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Use of Paper Ash and Lime as a Sustainable Stabilized Materials for Lateritic Soil

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Abstract
This research investigates the effectiveness of paper ash and lime for stabilizing lateritic soils in road construction applications. We assessed varying concentrations of paper ash and lime (0%, 3%, 6%, and 9%) to evaluate their effectiveness for soil stabilization. Initial analyses, including grain size distribution through wet sieving, specific gravity, moisture content, and Atterberg limits, were conducted to classify the soil. Following this, strength and compaction tests utilized standard proctor compactive energy, a method well-suited for field application. The findings indicated a general reduction in Atterberg limits (liquid limit, plastic limit, and plasticity index), an increase in maximum dry density (MDD), and a decrease in optimum moisture content (OMC) with increased concentrations of paper ash and lime. A thorough analysis of the results, along with a comparison to established standards, demonstrated significant improvements in soil properties. Specifically, the study found that 6% paper ash provided optimal stabilization, while 9% lime was effective as a stabilizing agent. These materials are suitable for use in the construction of subgrades and subbases for roads, aligning with AASHTO standards.
Keywords: Atterberg limits. Maximum dry density. Optimum moisture content. Plastic limit. Shrinkage limit. Specific gravity.

1. Introduction

Engineers are increasingly tasked with finding appropriate materials for the construction of roadways and foundations. This has led to significant and ongoing research by individuals, corporations, and academic bodies on methods to enhance soil's engineering characteristics. Frequently, soils that are readily available lack the necessary qualities to support the intended loads, necessitating enhancements. This process, known as soil modification or stabilization, involves applying specific treatments to improve the soil index properties, strength, and resistance to shrinkage, swelling, and excessive settling. When such treated soil can endure stresses under all weather conditions without substantial deformation, it is typically considered to be stable (Amu *et al*., 2005). In the mechanical approach to soil stabilization, the engineering characteristics of soil are enhanced by incorporating particles that are absent in its natural composition (Huang *et al*., 2021). By compacting the soil mechanically, it is prepared for use as a fill substance in the building of embankments, earth dams, and road subgrades (Lay, 2005). (Olarewaju, 2004) argued that the modification method of soil stabilization typically does not produce a fully cemented, hardened, or semi-hardened material. This form of stabilization can be achieved through compacting, mechanical mixing, the addition of small quantities of cementing materials, or the use of chemical modifiers (Barman & Dash, 2022; Goodarzi *et al*., 2016). (Oyediran and Kalejaiye, 2011) described stabilization as the process of enhancing soil properties to optimize their suitability for construction purposes, involving mechanical, chemical, and occasionally biological techniques. According to (Ogunribido, 2011), the materials identified for use in stabilization can be classified as either agricultural or industrial waste. It is essential to incorporate specific chemical additives into naturally occurring lateritic soil to improve its engineering properties, particularly in terms of strength and water resistance. (Adakole, 1992) highlighted that lateritic soil is favored for construction largely because it naturally forms in areas experiencing substantial weathering, especially in tropical regions. This preference is also due to the limited availability of quality crushed aggregates, making it a cost-effective option. In tropical climates, such as in Nigeria, lateritic soil is subject to extensive chemical weathering and the leaching of minerals. (Sherwood, 1993)observed that fine-grained granular substances are most effectively stabilized owing to their substantial surface-to-diameter ratio. Clay soils, distinguished by their flat and elongated particles, possess a considerably larger surface area than other types. On the other side, silty materials are prone to stabilization difficulties due to their sensitivity to minimal moisture changes. Regarding peat soil, it characteristically contains more than 80% water and has high levels of porosity and organic matter, varying from muddy to fibrous textures. Although these deposits are generally shallow, they can reach several meters deep in extreme situations (Åhnberg & Holm, 2018; Cortellazzo & Cola, 2018). (Degirmenci *et al*., 2007) discussed the impact of paper ash on the soil plasticity index. Their observations indicated that the application of paper ash might lower the plasticity index, which is attributed to a rise in the liquid limits of the soil. (Senol *et al*., 2006) found that incorporating paper ash into soil alters its porosity and void ratio. The process of soil stabilization enables the soil particles to absorb more water, which in turn increases the optimum moisture content while reducing the maximum dry density. The ash derived from paper is amorphous and exhibits pozzolanic properties. Its ready availability and previous classification as waste make its use as a pozzolanic material particularly valuable, marking a significant breakthrough in this area.

The use of soil has surged notably in recent decades, leading to the degradation and destabilization of soil properties, which in turn diminishes its utility. Soil stabilization is aimed at enhancing the strength of soil and boosting its resistance to water-induced softening by bonding the soil particles together and waterproofing them. Traditional soil stabilization methods involving cement, lime, and bitumen are increasingly costly and have adverse environmental impacts. Utilizing paper ash and lime not only leverages the beneficial properties of these materials but also contributes to better land use management, thereby compensating for limited land availability. This approach offers dual benefits, enhancing the scope and impact of the project work. The lack of adequate geotechnical investigations in the past has led to numerous road failures and building collapses in Nigeria. Therefore, it is crucial to conduct thorough geotechnical investigations before initiating any civil engineering project. This research aims to evaluate the suitability of paper ash and lime as stabilization materials for lateritic soil. Specific objectives include collecting lateritic soil samples, assessing their properties before and after stabilization with paper ash and lime, and evaluating the performance of these materials at varying percentages.

2. Materials and Method

2.1 Materials

The materials utilized in this study include lateritic soil, paper ash, lime, and water.

2.2 Collection of Study Samples

The lateritic soil was collected along the Ijare road at coordinates 7°21'54"N latitude and 5°10'30"E longitude, approximately 1 meter across from the proposed God of Glory site in Aaye, Akure, Ondo State. This soil was disturbed and extracted from a depth of between 0.7m and 1m using a digger and spade. The digger removed the top agricultural layer down to 0.75m, which is the depth considered suitable for obtaining engineering-grade soil samples. Once the appropriate depth was reached, the soil was immediately packaged in polythene bags to preserve its natural moisture content.

The lime, employed as a stabilizing agent, was sourced from Pascal Chemical Laboratory, while the paper ash was acquired from the premises of the Federal University of Technology, Akure (FUTA). Once collected, the paper ash was stored in a cool, dry location to protect it from the effects of weather prior to incineration. The water used for testing during the study was potable and treated in the laboratory.

For this research, paper samples were gathered from the Federal University of Technology, Akure (FUTA). These samples were amassed in significant quantities and prepared through several steps:

(1) The papers were stored in a cool, dry place for a few weeks to ensure they were thoroughly dried.
(2) The dried papers were then burned to ashes at room temperature.

Following the preparation of the paper ash and the procurement of lime, lateritic soil was gathered from Ijare Road, Aaye, and subsequently oven-dried. Various tests were then conducted on this oven-dried sample.

2.3 Tests Conducted

The tests detailed below adhered to the British standard methods (BS 1337) and ASTM-STP 479 specifications, and were organized into two primary categories.

Preliminary tests: These tests aimed to identify and classify the soil. Conducted on oven-dried samples, the tests included measuring particle size distribution, specific gravity, and Atterberg limits.

Engineering property tests: These tests were designed to assess the strength characteristics of the soil in its natural state (control) and when mixed with different proportions of paper ash and lime. The mixtures examined included soil with 0%, 3%, 6%, and 9% paper ash, and similarly, soil with 0%, 3%, 6%, and 9% lime content. For these tests, the soil was oven-dried, pulverized, and separated into batches. Each batch was thoroughly mixed with the specific admixture until a consistent color was achieved, then water was added as necessary, mixed further, and compacted. The compaction tests applied the standard Proctor compactive energy, a method that is practical for field application; the tests utilized varying concentrations of paper ash and lime, specifically 0%, 3%, 6%, and 9%.

2.4 Specific Gravity

The specific gravity of soil solids is the ratio of a given volume of soil particles' weight in air to the weight of an equal volume of distilled water. This measure is typically used to relate the soil's weight to its volume. However, specific gravity has limited utility for soil identification or classification since it varies within a narrow range across most soil types (Emmanuel *et al*., 2024; Oyelami & Van Rooy, 2016).

Calculating the specific gravity of soils is crucial for determining other soil characteristics such as void ratio, porosity, and saturation degree, provided that the soil's bulk density is known. It is also essential for performing various laboratory tests.

Equipment Used: The equipment required for determining specific gravity includes a 50ml density bottle with a stopper or lid, distilled water, a stirrer, and a weighing balance accurate to 0.1g (see Figure 1).

Figure 1: Measurement of Glass Jar Weight for Specific Gravity Assessment

Procedure: The procedure began with cleaning, drying, and weighing the density bottle, stopper included, to an accuracy of 0.1g, recorded as W_1. Next, approximately 100 g of oven-dried soil was added to the bottle, which was then weighed and recorded as W_2. Water was then added to the bottle, filling one-third of it, and the soil-water mixture was stirred thoroughly to release any trapped air; this mixture was then left undisturbed for 30 minutes. After this period, the bottle was filled to two-thirds capacity with water, stirred again, sealed with the stopper, and left to sit for 24 hours. Following this, the bottle was filled to the top with water, ensuring the absence of air pockets, and weighed, noted as W_3. The final step involved emptying and cleaning the bottle, then filling it completely with water, again checking for voids, and weighing this as W_4. The specific gravity was calculated using the formula below:

$$S.G = \frac{Weight\ of\ Sample}{Weight\ of\ equal\ volume\ of\ water} \quad (1)$$

$$S.G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad (2)$$

where,
SG = Specific Gravity of the soil
W_1 = Weight of the empty density bottle.
W_2= Weight of the density bottle plus 100g of dry soil.
W_3= Weight of the density bottle with 100g of soil and water.
W_4 = Weight of the density bottle filled with water only.

2.5 Particle Size Distribution

The particle size distribution (PSD) test is an essential classification method for soil, as it highlights the relative quantities of various particle sizes within a sample. This test enables the identification of whether a soil sample is primarily composed of gravel, sand, silt, or clay particles. Sieve analysis, applicable to both non-organic and organic granular materials such as sands, crushed rock, and clays, facilitates this determination. The results of this test are crucial for assessing the properties of the aggregate and determining its suitability for various civil engineering applications. According to (Al-Hashemi *et al*., 2021), the soil's grain size distribution should be ascertained using ASTM D 422 test method. This distribution curve is instrumental in calculating parameters vital for resolving numerical retention criteria (see Equation 3 and 4).

$$\text{Percentage retained } (\%) = \frac{Weight\ of\ sample\ retained}{Total\ weight} \times 100\% \tag{3}$$

$$\text{Percentage passing} = 100\% - \text{commutative percentage retained } (\%) \tag{4}$$

General Requirements includes;

Sample Mass: The required mass of the soil sample for sieving is specified.

Accuracy of Weighing: The necessary accuracy for weighing depends on the sample or subsample size, as outlined below in Table 1:

Table 1 - Minimum Accuracy of Weighing.

	Minimum Accuracy (grams)
Fine-grained soils	0.1
Medium-grained soils	1.0
Coarse-grained soils	10

Sieve Size Systems: Various sieve size systems are currently in use. Any system may be employed in the testing process, provided that all sieves within a set conform to the same system. Differences in aperture sizes are manageable by using logarithmic grading charts. The sieve designations and sizes are detailed in Table 2.

Table 2- Sieves Designation and Their Sizes.

BS sieve aperture size	**Sieves to ASTM D422**	
	Nearest Designation	**Aperture Size**
75mm	3 inch	75mm
63	2 ½ inch	63.5
50	2 inch	50.8
37.5	1 ½ inch	38.1
28	-	
-	1 inch	25.4
20	¾ inch	19.05
14	-	
10	3/8 inch	9.52

Use of Sieves: Overloading a sieve can prevent fine materials from reaching the mesh, causing retention on the sieve and resulting in measurement errors. It is crucial to ensure that sieves are not overloaded.

Equipment Used: The test setup includes a range of sieves (from 4.75mm to 75μm), a precise digital scale readable to 0.1g, an oven that maintains temperatures between 105°C and 110°C, along with equipment like a scoop, a brush for sieves, and various containers (see Figure 2)

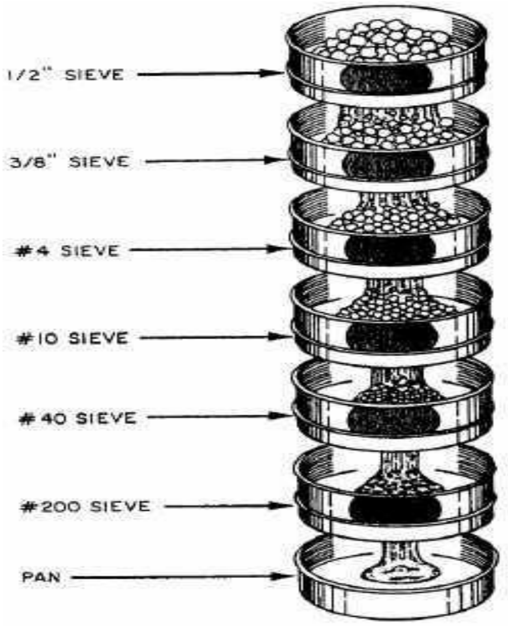


Figure 2 - Set of Sieves

Procedures: 400g of oven dried sample was weighted. The set of sieves were weighed and recorded, and there were then arranged in ascending order. The oven dried soil sample was then poured carefully into the sieve from the top and covered with the sieve lid. Subsequently, the stacked sieves were then shake vigorously for about 10 minutes. After shaking, the sieves were then separated and carefully weighed and recorded as the weight of soil retained on the sieve.

Data Analysis: Calculate the mass of soil on each sieve by subtracting the sieve's empty weight from its weight with soil. Document these values as the retained weights. These should roughly equal the initial sample mass, with a loss over 2% considered excessive.

To find the percentage retained on each sieve:

$$\%\, Retained = \frac{Mass\ of\ soil\ retained\ (g)}{Mass\ of\ dry\ sample} \times 100 \tag{5}$$

To determine the percentage finer, subtract the cumulative percentage retained from 100%.

$$\%\, passing = 100\% - \%\, retained \tag{6}$$

Plot a graph of % passing against sieve aperture sizes.

2.6 Atterberg Limits

The state of fine-grained soil varies with its water content. When water is added, it surrounds each soil particle with a film, making them more mobile. Atterberg (1911) identified four distinct states of soil based on moisture content namely: liquid limit, plastic limit, shrinkage limit and plastic index.

Liquid limit: It is defined as the moisture content at which plastic soil takes on liquid characteristics, typically determined when a standard groove closes under 25 taps in a Casagrande device. This is plotted on a flow curve, which correlates moisture content with the taps needed.

Equipment Used:
This includes the Casagrande cup, grooving tools, moisture cans, a precision scale, a glass base plate, a spatula, distilled water, and an oven set to 105°C (see Figure 3).

Figure 3-Tools for Atterberg limits testing

Procedures: A 250g soil sample was sieved through a 425µm mesh and mixed with a small amount of distilled water until it formed a smooth paste. This mixture was placed into the Casagrande cup of a liquid limit apparatus, compacted to remove air pockets, and spread to a depth of 10mm. A groove was then made down the center using a grooving tool. The apparatus was operated at roughly two drops per second, noting the number of drops required for the soil to close a 13mm gap at the groove. Samples were collected from the closed groove, weighed immediately, and recorded. This process was repeated with gradual additions of water, with each iteration sampled and recorded. Finally, the samples were oven-dried for 24 hours and their dry weights recorded. The experiment was also conducted with paper ash and lime mixtures at 3%, 6%, and 9% to study their effects on the soil.

Plastic Limit: This is the moisture content at which the soil, when rolled into threads approximately 3mm thick, begins to break apart. The difference between the liquid and plastic limits, known as the Plasticity Index (PI), indicates the soil plasticity range (see Equation 7).

$$PI = LL - PL \quad (7)$$

Procedures: A 40g sample of soil initially used for a liquid limit test was partially dried until it achieved a plastic consistency, suitable for shaping into spheres. This soil was then manually shaped and rolled between the palms, allowing the heat from the hands to further dry the soil until slight cracks began to appear on its surface. Sufficient pressure was applied to form threads approximately 3mm in diameter through a series of forward and backward hand movements. This process was repeated to produce two such threads, which were then placed in a moisture content container for testing. The moisture content of both samples was calculated, and the average was taken and rounded to the nearest whole number, which established the plastic limit value (PL).

Shrinkage Limit: This limit is the moisture content at which a reduction does not lead to a volume decrease in soil, indicating its shrinkage potential. It's expressed mathematically as:

$$Linear\ shrinkage = \frac{(1 - L_d)}{L_o} \times 100 \quad (8)$$

where L_d is the length of the oven dried soil

L_o is the length of the wet soil sample in the mold.

Equipment used: For the test, a mold is prepared with petroleum jelly to prevent sticking, filled with soil, and then dried to measure shrinkage changes.

Procedure: The shrinkage mold was cleaned and coated with a thin layer of petroleum jelly on its inner surface to prevent the soil from sticking. Soil paste, adjusted to near the liquid limit, was then placed into the mold. It was tapped and smoothed out to eliminate any air pockets and leveled off at the top with a spatula. After filling the mold, the soil was placed in an oven for 24 hours. Following this period, the length of the dried soil within the mold was measured and recorded, and compared to its length before drying.

Plasticity Index (PI): PI quantifies the water content range over which soil remains plastic. Higher PI values suggest clays with greater water retention and plasticity.

2.7 Compaction Test

This test is a standardized laboratory procedure used to determine the moisture level at which a particular soil type attains its greatest compacted dry density. The density of compacted soil is dependent on its water content during the compaction process.

Equipment used: For this test, a cylindrical compaction mold with a detachable base and a 50mm high extension collar is used. The setup also includes a 2.5Kg rammer, a precision digital balance readable to 0.1g, a material mixing tray, a scoop, a measuring cylinder, containers for determining moisture content, a spatula, and a weighing scale (see Figure 4).

Figure 4- Compaction mold and rammer

Procedures: The test was conducted using soil in its natural state and with added paper ash and lime in increasing percentages of 3%, 6%, and 9% by mass. The setup involved securing the mold to the base plate with the collar on a sturdy base (e.g., a concrete floor). Initially, 3000g of oven-dried soil was spread on a tray and mixed with an initial 0% water by weight. This mix was then compacted into the mold in three equal layers, with each layer compacted with 25 blows from the 2.5Kg rammer. After compaction, the collar was removed, and the mold's surface was leveled using a spatula. The compacted soil's weight was measured to calculate the bulk density and noted on a data sheet.

Small samples from the top and bottom of the mold were collected in moisture cans, weighed, and then oven-dried for 24 hours to determine their moisture content and corresponding dry densities. The process was repeated with a 2% increase in water, maintaining the same compaction steps until the weight of the soil in the mold began to decrease.

Calculations were performed to ascertain the wet density of each compacted sample using the formula below:

$$wet\ density = \frac{Weight\ of\ soil\ compacted\ in\ mould}{Volume\ of\ mould}\ (\frac{kg}{m^3}) \quad (9)$$

$$Dry\ density, P_d = \frac{Wet\ density}{1+\frac{Moisture\ content}{100}}\ (\frac{kg}{m^3}) \tag{10}$$

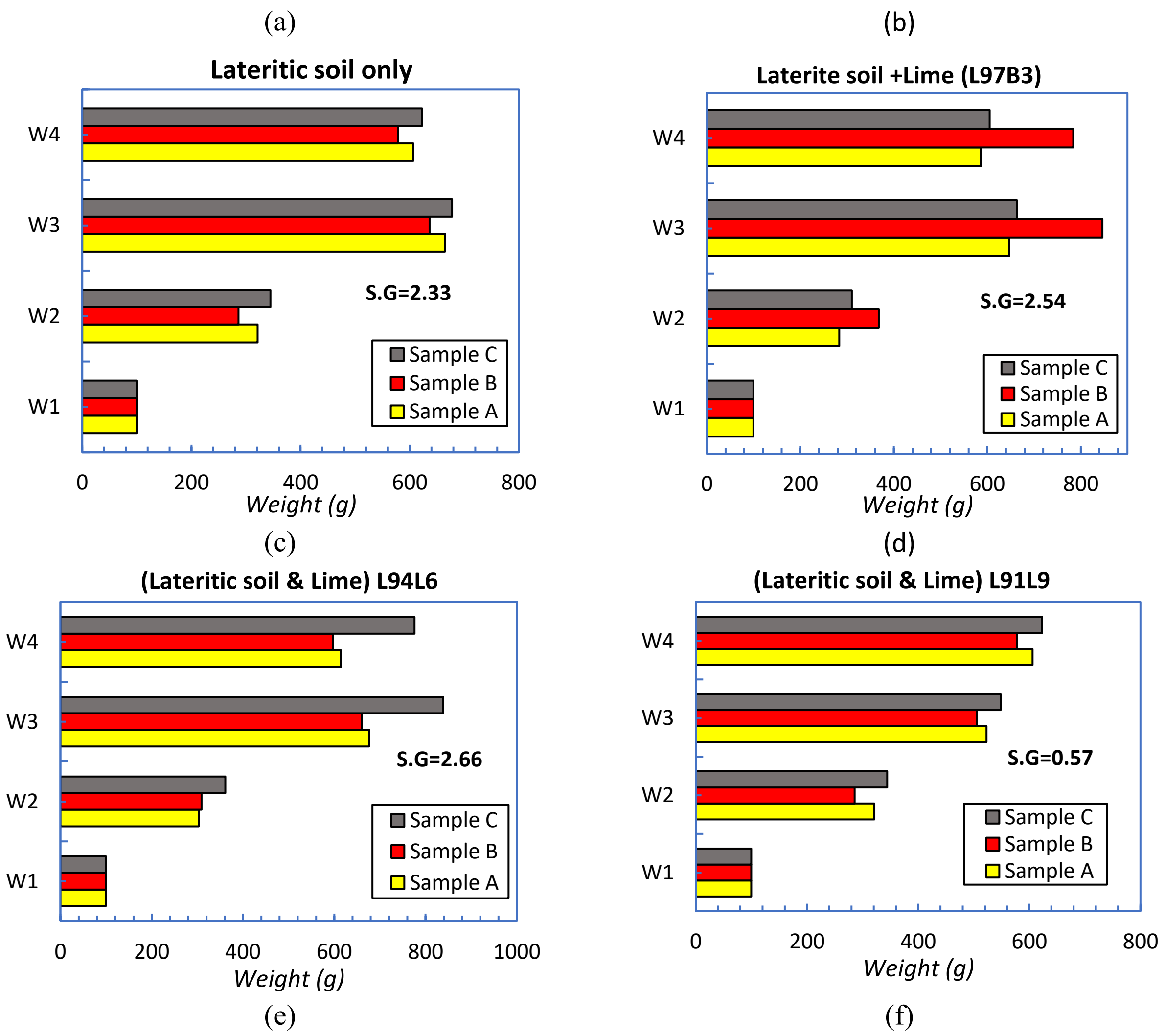
To determine the optimal moisture content and maximum dry density, a graph of dry density versus moisture content was plotted.

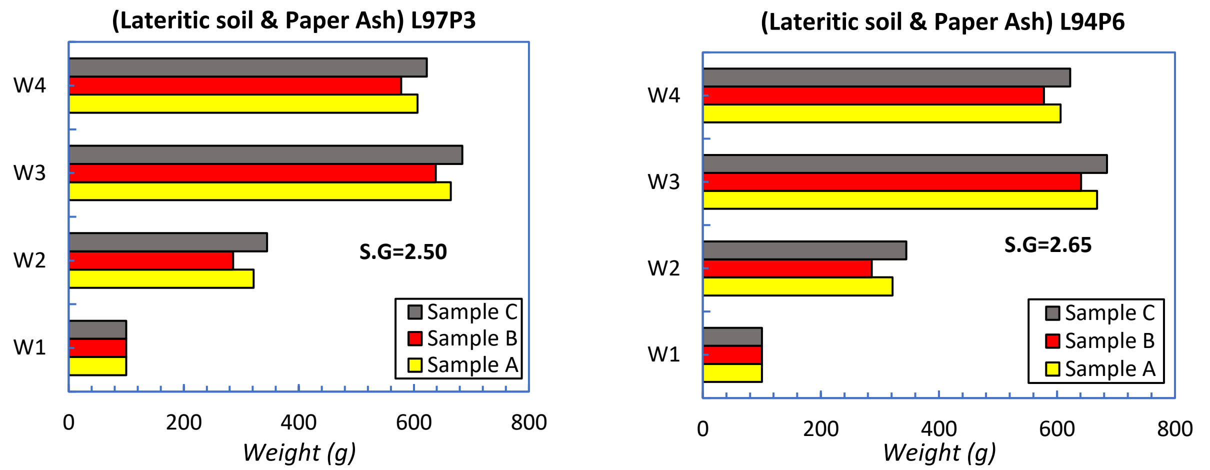
3. Results and Discussion

To identify, classify, and assess the engineering properties of lateritic soil from Ijare road, Aaye, Akure-Ondo state, laboratory tests were conducted on natural samples. These samples were stabilized using snail shell ash and cement. The findings from these tests are presented below.

3.1 Specific Gravity Analysis

The specific gravity of the lateritic soil tested was recorded at 2.33, falling within the typical range for lateritic soils. Research conducted by (Ob'lama *et al*., 2018) on the geotechnical properties of selected lateritic soils highlighted that their specific gravity typically ranges between 2.47 and 2.70. The study results indicated varying specific gravities when different percentages of lime were added to lateritic soil: 2.54 for 3% lime, 2.66 for 6% lime, and a notable decrease to 0.57 for 9% lime. Similarly, the addition of paper ash in proportions of 3%, 6%, and 9% resulted in specific gravities of 2.50, 2.65, and 2.44, respectively. A significant reduction in specific gravity was observed when 9% lime was combined with 91% laterite, underscoring that the predominant material in the mix generally determines the specific gravity of the blend (see Figure 5).





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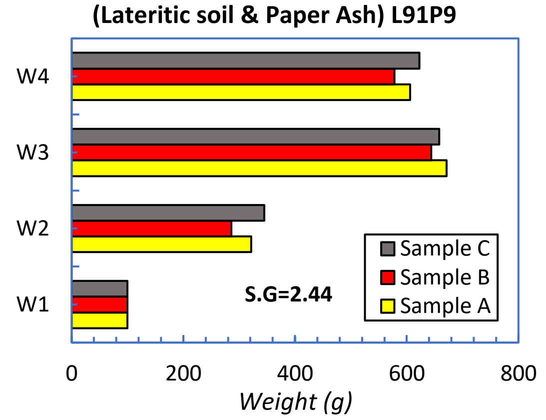


Figure 5-Specific gravity results for lateritic soil and its mixtures

3.2 Grain Size Distribution

The grain size distribution of lateritic soil was evaluated to assess its textural classification and suitability for various applications (see Table 3 and Figure 6). From the test results provided for L100, the percentage passing sieve no 200 (0.075mm) is 1.18%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 34.78% which satisfies the group A-1-b 50% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 3.25 and 0.93 respectively which makes it a poorly graded or uniformity graded soil according to the Unified Soil Classification System (USCS). The USCS standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

From the data obtained for L97L3, the percentage passing sieve no 200 (0.075mm) is 1.26%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 50.92% which satisfies the group A-3 51% minimum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 2.66 and 0.91 respectively which makes it a poorly graded or uniformity graded soil according to the USCS. The USCS standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

From data obtained for L96L4, the percentage passing sieve no 200 (0.075mm) is 0.66%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 43.74% which satisfies the group A-1-b 50% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 2.84 and 0.47 respectively which makes it a poorly graded or uniformity graded soil according to the Unified Soil Classification System (USCS). The (USCS) standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

For L91L9, the percentage passing sieve no 200 (0.075mm) is 0.82%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 34.88% which satisfies the group A-1-b 50% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 2.59 and 1.09 respectively which makes it a poorly graded or uniformity graded soil in Cu and well-graded soil in Cc according to the USCS. The USCS standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

For L97P3, the percentage passing sieve no 200 (0.075mm) is 0.36%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 24.06% which satisfies the group A-1-a 30% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 3.03 and 1.03 respectively which makes it a poorly graded or uniformity graded soil in Cu and well-graded soil in Cc according to the USCS. The USCS standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

For L94P6, the percentage passing sieve no 200 (0.075mm) is 0.14%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 16.6% which satisfies the group A-1-a 30% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 2.81 and 0.87 respectively which makes it a poorly graded or uniformity graded soil according to the USCS. The USCS standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

For L91P9, the percentage passing sieve no 200 (0.075mm) is 0.24%, which is less than 35%, making it a granular material according to the AASHTO classification. The percentage passing sieve no 40 (0.425mm) is 22.64% which satisfies the group A-1-a 30% maximum requirement according to AASHTO classification. The coefficient of uniformity and curvature are 3.2and 1.10 respectively which makes it a poorly graded or uniformity graded soil in Cu and makes Cc a well-graded soil according to the Unified Soil Classification System (USCS). The (USCS) standard states that for a poorly graded soil, percentage fines must be < 5%, Cu < 6 and/or 1>Cc>3.

Table 3- Grain size distribution results for laterite and its mixtures

Sieve size	L100	L97L3	L94L6	L91L9	L97P3	L94P6	L91P9
4.76 mm	99.00	98.6	98.64	97.98	95.22	95.94	96.32
2.36	92.26	93.02	90.84	91.18	86.18	85.2	86.3
1.07	90.04	91.6	88.86	89.48	83.24	81.68	83.94
0.60	55.36	70.36	63.42	63.42	49.58	44.28	48.16
0.425	34.78	50.92	43.74	34.88	24.06	16.6	22.64
0.212	10.62	13.92	12.76	8.44	4.60	3.84	7.74
0.15	5.36	7.08	7.26	5.12	2.36	2.94	5.20
0.075	1.18	1.26	0.66	0.82	0.36	0.14	0.24

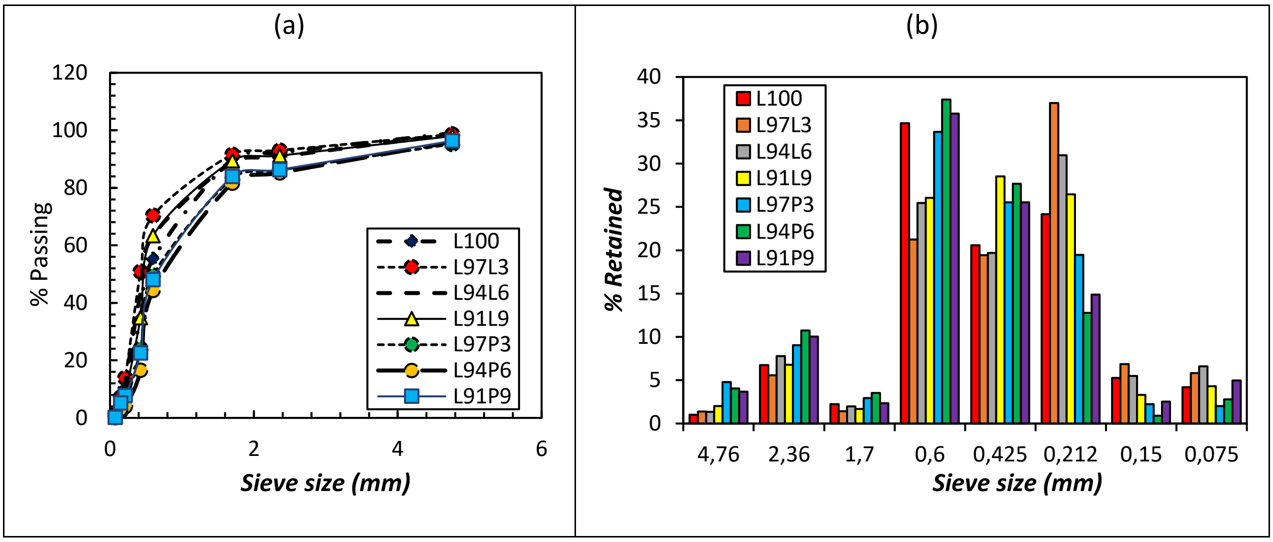
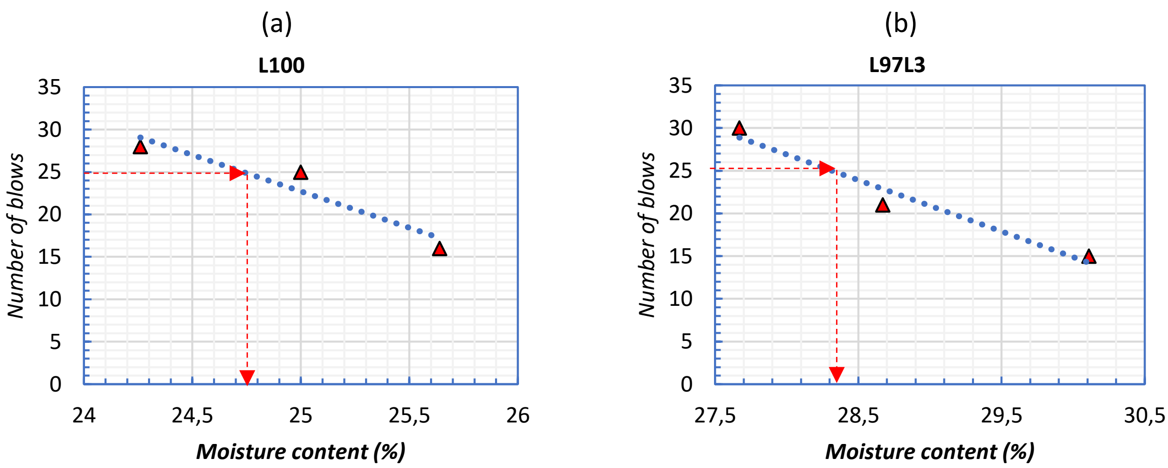


Figure 6-(a) Comparison of percentage passing with sieve size for laterite and its mixtures (b) comparison of percentage retained with the sieve size for all mixtures of laterite

3.3 Atterberg Limit Test Analysis

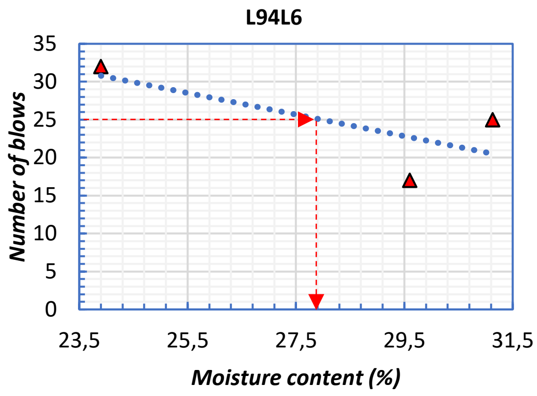
The liquid limit, plastic limit and plasticity index of laterite was 24.75%,17.65% and 7.1 % respectively, which witnessed an increase when 3% of lime was added yielding 28.30,22.22% and 6.08% as Liquid limit, plastic limit and plasticity index respectively. Also, when 6% of lime was added to laterite, a slight reduction takes place in the Atterberg limits obtained. The addition of 9% lime maintains a replica liquid limit as before and witnessed a sky-rocketed plastic limit of 28.6% far away from the plastic limit obtained for the previous percentage of lime added to laterite. The addition of paper ash to laterite has been extensively used in soil stabilization i.e. a soil improvement technique aimed at enhancing the geotechnical and engineering properties of soil in the construction field, However, the easy access and the economic implication of these materials to be used as stabilization material are essential factors to be considered. 3% of paper ash yielded a liquid limit of 26.1% and a plastic limit of 25% far away from the limits laterite. As an increase in paper ash content surfaced i.e. 6% of paper ash was added causing a reducing in the plastic limit as obtained in the previous limits. The addition of 9% paper ash yielded 26.1% ,13.3% and 12.8% as liquid limits, plastic limit and plasticity index respectively. From this assertion, it can be stated that as the percentage of lime increase, the liquid limit increases and the plasticity index partly increases. Also, an increment in the % of paper ash added leads to partial increment in the liquid limits and also cause the declining of the plasticity index.



LL = 24.75% PL = 17.65%
P.I = 7.10% SL = 0.50cm

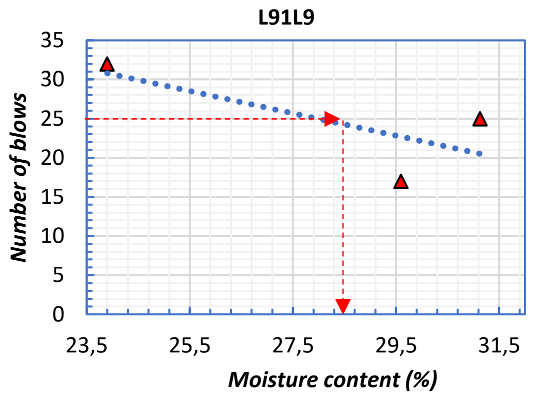
LL = 28.30% PL = 22.22%
P.I = 6.08% SL = 0.25cm

(c)



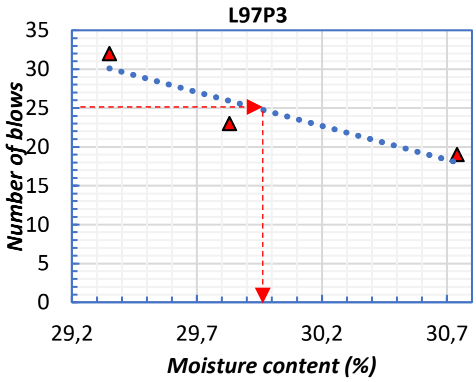
LL = 28.0% *PL = 20.0%*
P.I = 8.0% *SL = 0.40cm*

(d)



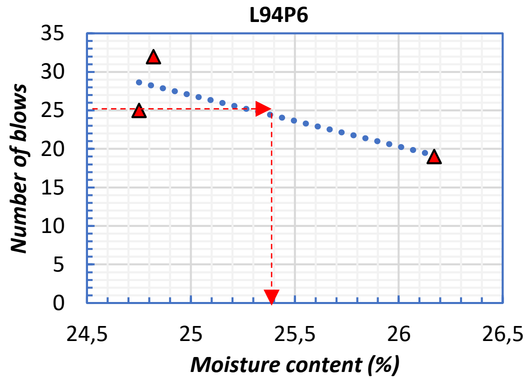
LL = 28.0% *PL = 28.6%*
P.I = 0.6% *SL = 0.45cm*

(e)



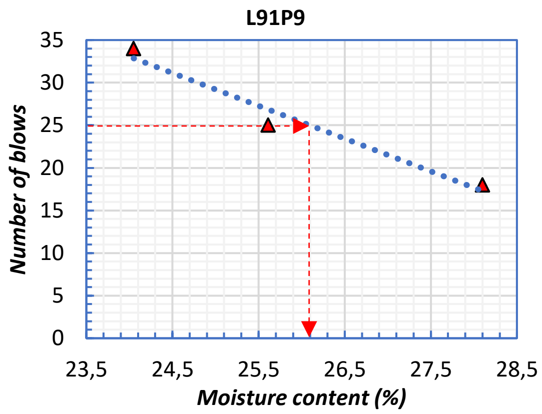
LL = 30.1% *PL = 25.0%*
P.I = 5.1% *SL = 0.3cm*

(f)



LL = 25.4% *PL = 12.5%*
P.I = 12.9% *SL = 0.5cm*

(g)

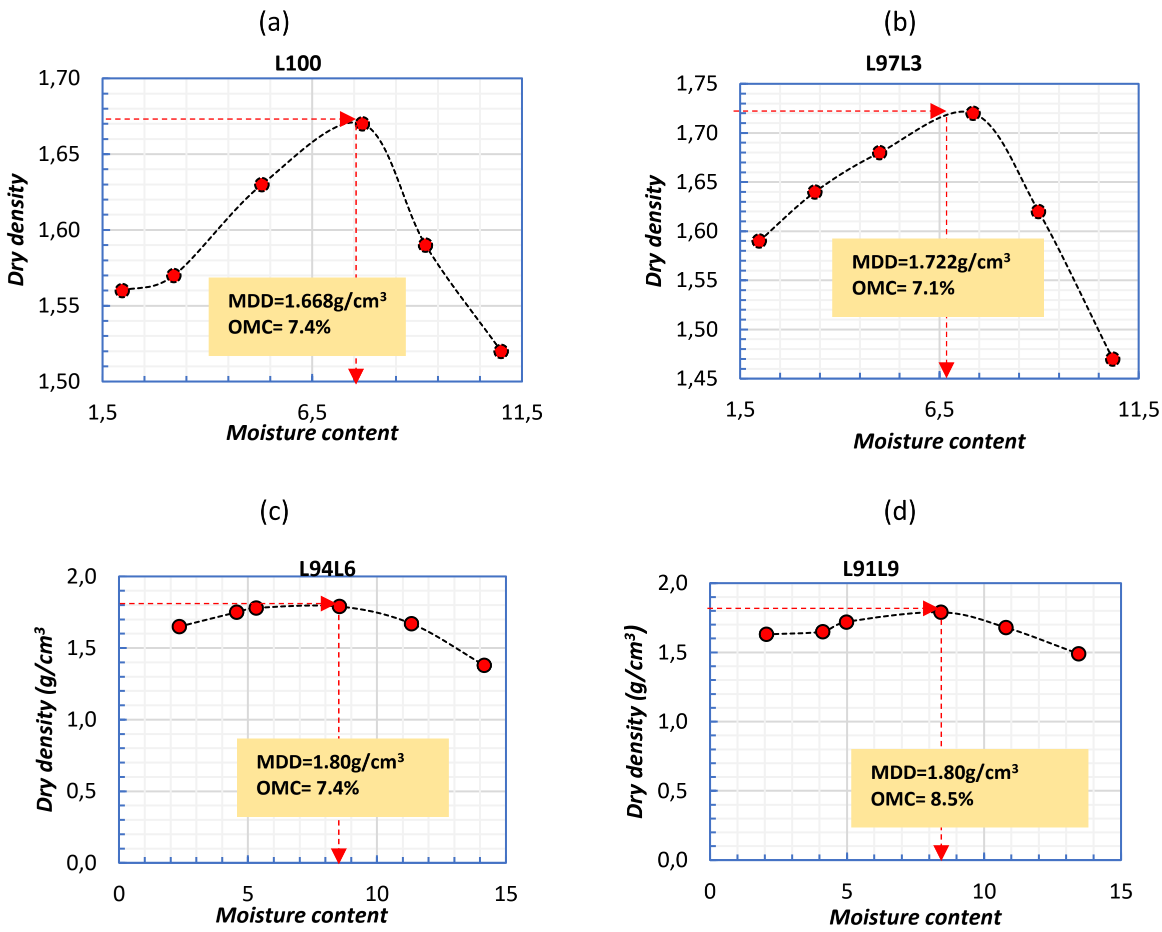


LL = 26.1% *PL = 13.33%*
P.I = 12.77% *SL = 0.8cm*

Figure 6-Variation of number of blows against moisture content for lateritic soil and its mixtures

3.4 Compaction Test Analysis

The results obtained from the test indicates the variation of the maximum dry density (MDD) at different percentage of lime (see Figure 7). When 3% of lime was added, the MDD of laterite increased from 1.668g/cm3 to 1.722g/cm3. The addition of 6% lime increases the MDD from 1.722 g/cm3 to 1.80g/cm3, with the addition of 9% of lime, there was a fixed value in the maximum dry density giving 1.80 g/cm3. The optimum moisture content (OMC) varies as the laterite was blended with lime, the OMC decreases from 7.4% to 7.1% when 3% of lime was added. The OMC increases to 7.4% at the addition of 6% lime and also increases to 8.45% when 9% of lime was added. The addition of paper ash to laterite has been extensively used in soil stabilization i.e. a soil improvement technique aimed at enhancing the geotechnical and engineering properties of soil in the construction field, However, the easy access and the economic implication of these materials to be used as stabilization material are essential factors to be considered. When 3% of paper ash was added, the MDD of laterite increased from 1.668g/cm3 to 1.702g/cm3. The addition of 6% paper ash increases the MDD from 1.702 g/cm3 to 1.713g/cm3, with the addition of 9% of paper ash, there was a decrease in the maximum dry density giving 1.701 g/cm3. The OMC varies as the laterite was blended with paper, the OMC decreases from 7.4% to 7.2% when 3% of paper ash was added. The OMC decreases to 6.2% at the addition of 6% paper ash and also increases to 8.7% when 9% of lime was added.



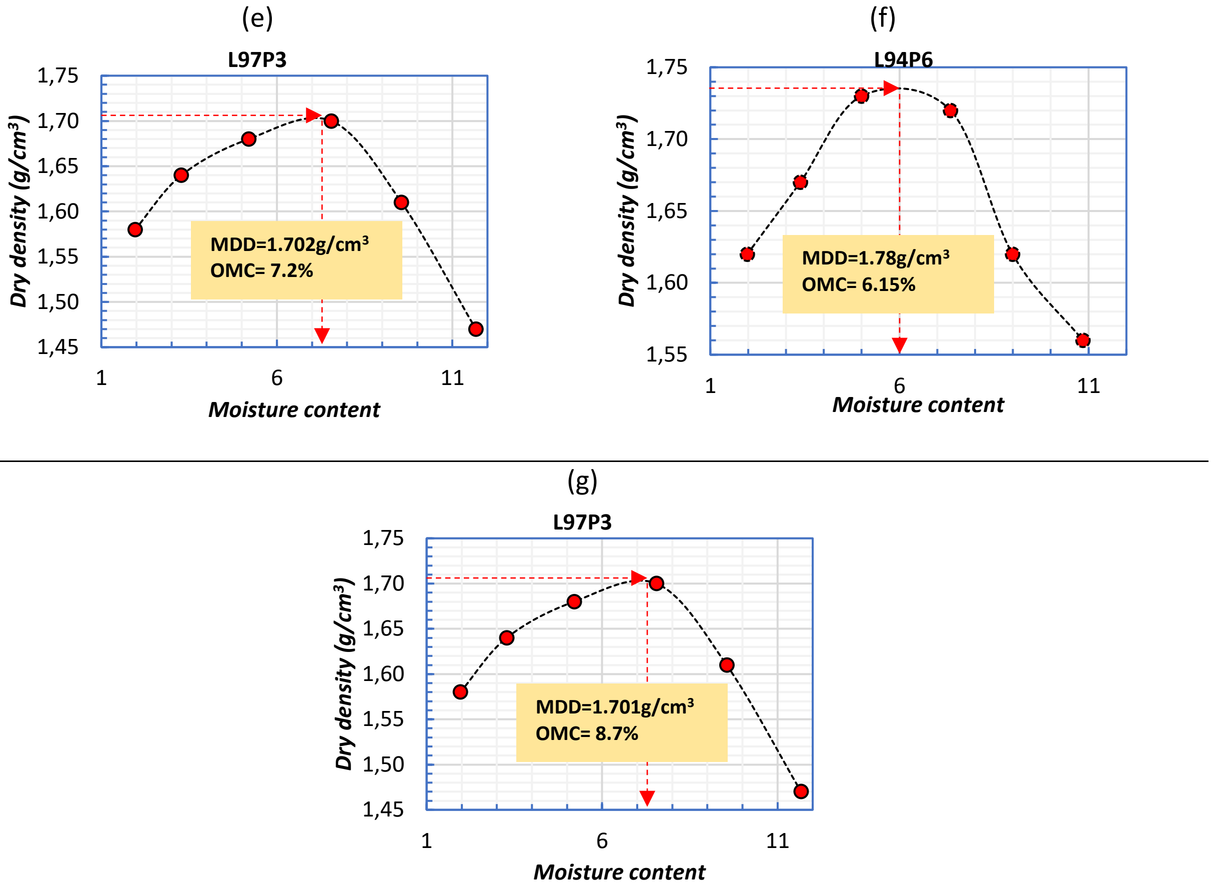


Figure 7-Variation of dry density against moisture content for lateritic soil and its mixtures

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