Reliability Evaluation of Compaction Water Content of Plantain Peel Ash Treated Lateritic Soil

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ABSTRACT: A first-order reliability method (FORM)was employed to assess the compaction water content, CWC (i.e optimum moisture content) of residual lateritic soil mixed with plantain peel ash (PPA) and compacted with British Standard Light (BSL)and British Standard Heavy (BSH)energies, for flexible pavement applications. A Multi-linear regression model was generated from values obtained via laboratory tests using Mini-tab R15 software, which served as a performance function that was applied for the analysis. Using the regression models for CWC, established distributions for the relevant soil factors, safety index (SI) was computed using CWC as a dependent factor and the soil factors Plantain Peel Ash (PPA); Plasticity Index (PI); Percentage File (PF); Specific Gravity (Gs) and Compactive Effort (CE)as self-determining factors). The results revealed that the safety index is sensitive to changeability in the soil factors. Outcome from the analysis show that Gs and CE are greatly affected by alteration in the coefficient of variation (COV), and so it is essential to control Gs and CE in lateritic soil–PPA mixes in road pavements. From the safety index values it reveals that PPA content has a minimal consequence as its value virtually remained constant at all COV used. Stochastically, lateritic soil mixed with PPA produces an acceptable safety index value of 1.0, as mentioned by the Nordic Committee on Building Regulation (NCBR) at 10% COV for BSH of compaction water content only. Therefore a more effective additive such as cement, lime, or bitumen is recommended for modeling CWC of lateritic soil-PPA mixes for road pavement at 10–100% series of COV.

KEYWORDS: Coefficient of variation; compaction water content; lateritic soil; plantain peel ash; reliability index

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I. INTRODUCTION

Lateritic soils are reddish tropically pedogenic deposits occurring in many nations like Australia, Asia, Africa, and South America. Lateritic soils are the outcome of tropical or sub-tropical weathering. Gidigasu, (1976), Sherman (1952), Maigen (1966), Muhammad and Yamusa, (2013), ishola et al., (2019) and Etim *et al.*, (2020) in their findings, reported on the two sets of these tropical soils chemically identified by those in which iron oxide is predominant (ferruginous laterite) and those in which alumina oxide is predominant (aluminous laterite). In tropical nations like Nigeria, lateritic gravels, as well as pisoliths, are predominantly available and this has been observed to be essential for gravel roads purposes as contained in the literatures (Osinubi and Bajeh, 1994; Muhammad and Yamusa, 2013; Etim *et al.*, (2020; Yohanna and Nwaiwu, 2021) and used widely as base material and equally as a sub-base material for roads to be subjected for medium or low traffic. Laterites are categorized as problem soil and non-problem soil. The problematic one is characterised by swelling, depressions, and lateral movement because of moisture effect or impact of wheel loads (Obeahon, 1993; Yohanna and Nwaiwu, 2021). The need to improve deficient lateritic soil is of paramount significance in other to achieve durable pavement and in other engineering applications such as landfills, embankments etc.

The conventional additives for improving deficient soils entail the use of industrially produced additives such as lime, cement, bitumen etc. However, high cost of additives like cement and lime yielded to consideration of agricultural waste such as plantain peel ash (PPA), waste wood ash (WWA), etc on the properties of unsuitable soils for use in engineering applicatons like roads. Agricultural waste exhibiting pozzalanic behaviour was applied and yielded great level of success in many engineering works (Oluremi, 2015; Osinubi, *et al.*, 2017). Research has been on-going on the possibility of using agricultural waste like sawdust ash (SDA), rice husk ash (RHA), bagasse ash (BA) etc. because their pozzolanic behaviour in treatment of deficient soils have recorded positive results (Phanikumar, 2004; Moses, 2008; Moses and Folagbade, 2010; Eberemu, 2011; Sani, 2012; Yohanna *et al.*,

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2016; Osinubi *et al.*, 2015; Etim *et al.*, 2017).The increasing price tag of these additives has remained a problem and the enhancement of lateritic soil with PPA having pozzalanic property may be relatively cheaper.

A reliability evaluation of a structure in engineering is well-defined as the assurance on its capacity to achieve its design determination within a specified time (Dey and Kudmetha, 2013). Reliability evaluation are founded on the probability philosophies which provide the platform for its measurement. The reliability of a system can be regarded as the likelihood of its acceptable performance based on certain given performance functions. This function is for a definite purpose and it is laid open to extreme settings within a given time (Dey and Kudmetha, 2013). Several kinds of research (Harrop-Willians, 1985; Gui *et al*., 2000; Eberemu, 2008; Nwaiwu *et al*., 2009; Yisa and Sani, 2014; Oluremi *et al.,* 2018) reported on reliability applications in geotechnical engineering for design with respect to varying rock and soil properties. Past researches (Nwaiwu *et al*, 2009; Yisa and Sani, 2014; Sani *et al*, 2014; 2017; Yohanna *et al*, 2018) made use of mathematical tools like the probability principle to define uncertainties in engineering design and weigh their consequences on field performance. These approaches are been used in assessing structural and geotechnical requirements like reliability estimate of strength and compaction properties, bearing capacity etc.

A FORM integrated in FORTRAN program was used to appraise the effect of compaction water content(CWC) on lateritic soil – PPA mixes. The aim is to generate safety index values for compaction water content (CWC) with respect to the soil self-determining variables.The objective was to determine the variability in safety index values base on laboratory– based model with respect to all the soil parameters.

A. Safety Factor

The elementary method for weighing the factor of safety (Safety factor) of a system in engineering was established on its permissible factor of safety determined on the basis of the particular opinion of responses from related systems. Engineers developed a method for measuring the safety factor defined as the relation between assumed nominal standards of capacity x and demand y (Kotegodaand Rosso, 1997, Duncan, 2000) as shown in Eq. (1).

$$Z = \frac{x}{y} \tag{1}$$

The variables x and y cannot be obtained with certainty, therefore are measured as probability distribution. Factor of safety designated by z = x/y with regard to the random variables x and y is similarly a random variable. The relationship between capacity x and demand y for the structure is defined as $z = x/y$. Probability Pr of a system of failure is explained as in Eq. (2).

$$P_T = P_T(Z < 1) - F_2 \tag{2}$$

The corresponding probability of nonfailure defined in Eq. (3).

$$R = 1 - P_T(Z < 1) = 1 - F_2 \tag{3}$$

After determining the combined probability distribution for variables x and y, the safety index of the entire system can be calculated by defining the comulative distribution function of x/y. Assuming peak demand Y_{max} does not surpass the least capacity X_{min} then a chances of failure of zero (pr = 0) and 100 percent reliability (r = 1) occurs. Under such condition, there is no overlapping of the two distributions (Oriola *et al.*, 2012).

B. Reliability/Safety Index

The mathematical explanation for the safety index is presented in Eq. (4).

$$\beta = \frac{\mu}{d} \tag{4}$$

The index is defined as the competence of an engineering design deduced as the standard deviation *d* within the average value of the safety margin.

$$E(s) = \mu \tag{5}$$

where its corresponding critical value *s* is 0.

The safety index (ß) is the relation of the mean and standard deviation of the system (Yisa and Sani, 2014). Alternatively, safety index is the inverse of COV of the safety margin, Thus ß = I/Vs, as explained in literatures(Kottegoda and Rosso, 1997;Yisa and Sani 2014; Oluremi *et al.,* 2018).

C. First-Order Reliability Method (FORM)

FORM is a deterministic and probabilistic design that differs in norm and engineering uses. Design problems comprise of component of several uncertainties. Probabilistic design is affected by the facts that a structure will agree with the functions assign to it to perform a design assignment (Afolayan and Abubakar, 2003).

For instance, let r and s be strength capacity and the loading effect of a system which are random variables, the goal of reliability analysis is to certify that r on no occasion is surpassed by s (Oriola *et al*, 2012). Therefore, r and s are generally functions of dissimilar parameters. In other to regulate the influence of the parameters on the behaviour of the system, a limit state equation (LSE) in relation to basic design factors is essential (Afolayan and Abubakar, 2003). This LSE is expressed as:

$$g(t) = g(x_{1,} x_{2,} \dots\dots\dots x_{n,}) = r - s \tag{6}$$

where x_1 for *i* = 1, 2, 3, 4, 5, 6, 7, 8….*n*, imply design factors.

The limit state for the system is explained by Eq. (7).

$$G(t) = 0 \tag{7}$$

II. MATERIALS AND METHODS

Soil used for this work was sourced from Osogbo, Osun State, Nigeria. The plantain peels use was acquired from a dump site in Osun State. Plantain peels obtained was first air dried then burnt into ashes, followed by sieving through sieve No 200 (0.075mm) to obtain plantain peel ash (PPA). The investigations on compaction water content, CWC (i.e optimum moisture content) and the parameters linked with water content of compaction were determined through the laboratory work. Soil sample was treated with 0, 2, 4, 6, 8 and 10% PPA to determine the index and compaction behaviour of the mofified soil which aid in developing the regression equation in Eq. (9).

The various factors considered were; CWC as dependent factors and PPA; PI; PF; Gs and CE as self-determining factors. CWC and PI were presumed to be lognormally distributed while PPA; PF and Gs were assigned normal distributions. The performance function employed was integrated into a FORTRAN program, as suggested in previous works (Osinubi et al., 2016, Yohanna et al., 2018) used for the modelling the CWC. The prediction of safety indices for single parameter at a time was achieved within 10 to 100% COV whereas the original values for other factors remained unchanged. The multi-linear regression model was established by means of Minitab R15 (see Eq. (9)) used to predict CWC from the laboratory results. Reliability analysis input values are displayed in Table 1. The regression modelling equation for CWC is shown in Eq. (10).

$$\mathrm{CW} = -1.1 - 0.044\mathrm{PPA} + 0.0278\mathrm{PI} + 0.0134\mathrm{PF} + 4.524\mathrm{Gs}1.758\mathrm{CE} \quad (9)$$

$$R^2 = 84.8\% \quad (10)$$

III. RESULTS AND DISCUSSION

The modelled Eq.(9) shows association amid the self-determining factors (PPA; PI; PF; Gs and CE) and the dependent factor (CWC). From the modelled, it can be inferred that, a good affiliation occurs between the self-determining factors and the CWC clearly evident by 84.8% regression coefficient recorded. From the established relationship, the engineering importance of this relation shows that the mentioned variables has a good effect on the CWC and thus need to be considered during performance to arrive at the required compaction density. Moisture control is considered as the proportion of compaction water added to the soil in the course of field compaction which alters the density and the corresponding structural strength of a flexible pavement. Morever, engineering performance and durability of roads cannot be properly explained outside the impact of the CWC which is greatly influenced by the factors in Eq. (9). It is thus of great significance to put these factors to use during field compaction of lateritic soil-PPA mixes to arrive at the required durable flexible pavemenet.

Table 1: Input data use for analysis.

S/No	Variables	Distribution type	Mean *E (x)*	Standard Deviation *S (x)*	COV (%)
1	Compaction Water Content	Lognormal	11.09	2.002	18.05
2	Plantain Peel Ash	Normal	5.00	3.570	71.4
3	Plasticity Index	Lognormal	21.62	4.870	22.53
4	Percentage Fine	Normal	46.58	19.780	42.46
5	Specific Gravity	Normal	2.47	0.044	1.78
6	Compactive Effort	Deterministic parameter	_	_	_

From Eq. (9), it can be observed that, increase in PPA and CE, results to a drop in CWC values as a result of their negative coefficient while opposite is the situation for PI, PF and Gs with positive coefficients. Also, Gs and CE with high coefficients have considerable influence on the CWC when compared to other factors. The inference of the coefficients for the factors can be applied in the field to asses the performance on the road. The site engineer should therefore ensure strict adhenrence to these conditions as it will have great impact on the compacted density of the soil in the field and thus, consequently affect the structural strength and durability of the road pavement.

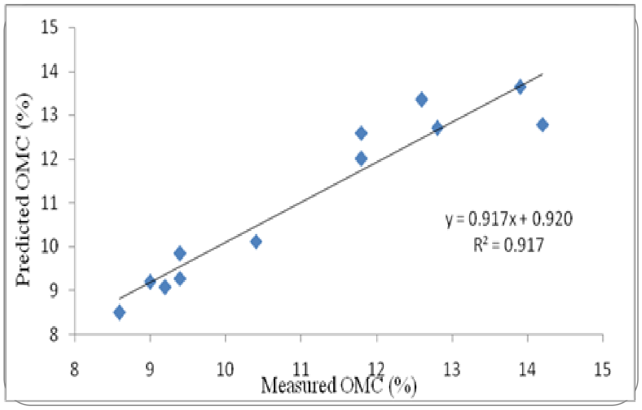

Figure 1: Predicted against measured CWC values.

The plot of affiliation between laboratory and predicted values from the model is shown in Figure 1. strong bond was recognized between them with a coefficient of determination of 0.9171 (Figure 1) and 0.721 to 9.918% errors (Table 2). The plot of CWC/Standardized coefficients (95% confidence interval) with variables is shown in Figure 2. The plot shows the impact of every one of the self-determining factors to the compaction water content.

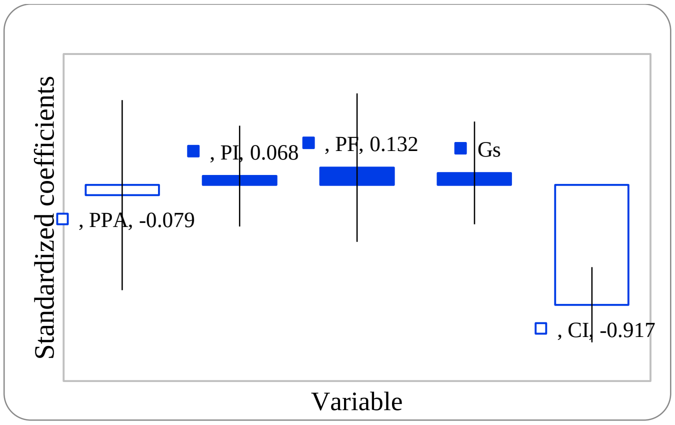

Figure 2: Plot of CWC/ Standardized coefficients (95% confidence interval) against Variable.

A. Influence of Compaction Water Content on Safety Index

The influence of compaction water content, CWC with safety index at 10– 100% COV is displayed in Figure 3. A linear declining trend was established with 10-100% range of COV for both BSL and BSH compaction energy. Although an initial increase was observed for BSL, it later decreased progressively with increase in COV. Safety indices varied substantially which is a signal that inconsistency in compaction water content has extreme impact on the safety index when used as pavement materials. As COV inclined from 10-100%, β values varied from -1.44 to -0.591 and -0.206 to1.58 for BSL and BSH respectively. Lower safety index values were noted for BSL than BSH which indicate that compactive effort has significant influence on the optimum moisture required to achieve the desired result. Therefore, care should be taken to safeguard that proper compaction energy is applied in the field at a regulated amount of moisture to achieve the required density in the field during road construction.

B. Influence of Plantain Peel Ash on Safety Index

Figure 4 shows the effect of variation in plantain peel ash (PPA)on safety index for BSL and BSH compaction energies correspondingly. The safety indices varied slightly with COV for both energies. Safety indices of -0.892, -0.892, -0.891, -0.891, -0.891, -0.890, -0.890, -0.889, -0.889 and -0.888 were recorded for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% COV respectively, for BSL compaction energy. In the case of BSH energy level, safety indices of 0.869, 0.869, 0.869, 0.868 0.867, 0.867, 0.866, 0.865, 0.863 and 0.862 were recorded for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% COV respectively. The marginal changes in the safety index values is a pointer to the fact that alteration in PPA content has little impact on the treated soil when applied for use as sub-base materials in construction of roads.

Table 2 Measured and predicted CWC values derived from model.

S/No	PPA content (%)	Compactive effort	Compactive effort index	Measured CWC	Predicted CWC	Absolute Errors	% Errors
1	0	BSL	-1	13.90	13.64	0.261	1.877
2	2	BSL	-1	12.60	13.36	0.757	6.009
3	4	BSL	-1	12.80	12.71	0.092	0.721
4	6	BSL	-1	14.20	12.79	1.408	9.918
5	8	BSL	-1	11.80	12.59	0.795	6.736
6	10	BSL	-1	11.80	12.01	0.210	1.777
7	0	BSH	1	10.40	10.12	0.278	2.669
8	2	BSH	1	9.40	9.84	0.441	4.686
9	4	BSH	1	9.00	9.19	0.191	2.122
10	6	BSH	1	9.40	9.27	0.125	1.331
11	8	BSH	1	9.20	9.08	0.122	1.325
12	10	BSH	1	8.60	8.49	0.107	1.244

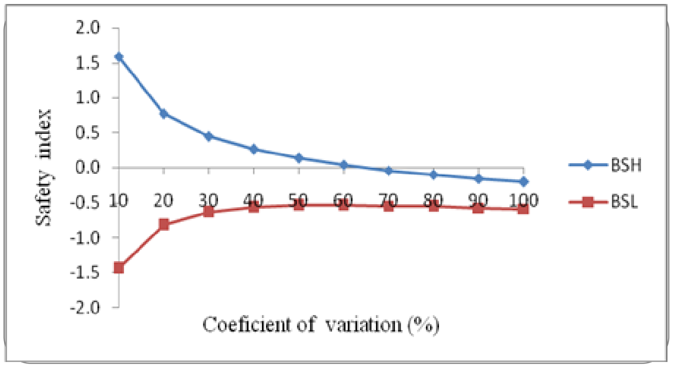

Figure 3: Changes in safety index with COV for compaction water content.

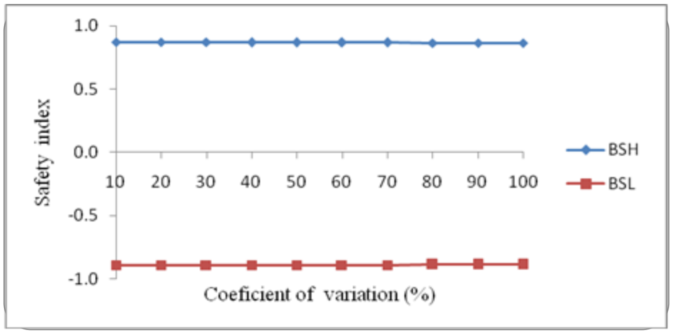

Figure 4: Changes in safety index with COV for plantain peel ash content.

C. Influence of Plasticity Index on Safety Index

The effect of variation in PI on safety index with changes in COV is displayed in Figure 5. The safety index varied slightly with changes in coefficient of variation for both BSL and BSH energy levels. Safety index values ranged between -0.896 and -0.812 for BSL compactive effort. However for BSH compactive effort, safety index values ranged between 0.861and 0.939 as the COV rise from 10 – 100%. The marginal increase recorded in the safety index values for both energy levels is an indication that changes in PI of the treated soil (which controls the swelling potential of the soil) has only a slight or no impact on the safety index for road pavement purposes. This presumed that plasticity index of lateritic soil treated with PPA has little effect on the performance of the road pavement.

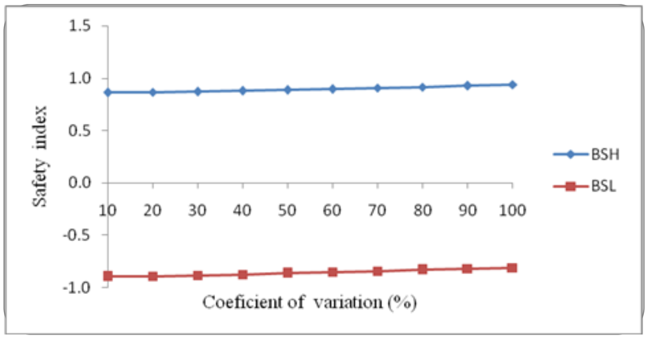

Figure 5: Changes in safety index with COV for plasticity index.

D. Influence of Percentage Fines on Safety Index

The outcome of safety index for percentage fines of lateritic soil – PPA mixtures with COV is displayed in Figure 6. The safety index marginally change with COV. As COV rise from 10 to100 %, safety indices changed from -0.895 to -0.864 for BSL compactive effort and 0.823 to 0.875 for BSH compactive effort correspondingly. Changes in the percentage fine has only slight influence on the water content of compaction as shown in the deviations in safety indices. This is an indication that for lateritic soil – PPA mixtures, the percentage fine is a secondary factor that should be skilfully supervised in the course of field compaction, specification and controlled for road pavement or every geotechnical engineering application where lateritic soil – PPA mixtures are used.

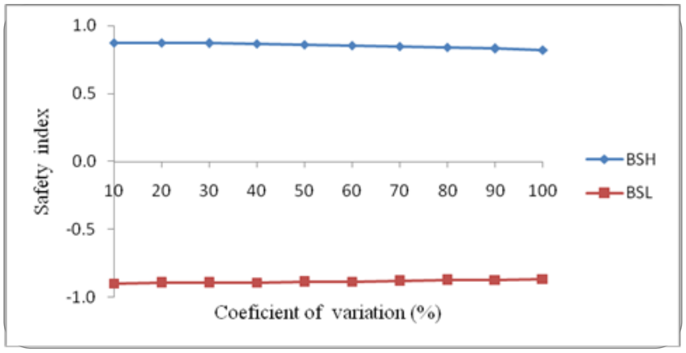

Figure 6: Changes in safety index with COV for percentage fine.

E. Influence of Specific Gravity on Safety Index

The differences in safety index for specific gravity of treated lateritic soil–PPA content with COV is displayed in Figure 7. Largely, safety index increased linearly with COV from 10 to 100% for BSL compaction energy, with safety index values increasing from -0.802 to -0.169. In the case of BSH compaction energy, safety index values dropped significantly with safety index values reducing from 0.734 to 0.141. Safety indices of -0.802, -0.63, -0.488, -0.39, -0.322, -0.273, -0.237, -0.209, -0.187and -0.169 were recorded for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% coefficient of variation respectively, for BSL compaction energy.

In the case of BSH energy level, safety indices of 0.734, 0.544, 0.414, 0.329, 0.271, 0.23, 0.199, 0.175, 0.157 and 0.141 were recorded for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% coefficient of variation respectively, for BSH energy level. Safety index varied substantially for both energies which is a sign that changes in specific gravity has substantial consequence on the safety index for used in road pavement. Therefore, caution should be taken to guarantee that this factor is properly structured in the field at a regulated amount of moisture to achieve the required density in the field during road construction.

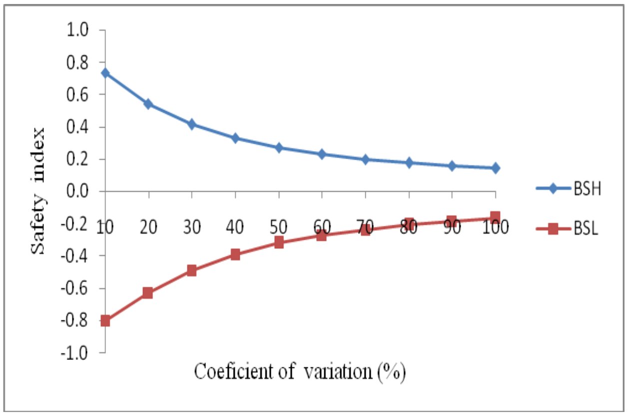

Figure 7: Changes in safety index with COV for specific gravity.

F. Sensitivity of Safety Indices for BSL and BSH Compaction

A relative sensitivity study of the safety indices of the lab based multi–linear regression model used was likened with the changes in the self-determining factors considered (PPA, PI, PF and Gs) to assess their influence on the compaction water content. It was generally noticed that safety indices changed for all the factors considered with Gs taking a major influence on the compaction water content than the other parameters. This is shown by the wide variation in safety indices with coefficient of variation (Figure 8 and Figure 9).PPA, PI and PF have marginal impact on the compaction water content of the modified soil denoted by slight changes in their safety indices with coefficient of variation. Greater safety indices were observed for BSH energy when compared to BSL energy for all the parameters studied.

For this reason, a good quality control measure for factors with major effect on the compaction water content is of significance in the course of field compaction specification and regulations when used as road pavement materials; so as to attain worthy flexible pavement materials with statistically meaningful safety index standards.

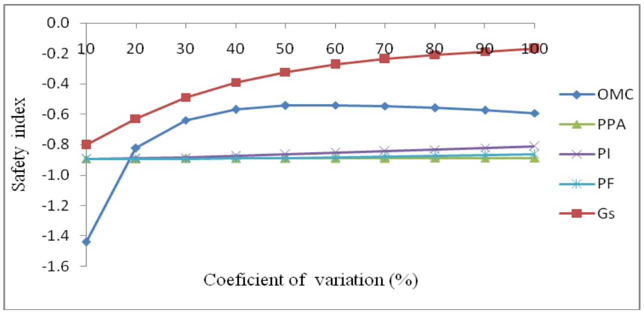

Figure 8:Changes in safety index for CWC of BSL compaction variables of lateritic –plantain peel ash mixes with COV.

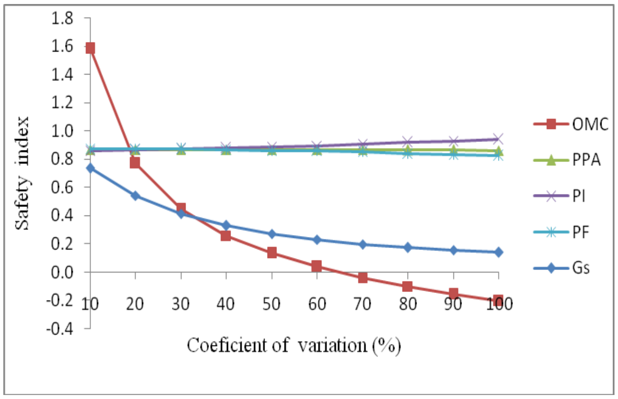

Figure 9:Changes in safety index for CWC of BSH compaction variables of lateritic –plantain peel ash mixes with COV

G. Statistical Study

Analysis of variance in two way (ANOVA) for the safety indices of all the results obtained for the soil factors (CWC, PI, PF and Gs) with respect to plantain peel ash (PPA) produced statistically significant (SS) effect. However, few exceptions in some cases were No significant (NS) effect was recorded as displayed in Table 3, by applying F-distribution test at significance level of 95% and 5% confidence interval. The plantain peel ash (PPA) and CE has major consequence on the results from the ANOVA test, because significant effect were recorded in most cases (see Table 3). Hence, it is vital to make sure that best blend of PPA content is added to the soil that will give rise to effective safety index values since they have been established to have influence on CWC.

H. Stochastic Model Evaluation

The safety index developed with respect to the various parameters measured are displayed in Table 4 . NCBR (NKB Report, 1978) as well as in related literatures (Yisa and Sani,2014; Yohanna and Nwaiwu,2021) stated that a safety index value of 1.0 is the required base value for serviceability limit state design of structural components. As shown in Table 4, only 10% at BSH compaction water content met the 1.0 lowest value stated. As stated in the code and literatures safety indices of less than 1.0 is unsafe for application in structural and geotechnical engineering fields.

From the results, the lower values may be presumed to be due to the low potency of PPA to inprove the geotechnical properties of the soil to meet the minimum safety index values.Thus, the use of more potent industrial additives like cement or lime is recommended in order to produce higher safety index values of greater than 1.0. Also, higher compaction energy of BSH recorded higher and wide range of safety indices this could be linked to the packaging effect of the compaction rammer that increased the density of compacted soil.

Table 3: Analysis of variance of safety indices.

Property	Source of Variation	Degree of freedom	F-value calculated	P-value	F-value calculated	SS
Compaction water content	Compactive effort	1	13.69385	0.004917	5.117355	SS
	PPA	9	0.140263	0.996324	3.178893	NS
Plasticity index	Compactive effort	1	4210248	7.9E-27	5.117355	SS
	PPA	9	445.5488	7.83E-11	3.178893	SS
Percentage fine	Compactive effort	1	36027.42	1.59E-17	5.117355	SS
	PPA	9	0.067783	0.999775	3.178893	NS
Specific gravity	Compactive effort	1	29.3089	0.000425	5.117355	SS
	PPA	9	0.002485	1	3.178893	NS

Table 4: Water content of plantain peel ash treated lateritic soil and satisfactory safety index for compaction.

Variables Factors	Beta Value		Satisfactory Range of COV (%)
	BSL	BSH	
Compaction water content	-1.44 to -0.591	-0.206 to 1.58	10% BSH
Plantain peel ash	-0.892 to -0.888	0.862 to 0.869	Nil
Plasticity index	-0.896 to -0.812	0.861 to 0.939	Nil
Percentage fine	-0.895 to -0.864	0.823 to 0.875	Nil
Specific gravity	-0.802 to -0.169	0.141 to 0.734	Nil

IV. CONCLUSION

A reliability approach was used to appraise the CWC of lateritic soil–PPA mixtures and compacted with BSL and BSH energies, for road applications. Multi-linear regression model was established from laboratory measured data using Mini-tab R15 software which operated as a performance function for the reliability analysis. Results show that Gs and CE are affected by the change in COV and therefore must be strictly measured in lateritic soil–PPA mixes compacted with BSL and BSH energies for road pavements. It was obvious from the safety index that PPA content has minor effect and was not significantly different at all values of COV used.

Analysis of variance produced statistically significant (SS) effect with few exceptions in some cases. Gs have a more significant influence on the compaction water content than the other parameters and this is shown by the wide variation in safety indices with coefficient of variation. Stochastically, lateritic soil mixed with PPA gave adequate safety index value of 1.0 as endorsed by the NCBR at 10% COV for BSH of compaction water content only. The engineering performance and durability of roads cannot be properly explained outside the impact of the compaction water content which is greatly influenced by the factors in the model. It is thus of great significance to put these factors to use during field compaction of lateritic soil-PPA mixes to arrive at the required durable flexible pavement.

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