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MODELING AND EVALUATION OF THE STRENGTH PROPERTIES OF OKE-BALE SOFT SOIL AMENDED WITH CALCIUM CHLORIDE SALT

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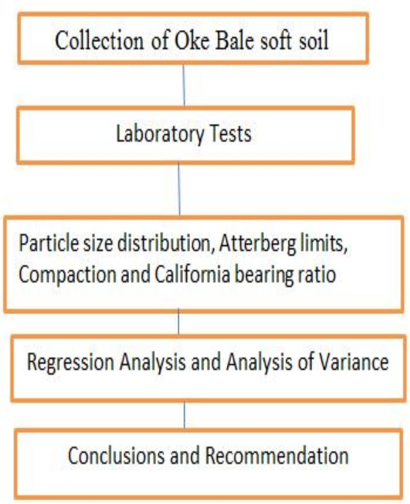
Graphical abstract



Abstract

This research aimed to model and assess the impact of calcium chloride salt (CCS) on the Oke Bale soft soil, known as Lateritic soil, in Osogbo, Nigeria, as a potential pavement material due to high cost of conventional materials. The conducted laboratory tests included particle size distribution, Liquid limit (LL), Plastic limit (PI), and Plasticity index (PI), compaction (Maximum dry density (MDD); Optimum moisture content (OMC) with compactive efforts of British Standard Light, West Africa Standard, and British Standard heavy, and unsoaked California bearing ratio (CBR) on both Oke bale soft soil and modified soil. The soft soil underwent stabilization with varying concentrations of CCS at 0, 4, 8, 12, and 16%. The results were analyzed using regression analysis and Analysis of Variance (ANOVA). The findings indicated advancement in the gradation of lateritic soil as the percentage of CCS salt increased. Additionally, the PI lessened from the value of 14.68% in the regular lateritic soil to the value of 11.49% at 12% CCS content, afterward amplified to the value of 15.6% at 16% CCS content. Simultaneously, the LL of the natural lateritic soil decreased from 60.05% to 35.55% at 16% CCS content. The MDD of original lateritic soil for BSL, WAS, and BSH decreased from 1.63 to 1.45 Mg/dm^3, 1.66 to 1.48 Mg/dm^3, and 1.69 to 1.52 Mg/dm^3 at 4% CCS content, subsequently increasing up to 16% CCS, respectively. Although the OMC amplified from 19.47% to 24.0%, 18.22% to 22.73%, and 17.44% to 21.85% at 4%, it later increased up to 16% CCS, respectively. At 8% CCS content, the CBR value improved from 13.22% to 24.65%, 14.44% to 26.28%, and 15.68% to 28.62% for BSL, WAS, and BSH compactive effort, respectively. Regression analysis indicated that grading properties, MDD, LL, PF, and PI influenced strength qualities of Oke-bale lateritic soil amended with CCS, with positive coefficient values. Furthermore, regression analysis suggested a solid bond between the measured and predicted values of CCS-LS. However, statistical significance was shown in the lateritic-CCS mixed analyses of variance during the duration of the test. Based on the outcome of CBR test, 8% CCS-lateritic soil mixture could be effectively utilized to enhance low-traffic roads.

Keywords: Regression analysis, Analysis of variance, Compaction, California bearing ratio, Calcium chloride salt,

1.0 INTRODUCTION

Soil strength is a critical geotechnical property essential for various engineering and construction applications [1]. It pertains to the soil's ability to withstand imposed loads without undergoing significant failure or deformation. Determining soil strength involves applying mechanical energy to enhance the stability and safety of structures and foundations established on or within the ground. A comprehensive understanding of soil strength, especially in the case of the most commonly used soil in pavement construction, particularly laterite, is indispensable [2]. This understanding will result in a positive reduction of pore spaces and the rearrangement of soil structure [3].

Laterite soil is a type of soil formed through weathering processes, primarily prevalent in humid, tropical regions with well-drained soils [3,4,5,6]. The occurrence of aluminum and iron in laterite enables its formation in warm and tropical climates [7]. Additionally, the notable iron oxide content imparts a unique rusty red color to the majority of lateritic soils [3]. It is a commonly used material for road pavement construction in Nigeria and other regions. The cementing agents, known as sesquioxides, present in lateritic soils enhance their value as construction materials [8]. Nevertheless, specific lateritic soils harbor an abundance of clay minerals, posing a threat to their strength, stability, and capacity to endure designated traffic loads. It is known that certain laterite categories display undesirable behaviours such lateral movement, distension, and indentation. [9]. Contrasting with lateritic soils, primarily composed of minerals like chlorite and kaolinite, certain laterite soils enclose expanding clay in minerals for example montmorillonite and illite. These minerals raise pore pressure, diminish shear strength and heighten the likelihood of swelling [10].

These challenges have prompted researchers to explore diverse methods for enhancing the geotechnical properties of soils, especially those presenting challenges in construction [3,4,5,8]. While conventional soil improvement additives like cement, lime, and bitumen have been utilized, their cost-effectiveness is not always assured. Consequently, researchers have shifted their attention to locally available waste materials from industrial and agricultural sources, including Plantain peel ash, steel slag, rice husk ash, iron ore tailings, locust bean, among others [4,11,12,13].

Calcium chloride is a salt produced as secondary product of sodium carbonate formation, has emerged as a viable alternative to lime. An alkaline earth metal salt usually has up to six water molecules when it is in liquid and stable state. Liquid and dry granular or flake versions are both commercially accessible, with concentrations varying from 30% to 94%. It is preferred due to its ease of conversion into calcium-charged upper layer as opposed to lime [14]. Hausmann [15] talked about the environmentally friendly $CaCl_2$ in fine particles suppression on unsealed roads, transportation routes in mining and as a supplemental ingredient to strengthen soils that have been lime- or cement-treated. As indicated by Shon et al. [16], applying calcium chloride to soil results in an augmentation of both density and strength in the compacted soil. Additional research by Zumrawi and Eltayeb [17] suggests that a higher content of calcium chloride salt enhances dry density while decreasing optimal moisture content, ultimately boosting strength. Sani et al [18] also observed that calcium chloride salt improves the engineering behavior of lateritic soil collected in Shika, Zaria. Ishola et al.,[13] used regression analysis to report the result of California bearing ratio on the compacted mixture of iron ore tailings and lateritic soil to be significant.

Additionally, the research carried out by Bello and Adegoke [19] regarding the regression analysis of the CBR and UCS of the mixture of yellowish clay soil and lime demonstrated positive significance. Ishola et al. [20] studied the compaction characteristics of calcium salt with lateritic soil by considering a lower energy level, specifically the British Standard Light, and reported positive results for the mixture. Almajed *et al.,*[2021] investigates an alternative approach to the chemical improvement of clayey soil by examining the efficacy of cement and calcium chloride. Their investigation displayed the enhancement the soil's strength and durability through the evaluation of different concentrations of $CaCl_2$ along with a consistent 2% cement addition. The outcome of their findings reported that the combination of cement and calcium chloride effectively stabilizes expansive soil, leading to lesser swelling pressure and compression index. Bhardwaj and Kumar [22] conducted a study on the utilization of gypsum and calcium chloride for enhancing the engineering strength of clayey soil. Their research involved Standard Proctor tests, California Bearing Ratio and Free Swell Index measurements, tests to evaluate the influence of varying gypsum percentages and a constant calcium chloride percentage on soil strength. Their findings led to the conclusion that the addition of gypsum and calcium chloride as stabilizing agents significantly increases the CBR value for clayey soils.

However, limited research has been conducted on the higher compacting effort and modeling application of calcium chloride for enhancing Oke bale lateritic soil. Consequently, this study aims to predict and evaluate the strength model of the calcium chloride-lateritic soil mixture. This research endeavors to contribute valuable data to the scant body of knowledge regarding the application of $CaCl_2$ salt in the lateritic soil enhancement.

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2.0 METHODOLOGY

2.1 Materials

2.1.1 Oke Bale Lateritic soil

The lateritic soil employed in this research was collected from the Oke Bale region in Osogbo, Nigeria. A review of geographical and soil maps of Nigeria, as outlined by Bello et al. [23], Recognized the original study location soil as a fundamental igneous rock., which, through weathering, gives rise to poorly improved lateritic soils

2.1.2 Calcium chloride Salt

The calcium chloride salt was acquired from a store supplying laboratory equipment in Osogbo, Nigeria.

2.2 Methods of Testing

The natural lateritic soil underwent laboratory tests, including specific gravity, particle size distribution, Atterberg limit, compaction, and california bearing ratio (CBR). The soil properties were assessed following the procedures specified in BS 1377 [24], while modified tests adhered to the guidelines of BS 1924 [25]. CBR tests were conducted at the OMC and MDD using BSL, WAS and BSH compactive efforts for soil-CCS. The testing procedures, particularly for CBR, were in accordance with the specifications outlined in the FMWH [26]. The lateritic soil compacted in the mould underwent a curative measure under the period of six days before being subjected to examination at a uniform loading speed.

2.2.1 Consistency Limits

The LL test was conducted utilizing the Cassagrande apparatus, following the guidelines outlined in ASTM standards (ASTM D4318-10). Similarly, the plastic limit test also adhered to ASTM standards (ASTM D4318-10). These studies were carried out in order to look into the efficacy of calcium chloride salt and its consistency limitations.

The Equation (1) indicates parameters associated with consistency limit.

$$PI = LL - PL \quad \text{Eqn. (1)}$$

2.2.2 Compaction

A 3kg sample of lateritic soil was obtained and passed through a No. 4 sieve to remove clods. The weight of the soil mass and the mold without the collar was measured. The soil was spread on a flat tray, and water was gradually added to achieve the desired moisture content (w). The collar was lubricated, and the soil was compacted in the mold through three layers. Each layer received blows from hammers weighing 2.5 kg, 4.5 kg, and 4.5 kg for BSL, WAS, and BSH compactive efforts, respectively. The drops were consistently applied manually. The soil mass filled the mold, extending into the collar but not exceeding one centimeter. After carefully removing the collar, the soil extending above the mold was trimmed with a sharp straight edge. The soil, along with the mold, was weighed and extruded from the mold using a metallic extruder. The water content from both the top and bottom of the sample was determined. The process was then repeated by adding more water to achieve a higher water content, w.

2. 2. 3 California Bearing Ratio

Compaction of the lateritic soil was excuted in the 2360 cm³ mould, sealed in a polythene sack, and allowed to mend for six days. Subsequently, it was dipped in a water tank for 24 hours and subjected to examination as described in the procedures specified in BS 1377 [24]. The CBR is determined by calculating the pressure applied by the plunger in to penetration depth of the sample, establishing the connection between pressure and penetration. A curve depicting the connection between force and penetration was created by utilizing the documented penetration and pressure values. The CBR value for the soil-CCS was measured at penetrations of 2.5 mm or 5.0 mm, with the higher of the two values being adopted as the CBR value.

$$CBR = \frac{Measured\ value}{Standard\ Value}\ x\ 100 \quad \text{Eqn. (2)}$$

3.0 RESULTS AND DISCUSSION

3. 1 Index qualities of the Oke Bale Lateritic Soil

The soil underwent various tests to characterize its qualities, including specific gravity, particle size distribution, Atterberg limits (LL, PL and PI), compaction properties (MDD and OMC), and CBR. Figure 1 depicts the grading curve of the collected soil sample. A summary of the soil qualities is presented in Table 1, and Table 2 provides information on the physiochemical composition of the lateritic soil.

Table 1: Index qualities of the Oke bale lateritic soil

Properties	Quantity
Moisture Content. (%)	19.3
Specific. Gravity	2.67
Atterberg limits (%)	
Liquid limit	60.05
Plastic limit	45.37
Plasticity index	14.68
Percentage Passing 200 Sieve	37.14
AASHTO. Classification	A-7-6 (5)
Compaction characteristic	
Maximum. dry density, Mg/dm^3	1.63
Optimum Moisture. Content. (%)	19.47

Table 2: Physiochemical Composition of Lateritic soil

Oxide Composition	Lateritic Soil
SiO_2	35.60
Al_2O_3	27.40
Fe_2O_3	24.0
P_2O_5	-
SO_3	0.85
K_2O	-
TiO_2	-
MnO	2.00
Na_2O	-
CuO	-

CaO	0.28
ZnO	0.09
MgO	-
Loss of Ignition	14.6

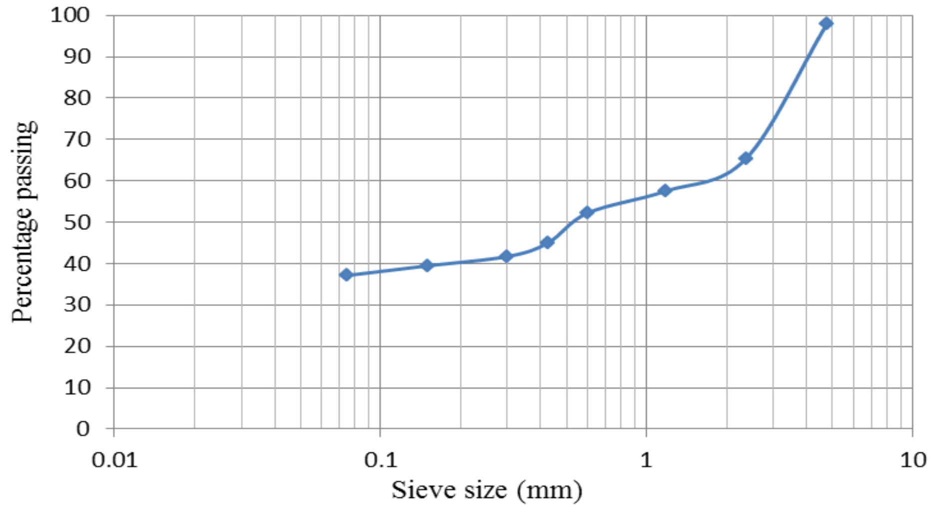

Figure 1: Particle size distribution curve of the natural soil

3.2 Consistency Limits

The LL, PL and PI of the CCS-lateritic soil combination are among the consistency limitations, also known as Atterberg limits. Figure 2 illustrates these limits, demonstrating a decrease in LL, PL, and PI as the CCS treatment increased. Specifically, the LL and PL decreased from 60.05% to 35.55% and 45.37% to 17.95%, respectively, up to 16% CCS content. The PI primarily lessened from 14.70% to 11.50% at 12% CCS content, and subsequently amplified to 15.6%. This observed trend is likely due to broad chemical hydration of CCS in the mixture of lateritic soil, leading to the accumulation and bonding of particles into bigger bands, as suggested by previous studies [28-29]

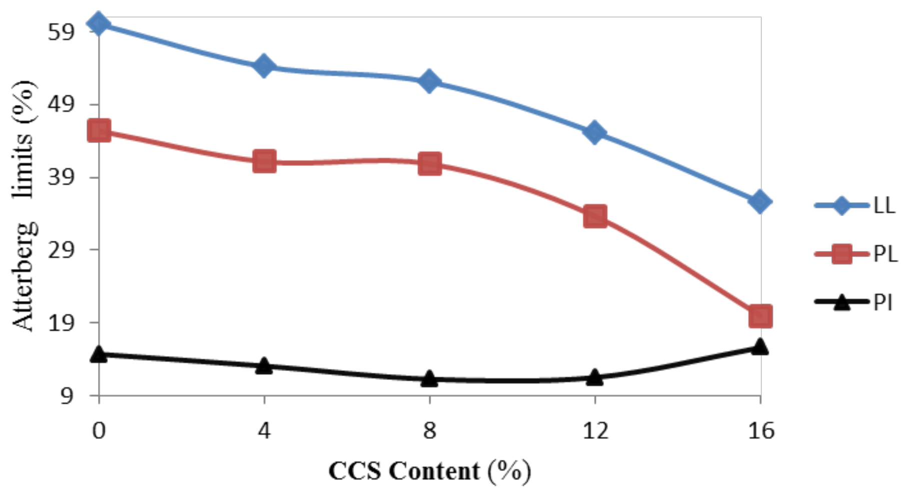

Figure 2: Changes in the Atterberg Limit of Lateritic Soil After Calcium Chloride Salt Treatment

3.3 Compaction Characteristics

3.3.1 Maximum Dry Density

In Figure 3, the curve depicting the MDD of lateritic soil for BSL, WAS, and BSH is illustrated. Initially, at 4% CCS, the MDD values showed a decrease from 1.63 Mg/dm^3 to 1.45 Mg/dm^3, 1.66 Mg/dm^3 to 1.48 Mg/dm^3, and 1.69 Mg/dm^3 to 1.52 Mg/dm^3 for BSL, WAS, and BSH, respectively. However, as the percentage of CCS increased, the MDD values subsequently rose. A related pattern was documented by Edeh et al. [30] when sawdust ash was utilized in enhancement of the qualities of lateritic soil. This observed trend in MDD is likely a result of the CCS particles agglomerating with the fine fraction of the soil. These aggregates of the soil occupy more space, which leads to an expansion in volume and subsequently reduces dry densities, as noted by Osinubi et al. [29], conversely, the rise in MDD is attributed to CCS filling the gaps within the content of moisture content in the soil, resulting in the clustering and aggregation of clay particles through ion exchange, as elucidated by Salahudeen et al.[31]

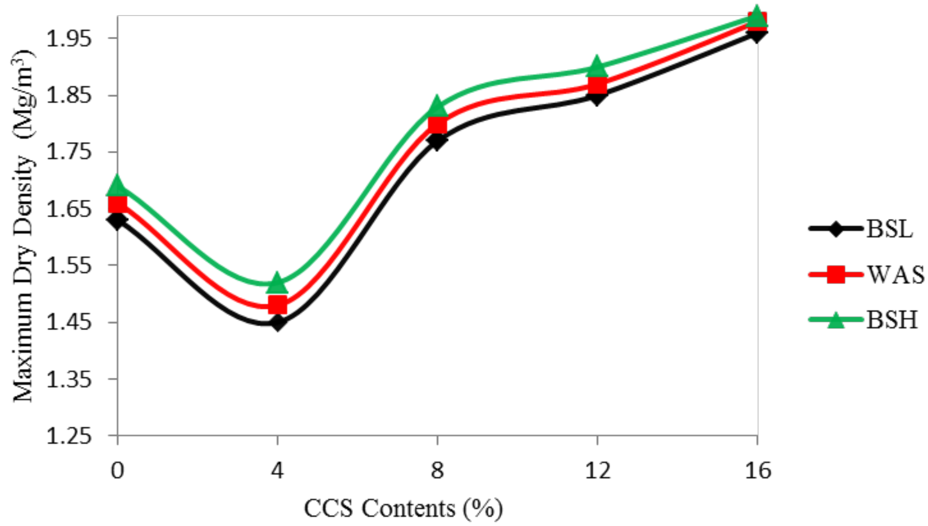

Figure 3: Changes in the MDD of Lateritic Soil After Calcium Chloride Salt Treatment

3.3.2 Optimum Moisture Content

The graph in Figure 4 displays the variation in OMC for BSL, WAS, and BSH compactive efforts in CCS-treated lateritic soil. Initially, at 4% CCS, the OMC for BSL, WAS, and BSH compactive efforts increased from 19.47% to 24.0%, 18.22% to 22.73%, and 17.44% to 21.85%, respectively. However, as the CCS content increased beyond 4%, the OMC subsequently decreased, reaching as low as 16%. The initial heighten in OMC can be credited to the advanced concentration of CCS in the lateritic soil. This increased CCS content resulted in a greater surface area for the particles, necessitating a higher water content to effectively lubricate the entire mixture, as discussed by Ishola et al.[4].

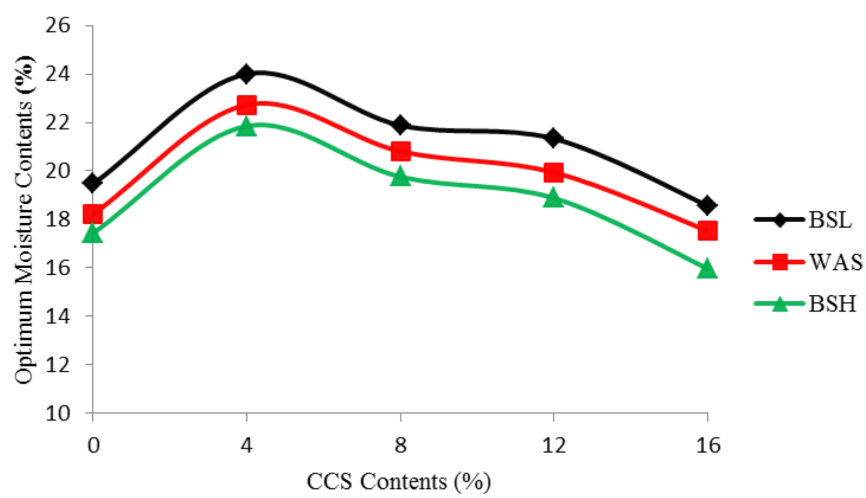

Figure 4: Changes in the OMC of Lateritic Soil After Calcium Chloride Salt Treatment

3.4 California Bearing Ratio

Figure 5 illustrates the CBR variations in the CCS-lateritic soil mixture for BSL, WAS, and BSH. Initially, the unsoaked CBR values for the Oke bale soil under BSL, WAS, and BSH increased from 13.22% to 24.65%, 14.44% to 26.28%, and 15.68% to 28.62%, respectively, reaching their peak at 8% CCS. However, as the CCS content increased beyond 8%, the CBR values decreased to 8.95%, 10.22%, and 12.16% respectively, at 16% CCS. The primary heighten of CBR values can be attributed to the availability of a sufficient amount of calcium, which is necessary in the development of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds are crucial for enhanced strength, as discussed by Salahudeen and Akije [31-32]. It's worth noting that the unsoaked CBR values obtained do not meet the least CBR requirement of 30% indicated by FMWH [26] for base materials. however, meet the requirement for sub-grade materials.

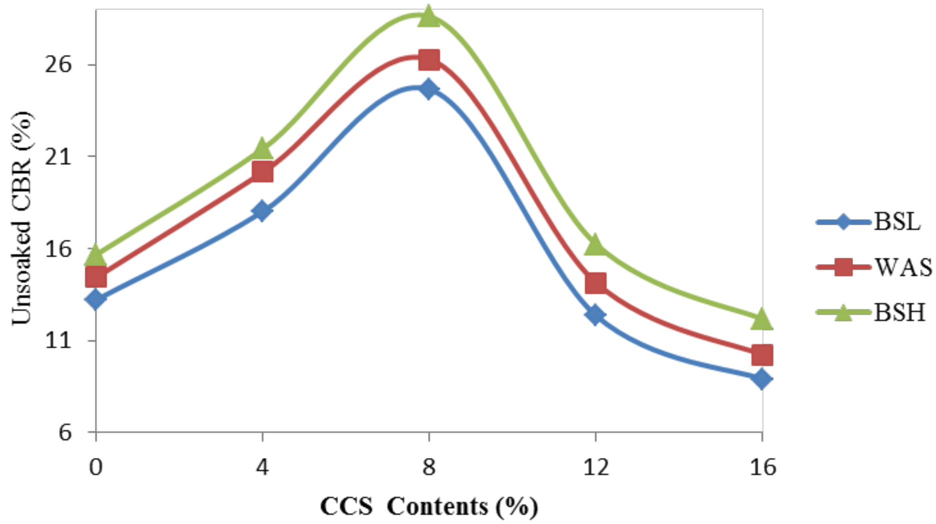

Figure 5: Changes in the CBR of Lateritic Soil After Calcium Chloride Salt Treatment

3.5 Analysis Regression Of Strength Properties Of CCS-Oke Bale Lateritic Soil.

The outcomes of the regression analysis indicated that the strength properties of Oke-bale lateritic soil-CCS mixture were affected by grading properties, compaction characteristics, and the applied compactive effort. This aligns with earlier findings by Oluremi et al. [2], who noted that the effectiveness of laterite soil in pavement structures is mainly contingent on its particle size features, and strength of the particles, and the extent of soil compaction. In this analysis, several geotechnical properties were considered, which are the key factors influencing the strength properties. These properties include calcium chloride salt, MDD, OMC, compactive effort index values (-1, 0 and 1) for BSL, WAS, and BSL compactive efforts respectively, liquid limit, percentage of fine, and plasticity index. Among these properties, calcium chloride salt, MDD, liquid limit, PI, and PI have the most significant impact on the strength property, as they have positive coefficients. Conversely OMC and compactive index values have negative coefficients, indicating their relatively lower significance in affecting the strength. The correlation coefficient values (R^2) indicate a solid bond between CBR and these parameters in Eq. (3), with an R^2 value of 99.8%. The regression equation is as follows:

$$\boldsymbol{CBR} = -813.935 + 7.975\, CCS + 15.850\, MDD - 1.171\, OMC - 0.073\, CE + 4.374\, LL + 14.353\, PF + 1.901\, PI \quad \text{Eqn. 3}$$

Where
CCS = Calcium chloride salt, MDD = Maximum dry density, OMC = Optimum moisture content,
CE = Compactive effort index, LL = Liquid limit, PF = Percentage fine, PI = Plasticity index
The regression model, as shown in Equation 3, was initiated with the help of Minitab R15. It uncovers a powerful connection between the CBR values acquired from testing facilities and predicted values by the model. The coefficient of determination (R) for compaction energies at different standards, including BSL,WAS and BSH, were determined to be 0.9992, 0.9993, and 0.999, respectively. These results are depicted in Figure 6, Figure 7 and Figure 8. Additionally, in Table 3, information about the calculated absolute percentage errors was revealed, which ranged from 0.26% to 3.10% for BSL, 0.70% to 1.83% for WAS, and 0.47% to 1.997% for BSH compaction energies.

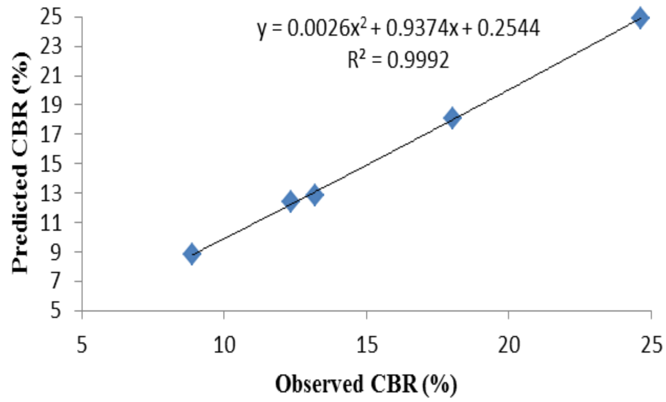

Figure 6: BSL Compaction variation model of measured CBR against predicated CBR value

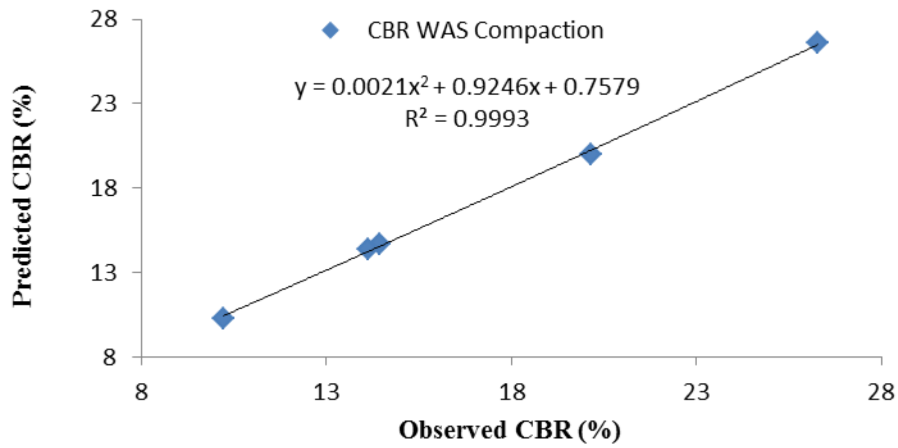

Figure 7: WAS Compaction variation model of measured CBR against predicated CBR value

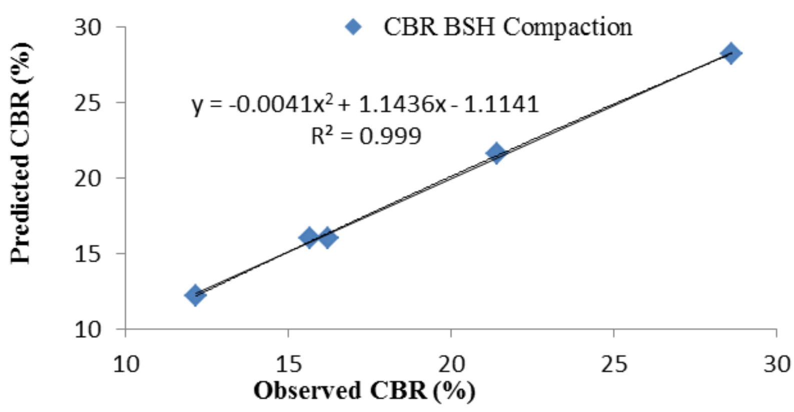

Figure 8: BSH Compaction variation model of measured CBR against predicated CBR value

Table 3: Measured CBR value and predicted CBR value of model result

Compactive Effort	CCS Content	Observed CBR (%)	Predicted CBR (%)	Absolute error	Percentage error
	0	13.22	12.81	0.410	3.102
	4	18.02	18.12	0.099	0.550
BSL	8	24.65	24.91	0.259	1.052
	12	12.35	12.38	0.032	0.260
	16	8.9	8.84	0.058	0.646

	0	14.44	14.68	0.236	1.636
	4	20.15	20.01	0.141	0.701
	8	26.28	26.57	0.285	1.084
WAS	12	14.14	14.4	0.260	1.836
	16	10.22	10.3	0.084	0.825
	0	15.68	15.99	0.312	1.990
	4	21.43	21.6	0.170	0.795
BSH	8	28.62	28.2	0.423	1.479
	12	16.23	16.04	0.187	1.150
	16	12.16	12.22	0.057	0.465

3.6 Analysis of Variance

The statistical analysis of the collected data, encompassing parameters such as CBR, CCS, MDD, OMC, CE, PI, and PF, through the analysis of variance (ANOVA), produced statistically significant results, as detailed in Table 4. These outcomes were derived using the F-distribution test at a 95% confidence level., it was evident that the strength properties had a substantial impact on the results derived from the ANOVA test.

Table 4: Analysis of variance for california bearing ratio

Variables	Sources of Variations	Degree of freedom	Fcal	Fcrit	P-values	Remarks
CBR	CCS	4	2.8981	3.2592	0.06864	NSS
	Strength property	3	4.2411	3.4903	0.0293	SS
MDD	CCS	4	1.2233	3.2592	0.3518	NSS
	Strength property	3	5.1271	3.4903	0.0164	SS
OMC	CCS	4	0.9623	3.2592	0.4629	NSS
	Strength property	3	13.3194	3.4903	0.0004	SS
LL	CCS	1	66.6771	5.3177	3.7670E-05	SS
	Strength property	8	-	-	-	SS
PI	CCS	1	3.1148	5.3177	0.1156	NSS
	Strength property	8	-	-		SS
PF	CCS	1	96.6864	5.3177	9.6246E-06	SS
	Strength property	8	-	-	-	SS

NSS = Statiscally significant , SS = Statiscally significant

4.0 CONCLUSIONS

This research resulted in the following findings:

i. The types of soft soil utilized was grouped as A-7-6 (5) for AASHTO and CL for soil USCS.
ii. The PI of the soft soil treated with CCS decreased until reaching 12% CCS content. A consistent decrease in MDD was noted and accompanied by a simultaneous increase in OMC with the addition of CCS content, up to 4%.
iii. The strength of the lateritic soil treated with CCS increased up to 8% CCS content. This indicates enhancements in the soil's strength, thereby boosting the load-carrying capacity of pavements and suggesting its potential for enhancing low-traffic roads.
iv. The output of the regression analysis illustrated that MDD, liquid limit, percentage of fine particles, and plasticity index have a significant impact on the CBR values of the soil. Additionally, the analysis of variance indicated that both CCS and the soil's strength properties significantly affect the CCS-treated Oke Bale lateritic soil as a pavement construction material

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References

[1] Ishola, K., Ijimdiya, T. S., Yohanna, P., and Osinubi, K. J. 2020. Evaluation of shear strength of compacted iron ore tailings treated lateritic soil. *Platform: A Journal of Engineering*, *4*(3): 48-58. https://myjms.mohe.gov.my/index.php/paje/article/view/8814

[2] Oluremi, J. R., Yohanna, P., Ishola, K., Yisa, G. L., Eberemu, A. O., Ijimdiya, S. T., and Osinubi, K. J. 2017. Plasticity of Nigerian lateritic soil admixed with selected admixtures. *Environmental Geotechnics,* 6(3): 137–145. https://doi.org/10.1680/jenge.15.00085

[3] Alhassan, M. and Mustapha, A.M. 2017 "Review: Utilization of rice husk ash for improvement of deficient soils in Nigeria" *Nigerian Journal of Technology*, 36(2): 386 – 394.

[4] Ishola, K., Agbolade, I. C., & Yohanna, P. 2019a. Effect of Plantain Peel Ash on Gradation and Compaction Characteristics of Tropical Soil. FUOYE *Journal of Engineering and Technology,* 4(2): 28-33. https://doi.org/10.46792/fuoyejet.v4i2.382

[5] Ishola, K., Olawuyi, O.A., Bello, A.A. and Yohanna, P. 2019b Effect of Plantain peel ash on the strength properties of tropical red soil.

Nigerian Research Journal of Engineering and Environmental Sciences 4(1): 447-459

[6] Oke, J. A. and Olowoyo, M. K. 2019. Stabilization of laterite soil with eggshell powder and sodium silicate used as fill material in road construction. *Arid Zone Journal of Engineering, Technology and Environment.* 15(3): 586-597.

[7] Oluremi, J.R., Siddique, R., and Adeboje, E.P 2016. "Stabilization Potential of Cement Kiln Dust Treated Lateritic Soil" *International Journal of Engineering Research in Africa*, 23: 52-63.

[8] Joel, M. and Agbede, I.O. 2011. Mechanical-Cement Stabilization of Laterite for Use as Flexible Pavement Material. *Journal of Materials in Civil Engineering*. 23: 146-152.

[9] Yohanna, P., Ishola, K., Aondover, C.M., Fortunatus, J.K., Fwangshak, G.M., Badamasi, A. 2022. A comparative study on properties of lateritic soil treated with rice husk Ash and metakaolin geopolymer. *Acta Technica Corviniensis* 1: 65-70

[10] Gidigasu, M.D. 1976. Laterite Soil Engineering, Elsevier Scientific Publishing Company, Amsterdam.

[11] Bharti, G., Shukla, B. K., Kumar, A., and Hurukadli, P. N. 2023. Stabilization of black cotton soil using steel slag. In *AIP Conference Proceedings*. 2800(1). AIP Publishing

[12] Sen, D. 2021. Stabilization of Black Cotton Soil using Fly Ash. International *Journal for Research in Applied Science and Engineering Technology,* 9(3): 1100–1106. https://doi.org/10.22214/ijraset.2021.33455

[13] Ishola, K., Adeyemo, K.A, Kareem, M.A., Olawuyi, O.A., Yisa, G.L. Ijimdiya, T.S. 2023. Compaction Characteristics and Workability of The Lateritic Soil-Iron ore Tailings in Pavement Construction. *Journal of Civil Engineering, Science and Technology* 14(2)**:** *117 – 128*. https://doi.org/10.33736/jcest.5337.2023\

[14] Petry, T.M. and Armstrong, J.C. 1989, "Stabilization of Expansive Clay Soils", TRR-1219, TRB, 103- 112.

[15] Hausmann MN (1990) Engineering principles of ground mod-ification. McGraw- Hill, New York

[16] Shon CS, Saylak D, Mishra S 2010. Combined use of calcium chloride and fly ash in road based stabilization. *Journal of the Transportation Research Board*. 2186: 120–129

[17] Zumrawi, M.M, Eltayeb, K.A 2016. Laboratory investigation of expansive soil stabilized with calcium chloride. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering.* 10(2): 223–227

[18] Sani, J. E., Etim, R.K. and Joseph, A. 2018. Compaction behaviour of lateritic soil–calcium chloride mixtures. *Geotechnical and Geological Engineering,* 37: 2343-2362.

[19] Bello, A.A and Adegoke, C. W. 2013. Regression Analysis of Compaction Delay on CBR and UCS of Lime Stabilized Yellowish Brown Lateritic Soil. *Electronic Journal of Geotechnical Engineering*, 18: 3301-3314

[20] Ishola, K., Olawuyi, O. A., Yohanna, P., Bello, A. A., Sani, R. O., and Akin, O. O. 2021. Reliability Evaluation of Compaction Water Content of Plantain Peel Ash Treated Lateritic Soil. Nigerian Journal of Technological Development, 18(1): 47–54. https://doi.org/10.4314/njtd.v18i1.7

[21] Almajed, A., Dafalla, M., & Shaker, A. A. 2023. The Combined Effect of Calcium Chloride and Cement on Expansive Soil Materials. *Applied Sciences*, *13*(8): 4811. https://doi.org/10.3390/app13084811

[22] Bhardwaj, K.A and Kumar, S. 2019. Stabilization of Soil with Calcium Chloride using Gypsum. *International Journal for Research in Applied Science & Engineering Technology* 7(12): 117-126

[23] Bello, A.A., Ige, J.A. and Ayodele, H. 2015. "Stabilization of Lateritic Soil with Cassava Peels Ash. *British Journal of Applied Science and Technology*,7(6): 642-650.

[24] B. S.1377 1990 "Methods of testing soil for civil engineering purposes, British standards institute London.

[25] B. S.1924 1990 "Methods of testing for stabilized soils, British standards institute", London.

[26] Nigerian General Specifications 1997. Roads and Bridges. Federal Ministry of Works, Abuja, Niger

[27] ASTM. 1994e. "Standard test methods for liquid limit, plastic limit, and plasticity index of soils." D4318-10, West Conshohocken, PA, 1–16.

[28] Chew, S.H., Kamruzzaman, A.H.M., and Lee, F.H. 2004. Physicochemical and engineering behavior of cement-treated clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 130(7): 696–706.

[29] Osinubi, K. J., Edeh, J. E., and Onoja, O. W. 2012. "Sawdust ash stabilization of reclaimed asphalt pavements." *Journal of ASTM International*. 9(2): 454–467

[30] Edeh, J., Agbede, I., and Tyoyila, A. 2014." Evaluation of Sawdust Ash-Stabilized Lateritic Soil as Highway Pavement Material." *Journal of Materials in Civil Engineering,* 26(2): 367-373

[31] Salahudeen, A.B., and Akiije, I. 2014. "Stabilization of highway expansive soils with a high loss on ignition content kiln dust". *Nigerian Journal of Technology*, 33(2): 141-148.

[32] Salahudeen, A. B., Eberemu, A. O., & Osinubi, K. J. 2014. Assessment of Cement Kiln Dust-Treated Expansive Soil for the Construction of Flexible Pavements. Geotechnical and Geological Engineering, 32(4): 923–931. https://doi.org/10.1007/s10706-014-9769-0