added, the MDD decreased to 17.90 kN/m³ while the OMC increased substantially to 21.60%. This increase in moisture requirement may be attributed to the hydration of lime and the initiation of cation exchange reactions between the lime and clay minerals in the soil. At 7.5% lime content, the MDD further decreased to 17.30kN/m³ while the OMC increased to 26.40%, indicating that more water was required to facilitate the flocculation and agglomeration of soil particles. The increased moisture demand is associated with the pozzolanic reactions occurring within the soil-lime mixture.

Further increase in lime content at 9%, the MDD reduced slightly to 17.20kN/m³, while the OMC decreased to 21.75%. This suggests that the soil-lime system had begun to stabilize, requiring less moisture than at 6% lime content [15]. The reduction in dry density is consistent with the replacement of heavier soil particles by lighter lime particles and the formation of larger aggregated soil structures. At 9% lime content, the lowest MDD of 17.20 kN/m³ was recorded, while the OMC decreased further to 21.75%. The continued decrease in MDD may be attributed to the lower specific gravity of lime compared to the soil particles. The reduction in OMC beyond 6% lime content indicates that sufficient lime was available to complete most of the hydration and pozzolanic reactions, thereby reducing the additional moisture requirement.

Therefore, the results show that increasing lime content generally decreases the Maximum Dry Density and increases the Optimum moisture content of the soil, particularly at lower lime percentages. These changes are attributed to flocculation, agglomeration, hydration, and pozzolanic reactions between the lime and soil particles. The findings indicate that lime treatment modifies the soil structure and improves its engineering properties, making it more suitable for use in road construction and other geotechnical applications.

The California Bearing Ratio (CBR) test was conducted to evaluate the load-bearing capacity and strength characteristics of the soil samples treated with different percentages of lime. The CBR value is an important parameter used in the design of pavement subgrades, where higher CBR values indicate better resistance to penetration and improved load-carrying capacity. The CBR for the natural and treated soil is presented in Table 4.

The graphical illustration for the natural and treated soil at specified percentages is presented in Figure 6.

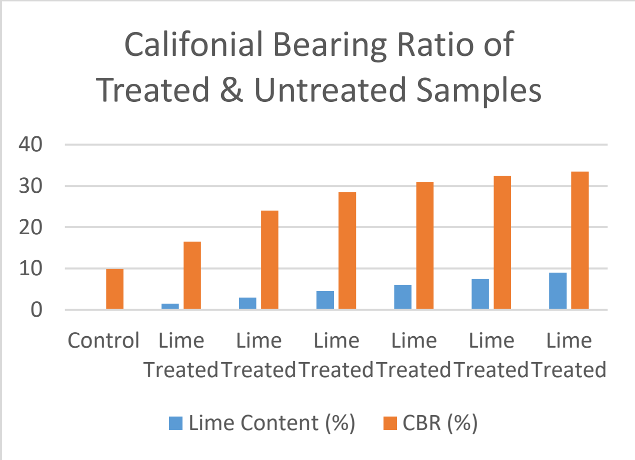

Figure 6. California Bearing Ratio Chart

The untreated (control) soil recorded a CBR value of 9.88%, indicating relatively low bearing strength. The CBR values increased significantly when lime was added. The soil treated with 1.5% lime achieved a CBR value of 16.50%, while the estimated values for 3% and 4.5% lime treatment were 24.00% and 28.50%, respectively. The highest CBR value of 33.50% was obtained at 9% lime content. The progressive increase in CBR values with increasing lime content demonstrates the effectiveness of lime stabilization in improving the soil strength [16]. Lime treatment promotes pozzolanic reactions between lime and clay minerals, resulting in the formation of cementitious compounds that enhance soil stiffness and bearing capacity [17]. Therefore, the stabilized soil exhibits better engineering properties and is more suitable for use as a pavement subgrade material compared to the untreated soil.

V. Conclusions

Based on the laboratory investigations carried out on the natural and lime-stabilized lateritic soil samples, the following conclusions can be drawn:

1. The natural lateritic soil possesses moderate engineering properties but exhibits relatively high plasticity and low bearing capacity, which may limit its direct use as a pavement subgrade material without improvement.
2. Lime stabilization significantly improved the consistency characteristics of the soil. The plasticity index decreased from 23.91% to 12.74% as lime content increased from 0% to 7.5%, indicating a substantial reduction in plasticity and moisture susceptibility. The addition of lime altered the compaction characteristics of the soil. Maximum dry density decreased while optimum moisture content generally increased due to hydration and pozzolanic reactions associated with lime treatment. Lime stabilization enhanced the engineering performance of the lateritic soil through the formation of cementitious compounds that improved soil structure, strength, and durability. The results confirm that lime is an effective stabilizing agent for lateritic soil and can be successfully used to improve weak subgrade materials for road construction and other geotechnical applications.
3. The California Bearing Ratio increased progressively with increasing lime content, rising from 9.88% for untreated soil to 33.50% at 9% lime content. This demonstrates a remarkable improvement in load-bearing capacity and pavement support characteristics.
4. Among the lime contents investigated, 7.5% lime treatment produced the highest improvement in bearing capacity and the lowest plasticity index, indicating the best overall performance under the conditions of this study

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