

Reliability Estimate of Unconfined Compressive Strength of Black Cotton Soil stabilized with Bagasse Ash and Cement Kiln Dust

Hamidu, H. I.¹, Sani J. E.², Bello A. O., and Yisa G. L.³

¹Department of Civil Engineering, Kaduna Polytechnics, Kaduna.

²Department of Civil Engineering, Nigeria Defence Academy, Kaduna State, Nigeria.

³Nigeria Building and Road Research Institute, Ota, Ogun State, Nigeria.

Abstract: Reliability of estimates of strength characteristic values from laboratory results for specimens compacted at the energy levels of British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) for compacted bagasse ash treated black cotton soil using cement kiln dust (CKD) as an activator was developed by incorporating data obtained from Unconfined compressive strength (UCS) test gotten from the laboratory test to produce a predictive model. Data obtained were incorporated into a FORTRAN-based first-order reliability program to obtain reliability index values. variable factors such as water content relative to optimum (WRO), hydraulic modulus (HM), bagasse ash (BA), cement kiln dust (CKD), Tri-calcium silicate (C3S), Di-calcium silicate (C2S), and maximum dry density (MDD) do not produced acceptable safety index value of 1.0 at the three energy levels namely BSL, WAS and BSH compactive effort at coefficient of variation (COV) ranges of 10-100%. Observed trends indicate that the WRO, HM, BA and MDD is greatly influenced by the COV and therefore must be strictly controlled in CKD/BA treated black cotton soil. Stochastically only BSH compactive efforts are the only energy levels that can be used to model the 7 days unconfined compressive strength of compacted CKD/BA treated black cotton soil because the safety index values obtained are closer to the acceptable 1.0 safety index for serviceability limit state design (model 1) of structural components.

Keywords: Compaction, Compactor weight, Hydraulic Modulus, Bagasse Ash, Black Cotton Soil, Cement Kiln Dust, Reliability Analysis, Reliability Index, Unconfined Compressive Strength.

1.0 Introduction

The need to reduce the uncertainties in geotechnical engineering during design and construction in terms of the variable nature of soil and rock properties and other in situ conditions has become a major challenge because of the uncertainties about the reliability of design and construction methods, and uncertainties about the costs and benefits of proposed design strategies. Probability theory is a mathematical tool that can be used to formally include such uncertainties in an engineering design and to assess their implications on performance (Yisa and Sani, 2014).

Black cotton soil (BCS) is an expansive soil that principally occurs in arid and semi arid regions of the tropical/temperate zones marked with dry and wet seasons; and with low rainfall, poor drainage and exceedingly great heat. The climate condition is such that the annual evapotranspiration exceeds precipitation (Chen, 1988; Nelson and Miller, 1992; Warren and Kirby, 2004). These soils are predominant in the Northeastern part of Nigeria occupying an area of about 10.4×10^4 km (Ola, 1983). Black cotton soils owe their specific properties to the presence of swelling clay minerals, mainly montmorillonite. As a result of the wetting and drying, massive

expansion and contraction of the clay minerals takes place. Contraction leads to the formation of the wide and deep cracks. Cracks measuring 70 mm wide and over 1m deep have been observed (Adeniji, 1991) and may extend up to 3 m or more in the case of high deposits. Surface material accumulates in these cracks during the dry season and is “swallowed” by the soil in the wet season, creating the ‘self mixing’ or ‘self mulching’ action of the black cotton soils.

Bagasse ash treated black cotton soil used on cement kiln dust as an activator recorded great improvement in terms of strength gain (Bello, 2014). The peak value of the treated soil at BSL, WAS and BSH compactive efforts falls short of 1710 kN/m² specified by TRRL (1977) for base material but meet the requirement of 687–1373 kN/m² for sub-base as specified by Ingles and Metcalf (1972).

Strength is one of the major material properties of BCS that can be significantly affected by variability in composition and admixtures. Engineering analyses and designs require the application of probabilistic methods as deterministic approaches do not rigorously account for these uncertainties. Probability theory has been widely accepted and used in engineering. The application of probability theory to engineering analysis requires the knowledge of some statistical attributes of the relevant random variables such as their mean values and standard deviations (Kaymaz et al., 1998). One of such probabilistic methods is reliability analysis which has been used in geoenvironmental engineering (Gilbert and Tang, 1995; Rowe and Fraser, 1995; Nwaiwu et al, 2009).

Reliability analysis provides a frame work for establishing appropriate factors of safety and other design targets and leads to a better appreciation of the relative importance of uncertainties in different parameters (Christian and Baecher, 2001). Reliability analysis can be used to assess the suitability of compacted bagasse ash treated black cotton soil used with cement kiln dust on unconfined compressive strength.

2.0 Reliability Index

Another measure of the adequacy of an engineering design is the reliability index, defined as

$$B = \mu/d \quad (1)$$

This can be interpreted as the number of sigma units (the number of standard deviation dx) between the mean value of the safety margin.

$$E(s) = \mu \quad (2)$$

and its critical value

$$S = 0 \quad (3)$$

The reliability index of a system, denoted by β is defined as the ratio between the mean and standard deviation of the safety margin of the system.

By definition, the reliability index is the reciprocal of the coefficient of variation of the safety margin, that is $\beta = 1/V_s$ (Kottegoda and Rosso, 1997).

2.1 Concept of First – Order Reliability Method (FORM)

The probabilistic and deterministic approaches to design differ in principle. Deterministic design is based on total ‘discounting’ of the contingency of failure. Design problems involve element of uncertainty; unpredictability of randomness.

Probabilistic design is concerned with the probability that the structure will realize the functions assigned to it (Afolayan and Abubakar, 2003).

If r is the strength capacity and s the compositional effect(s) of a system which are random variables, the main objective of reliability analysis of any system or component is to ensure that r is never exceeded by s . In practice, r and s are usually functions of different basic variables. In order to investigate the effect of the variables on the performance of the system, a limit state equation in terms of the basic design variable is required (Afolayan and Abubakar, 2003).

This limit state equation is referred to as the performance or state function and expressed as:

$$g(t) = g(x_1, x_2, \dots, X_n) = r - s \quad (4)$$

Where x_i for $i = 1, 2, 3, \dots, n$, represent the basic design variables.

The limit state of the system can then be expressed as

$$G(t) = 0 \quad (5)$$

Reliability calculations provide a means of evaluating the combined effects of uncertainties and a mean of distinguishing between conditions where uncertainties are particularly high or low. In design evaluation involving the selection of a value for a soil parameter to be used for geotechnical analysis, reliability analysis, which involves the application of probabilistic concepts, is suitable for taking care of uncertainties (Duncan, 2000).

Soil reliability can be estimated from eq. (6) if the type of probability distribution function for K and its statistical parameters (mean, standard deviation, variance, etc) are

known. This is also possible only with the probability of survival as given in eq. (7):

$$P_s = 1 - P_f \quad (6)$$

Where P_s = probability of survival and P_f = probability of failure.

In the reliability analysis of compacted road pavement structure material, failure would occur when the 7 days UCS is less than the minimum value of 1720 kN/m² specified by TRRL (1977), for sub base during its service period or design life. The probability of failure (P_f) can then be formulated as:

$$P_f = P \{ S_c - S_o (WRO, HM, BA, CKD, C_3S, C_2S, E, MDD) \leq 0 \} \quad (7)$$

where:

S_c = Expected Strength

S_o = Specified regulatory minimum strength

WRO = Water with respect to optimum

HM = Hydraulic modulus

BA = Bagasse ash content

CKD = Cement kiln dust content

C_3S = Tri-Calcium Silicate

C_2S = Di-Calcium Silicate

E = Compactive Effort Index

MDD = Maximum Dry Density

which are parameters affecting the unconfined compressive strength and are used in predicting unconfined compressive strength values based on laboratory results and compound formations contents based on admixture combination ratio.

3.0 Materials and Methods

3.1 Database and Statistical Analysis

A database was compiled by extracting data on Bagasse ash stabilized black cotton soil using cement kiln dust as an activator from the laboratory test results of unpublished literature (Bello, 2014). The statistical

characteristics of the material composition and compaction variables for the black cotton soil are shown in Table 1.

3.2 Set-up of Numerical Experiments Reliability Analysis

The results of all laboratory experiments on strength and the parameters associated with strength were measured during the laboratory work. The various parameters measured include the following unconfined compressive strength UCS, water content with respect to optimum (WRO), hydraulic modulus HM, bagasse ash BA, cement kiln dust CKD, maximum dry density MDD, compactive effort index (E), and calculated compound compositions such as Tri-Calcium Silicate and Di-Calcium Silicate C₂S. Fundamentally, strength, water content with respect to optimum, maximum dry density C₂S and C₄AF are normally assumed to have a lognormal distribution (Eberemu, 2008; Stephen, 2010; Nwaiwu *et al*, 2009). While BA and CKD has a normal distribution (Eberemu, 2008; Stephen, 2010). The compactive effort index is an integer categorical variable describing compactive effort. It was assigned -1, 0 and 1 for British Standard light, West African Standard and British Standard heavy compactive efforts, respectively. These results were used to run a regression model for predicting laboratory UCS results. The

statistical analyses were carried out using the tools of analysis Mini-tab R15 software and the regression equation obtained is given in equation (8) bellow.

$$UCS(7) = -2687 - 22.3 WRO - 58.4 HM + 0.39 BA + 121 CKD - 21.2 E + 2.64 C3S + 2.84 C2S + 1863 MDD \quad (8)$$

Reliability analysis is intended to assess the suitability of compacted bagasse ash treated black cotton soil strength characteristic for use as a sub grade material. This becomes necessary due to the variability that might exist from black cotton soil obtained from one location to another and the compositional content of the additives. The statistical characteristics of the relevant black cotton soil – bagasse ash – cement kiln dust as well as physical properties of their probability distribution functions types were established.

The relevant statistical properties for black cotton soil – bagasse ash – cement kiln dust mixtures were then incorporated into FORTRAN programmes for a field based predictive model in order to evaluate reliability levels and to predict UCS using the ‘first order reliability methods’ version 5.0 (FORM 5) (Gollwitzer *et al.*, 1988). The input data for the reliability analysis from the laboratory strength results are shown in Table. 1.

Table.1. Input data for reliability based design for eight independent variable using FORM 5 from laboratory measured strength.

S/No	Variables	Distribution type	Mean E(x)	Standard Deviation S(x)	Coefficient of Variation COV (%)
1	Unconfined compressive Strength	Lognormal	7.6224E2	3.72E2	48.81
2	Water Content Relative to optimum (WRO)	Lognormal	1.583E1	1.901E0	12.01
3	Hydraulic modulus HM	Lognormal	1.138E0	1.586E0	139.37
4	Bagasse ash BA	Normal	5.0E0	3.435E0	68.7
5	Cement kiln dust CKD	Normal	4.0E0	2.844E0	71.1
6	Tri-calcium Silicate C ₃ S	Lognormal	1.911E2	2.15E2	112.51
7	Di-calcium Silicate C ₂ S	Lognormal	2.314E2	2.064E2	89.16
8	Maximum dry density MDD	Lognormal	1.7344E0	7.99E-2	4.61
9	Compactive effort E	Deterministic parameter	-1, 0, 1	-	-

Sensitivity analysis for each of the independent variables that affect strength was performed by varying the assumed values of coefficient of variation (COV) ranging from 10-100% to obtain reliability indices (safety indices or β -values). The safety indices for the seven independent variables evaluated that affect strength are: water content relative to optimum (WRO), hydraulic modulus HM, bagasse ash BA, cement kiln dust CKD, C₃S, C₂S, and Maximum dry density MDD; at compaction energy levels of British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) were obtained.

4. Results and Discussion

4.1 Unconfined Compressive Strength *Effect of Strength on Reliability Index*

The effect of unconfined compressive strength on reliability index as the coefficient of variation is varied when computed with a minimum value of 1710 kN/m² specified by TRRL (1977) is shown in Fig.1. Higher safety indices were recorded for higher compaction energies. Strength produced a linear decreasing relationship with coefficient of variation in the ranges 10-100% for all compactive effort. Safety index varied considerably which is an indication that variability of strength has drastic influence on the safety index. As COV increased from 10-100%, β value decreased from 0.83 to 0.0268, 0.86 to 0.046 and 0.89 to 0.065 for BSL, WAS and BSH compactions, respectively. Similar trend of decreasing safety index as COV increases is reported by (Yisa and Sani, 2014).

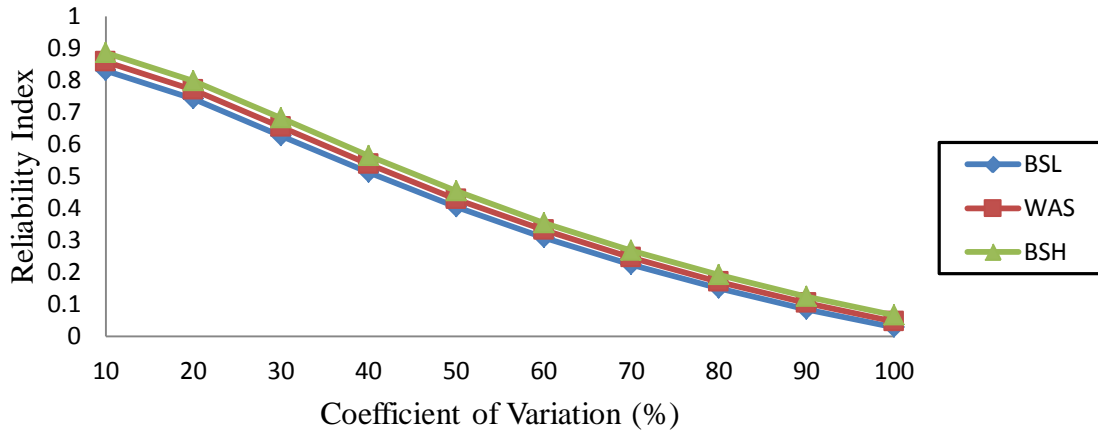


Fig.1: Variation of reliability index with coefficient of variation for 7 days unconfined compressive strength

Effect of Water Content Relative to Optimum on Reliability Index on the 7 days unconfined compressive strength

The effect of water content relative to optimum on reliability index as the coefficient of variation is varied is shown in Fig.2. Higher safety indices were recorded for higher compaction energies. Water content relative to optimum produced a

linear decreasing relationship with coefficient of variation in the ranges 10-100% for BSL, WAS and BSH compactive effort respectively. Safety index varied considerably which is an indication that variability of WRO has drastic influence on the safety index. As COV increased from 10-100%, β value decreased from 0.73-0.56, 0.75 to 0.59 and 0.78 to 0.62 for BSL, WAS and BSH compactions, respectively

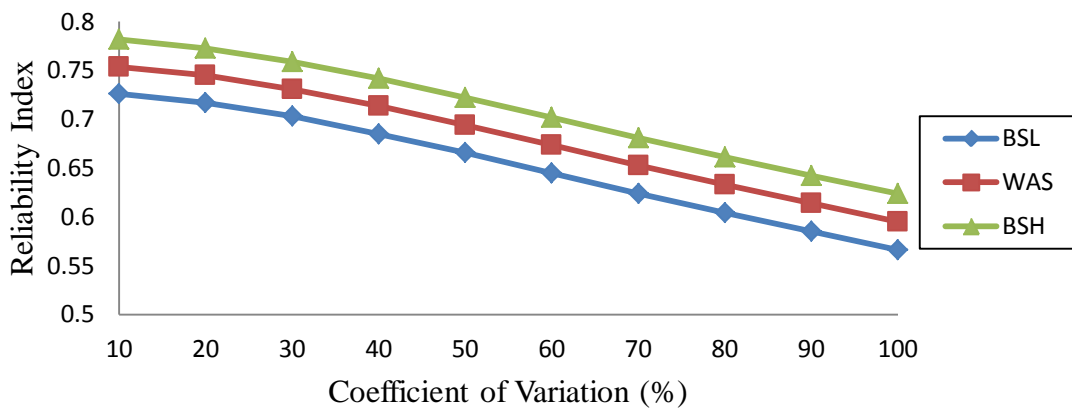


Fig.2: Variation of reliability index with coefficient of variation for water content relative to optimum

Effect of Hydraulic Modulus on Reliability Index on the 7 days unconfined compressive strength

The effect of hydraulic modulus on reliability index as the coefficient of variation is varied is shown in Fig.3. Higher safety indices were recorded for higher compaction energies. Hydraulic modulus produced a linear decreasing relationship

with coefficient of variation in the ranges 10-100% for BSL, WAS and BSH compactive effort respectively. This is an indication that variability of hydraulic modulus has drastic influence on the safety index. As COV increased from 10-100%, β value decreased from 0.76 to 0.74, 0.79 to 0.76 and 0.82 to 0.79 for BSL, WAS and BSH compactions energy respectively.

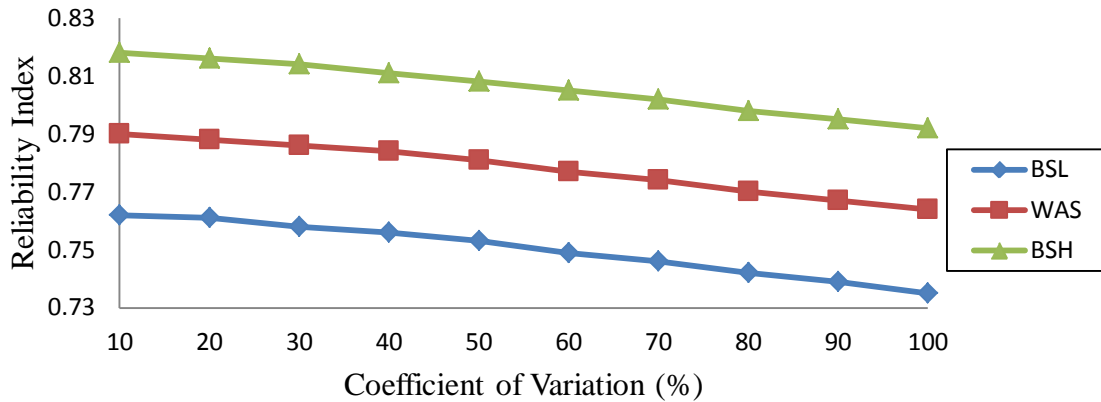


Fig.3: Variation of reliability index with coefficient of variation for hydraulic modulus

Effect of Bagasse Ash Content on Reliability Index on the 7 days unconfined compressive strength

The effect of bagasse ash content on reliability index as the coefficient of variation is varied is shown in Fig.4. Higher safety indices were recorded for higher compaction energies. Bagasse ash content produced a linear relationship with

coefficient of variation in the range 10-100% for BSL, WAS and BSH compactive effort only, while reliability or safety index remained constant. This is an indication that variability of bagasse ash has no drastic influence on the safety index. As COV increased from 10-100%, β value remain constant at 0.72, 0.75 and 0.78 for BSL, WAS and BSH compactions, respectively.

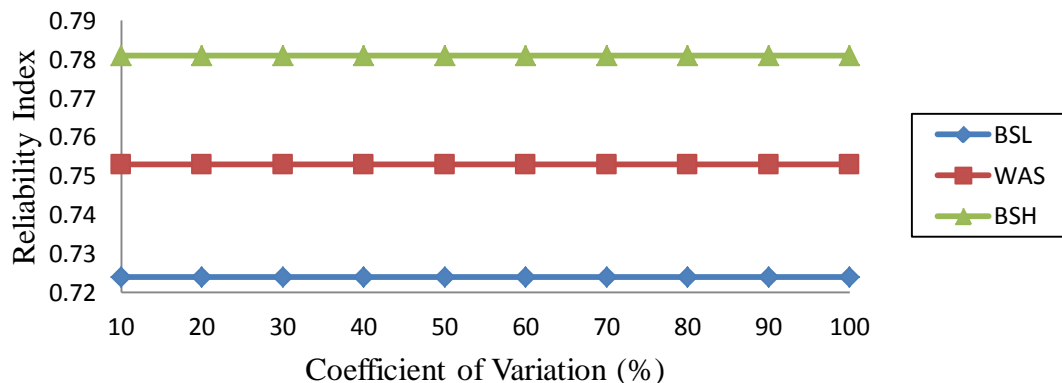


Fig.4: Variation of reliability index with coefficient of variation for bagasse ash

Effect of Cement Kiln Dust on Reliability Index on the 7 days unconfined compressive strength

The effect of cement kiln dust content on reliability index as the coefficient of variation is varied is shown in Fig.5. Higher safety indices were recorded for higher compaction energies. Cement kiln dust content produced a linear decreasing

relationship with coefficient of variation in the range 10-100% for BSL, WAS and BSH compactive effort. This is an indication that variability of cement kiln dust content has some drastic influence on the safety index. As COV increased from 10-100%, β value decreased from 0.81-0.66, 0.84-0.68 and 0.87 -0.71 for BSL, WAS and BSH compactions, respectively.

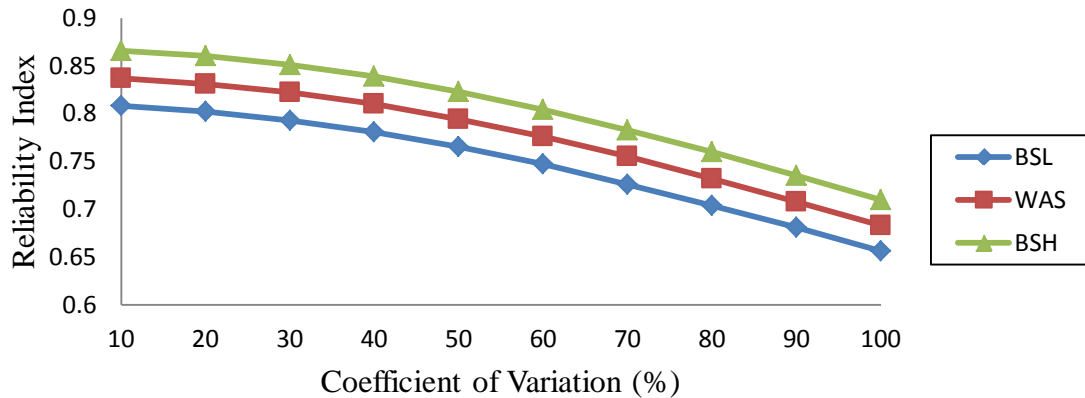


Fig.5: Variation of reliability index with coefficient of variation for cement kiln dust

Effect of Tri-calcium silicate on Reliability Index on the 7 days unconfined compressive strength

The effect of Tri-calcium silicate content on reliability index as the coefficient of variation is varied is shown in Fig.6. Higher safety indices were recorded for higher compaction energies. Tri-calcium silicate content produced a linear increasing

relationship with coefficient of variation in the range 10-100% for BSL, WAS and BSH compactive effort, while reliability or safety index varied slightly. This is an indication that variability of Tri-calcium silicate content has no effects on the safety index. As COV increased from 10-100%, β value also increased from 0.57 to 0.70, 0.60 to 0.73 and 0.64 to 0.76 for BSL, WAS and BSH compactions respectively.

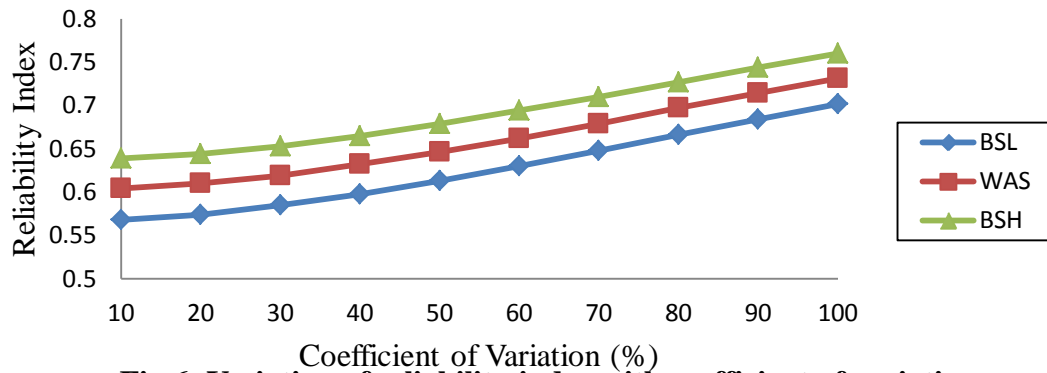


Fig.6: Variation of reliability index with coefficient of variation for tri-calcium silicate C₃S

Effect of Di-calcium silicate on Reliability Index on the 7 days unconfined compressive strength

The effect of Di-Calcium silicate content on reliability index as the coefficient of variation is varied is shown in Fig.7. Higher safety indices were recorded for higher compaction energies. Di-Calcium silicate content produced a linear increasing relationship with coefficient of variation in

the ranges 10-100% for BSL, WAS and BSH compactive effort. Safety index varied considerably which is an indication that variability of Di-Calcium silicate content has no drastic influence on the safety index. As COV increased from 10-100%, β value increased from 0.52-0.64, 0.55-0.67 and 0.59-0.70 for BSL, WAS and BSH compactions, respectively.

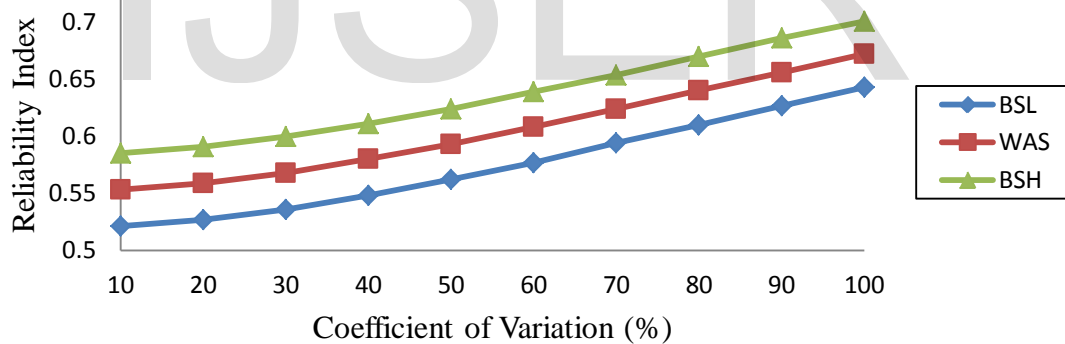


Fig.7: Variation of reliability index with coefficient of variation for di-calcium silicate C₂S

Effect of Maximum Dry Density on Reliability Index on the 7 days unconfined compressive strength

The effect of maximum dry density on reliability index as the coefficient of variation is varied is shown in Fig.8. Higher safety indices were recorded for higher compaction energies. Maximum dry density produced a non-linear relationship with

coefficient of variation in the ranges 10-100% for BSL, WAS and BSH compactive effort only. Safety index varied considerably which is an indication that variability of maximum dry density has drastic influence on the safety index. As COV increased from 10-100%, β value decreased from 0.69-0.58, 0.72-0.58 and 0.74-0.59 BSL, WAS and BSH compactions, respectively.

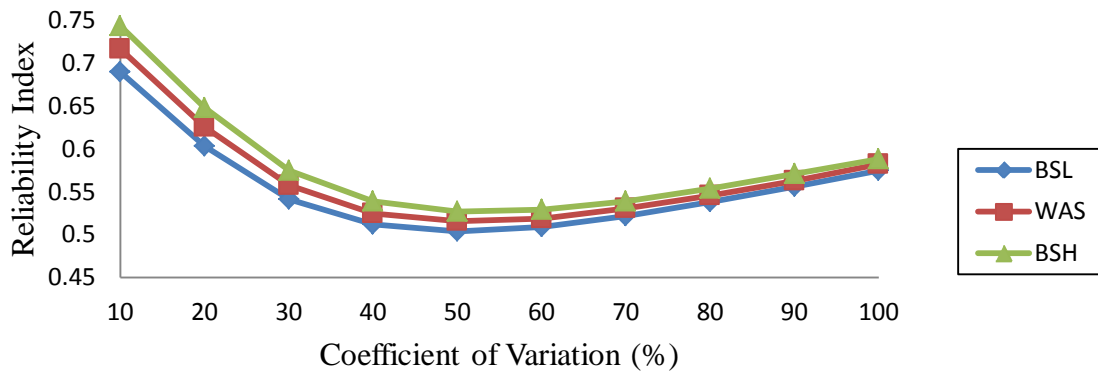


Fig.8: Variation of reliability index with coefficient of variation for maximum dry density

Statistical Significance of Safety Index Values

Statistical analysis of all the results obtained for the parameters (UCS, W.R.O., HM, BA, CKD, C₃S, C₂S, and MDD) under consideration using the two-way analysis of variance (ANOVA) with respect to the compactive efforts produced statistically significant (SS) results as shown in Table 2. Using the F-distribution test at 95% level of significance compactive effort has significant effect on the outcome of the results recorded from the ANOVA test.

Therefore care must be taken in ensuring that the compactive efforts that produced successful safety index are carefully monitored because they have influence on the value of the unconfined compressive strength. Table 2 shows that from the parameters, the one that has more significant effects on the unconfined compressive strength test is water content relative to optimum, follow by bagasse ash, follow hydraulic modulus, then di-calcium silicate, cement kiln dust, tri-calcium silicate then lastly maximum dry density.

Table.2: Analysis of variance of reliability index values

Variable	Source of variation	Degree of freedom	F – value calculated	P – value	F–value critical	SS
UCS 7 Day curing	COV	9	18340.27	8.83E-34	2.46	SS
	Compactive effort	2	440.73	5.15E-16	3.55	SS
Water content relative to optimum	COV	9	68792.54	6.01E-39	2.46	SS
	Compactive effort	2	58651.54	4.71E-35	3.55	SS
Hydraulic modulus	COV	9	1903.583	6.24E-25	2.46	SS
	Compactive effort	2	58381	4.91E-35	3.55	SS
Bagasse ash	COV	9	65535	--	2.46	SS
	Compactive effort	2	65535	--	3.55	SS
Cement kiln dust	COV	9	12923.29	2.06E-32	2.46	SS
	Compactive effort	2	12031.61	7.28E-29	3.55	SS
Tri-calcium silicate C ₂ S	COV	9	1235.597	3.03E-23	2.46	SS
	Compactive effort	2	2145.533	3.87E-22	3.55	SS
Di-calcium silicate C ₂ S	COV	9	4178.607	5.31E-28	2.46	SS
	Compactive effort	2	7577.893	4.65E-27	3.55	SS

Maximum dry density MDD	COV	9	241.0227	6.84E-17	2.46	SS
	Compactive effort	2	36.33714	4.79E-07	3.55	SS

SS = statistically significant at 5% level

COV= Coefficient of variation

Stochastic Model Assessment on the 7 days unconfined compressive strength

The safety index obtained for the three compactive efforts BSL, WAS, and BSH for the 7 days unconfined compressive strength are tabulated in Table 3. NKB Report

(1978) specified a safety index value of 1.0 as the lowest value for serviceability limit state design (model 1) of structural components. As shown in table 3, none of the safety index value obtained met the 1.0 lowest value for serviceability limit state design for structural component.

Table. 3: Stochastic Model Assessment of acceptable safety index

Variables	Beta Value			Acceptable Range of COV (%)		
	BSL	WAS	BSH	BSL	WAS	BSH
Factors						
UCS 7 Day curing	0.83-0.03	0.86-0.05	0.89-0.07	Nil	Nil	Nil
Water content relative to optimum	0.73-0.57	0.75-0.60	0.78-0.62	Nil	Nil	Nil
Hydraulic modulus	0.76-0.74	0.79-0.76	0.82-0.79	Nil	Nil	Nil
Bagasse ash	0.72-0.72	0.75-0.75	0.78-0.78	Nil	Nil	Nil
Cement kiln dust	0.81-0.66	0.84-0.68	0.87-0.71	Nil	Nil	Nil
Tri-calcium silicate C ₃ S	0.57-0.70	0.60-0.73	0.64-0.76	Nil	Nil	Nil
Di-calcium silicate C ₂ S	0.52-0.64	0.55-0.67	0.59-0.70	Nil	Nil	Nil
Maximum dry density MDD	0.69-0.58	0.72-0.58	0.74-0.59	Nil	Nil	Nil

Conclusion

Reliability estimates for 7 days unconfined compressive strength of compacted CKD/BA treated black cotton soil was under taken by incorporating a predictive model. This was developed from the data obtained from laboratory results for specimens compacted at the energy levels of British standard light (BSL), West African standard (WAS) and British standard heavy (BSH), respectively. Results were incorporated into a FORTRAN-based first-order reliability program and safety index values obtained. Generally, the safety indexes produced were not satisfactory because the beta values obtained are lower than 1.0 specified for serviceability limit state design at the three compactive effort. Compositional factor and

compound formations based on admixture combination ratio such as WRO, HM, CKD, BA, C3S, C2S and MDD do not produced acceptable safety index value of 1.0 at the three energy levels namely BSL, WAS and BSH compactive efforts at COV ranges of 10-100%. Observed trends indicate that the WRO, HM, BA and MDD is greatly influenced by the COV and therefore must be strictly controlled in CKD/BA treated black cotton. On the other hand CKD, C3S and C2S are not affected by

COV because they are responsible for the strength gain in the soil – CKD – BA mixture.

Stochastically, only BSH compactive efforts can be used to model the 7 days unconfined

compressive strength of compacted CKD/BA treated black cotton soil because the safety index is more close to the lower acceptable value of 1.0. Finally, care must be taken in ensuring that the compactive efforts required to produce successful safety index are carefully monitored during the construction.

References

Adeniji, F.A (1991). "Recharge function of vertisolic Vadose Zone in Sub-Saharan Chad Basin" *Proc. 1st Inter. Conf. on Arid Zone Hydrology and Water Resources, Maiduguri*, pp. 331-348.

Afolayan, J.O. and Abubakar, I. (2003), "Reliability analysis of reinforced concrete one-way slabs. The ultimate conditions", *Nigerian Journal of Engineering*, 11(2), 28 – 31.

Bello, A. O. (2014). Bagasse Ash Stabilization of Black Cotton Soil Using Cement Kiln Dust as an Activator. Unpublished M.Sc Thesis submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria.

Chen, F. H. (1988). *Foundation on Expansive Soils*. Elsevier Scientific Publication Company, Amsterdam.

Christian, J.T. and Baccher, G. B. (2001). Discussion of factor of safety and reliability in Geotechnical Engineering, *Journal of Geotechnical and Geoenvironmental Engineering*, A.S.C.E., 127(8): 700-703.

Duncan, M.J. (2000). "Factors of safety and reliability in geotechnical engineering. " *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 126(3), 307-316.

Eberemu, O. A. (2008). *Evaluation of compacted cement kiln dust treated laterite soil as hydraulic barriers in waste containment systems*. Unpublished Ph.D Dissertation submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria.

Gilbert, R.B., and Tang, W.H. (1995). "Reliability-based design for waste containment systems." *Geoenvironment 2000*. Geotechnical Special Publication, ASCE, No. 6, New York : 499-513.

Gollwitzer, S., Abdo, T. and Rackwitz, R. (1988) *First Order Reliability Method (FORM Version 5) Manual*, Munich, 1- 47.

Ingles, O. G. and Metcalf, J. B. (1972). *Soil Stabilization Principles and Practice*, Butterworths, Sydney.

Kaymaz, I., McMahon, C. and Xianyi, M. (1998) Reliability based structural optimisation using the response surface method and Monte Carlo simulation. *8th Int. Machine Design and Production Conf. Ankara*.

Nelson, D. and Miller, J. (1992). *Expansive Soils: Problems and Practices in Foundation and Pavement Engineering*. John Wiley and Sons, Inc. New York.

NKB - Report No. 36. (1978) Recommendation for loading and safety regulations for structural design. Nordic Committee on Building Regulation.

Nwaiwu C.M.O., Afolayan J.O., and Osinubi K.J. (2009) Reliability Estimates of Field Hydraulic Conductivity of Compacted Lateritic Soils *Continental Journal of Engineering Sciences* 4:36-47.

Ola, S.A. (1983). " The Geology and Geotechnical Properties of Black Cotton Soils of North Eastern Nigeria". *In S.A. Ola*

(Editor) *Tropical Soils of Nigeria in Engineering Practice*. A.A, Balkema, Rotterdam, pp. 260-278.

Rowe, R.K. and Fraser, M.J. (1995) Effect of uncertainty in the assessment of the potential impact of waste disposal facilities. *Geoenvironment 2000, Geotechnical Special Publication No. 46, ASCE*, New York, 270 - 284.

Stephen, I. T. (2010). *Evaluation of compacted cement kiln dust treated black cotton soil as hydraulic barriers in Waste containment systems*. Unpublished Ph.D Dissertation submitted to the Department of Civil Engineering Ahmadu Bello University, Zaria.

TRRL (1977), "A guide to the structural design of Bitumen surfaced Roads in tropical and Sub – Tropical countries", Transport and Road Research Laboratory, Road Note 31, H. M. S. O. London.

Warren, K. W. and Kirby, T. M. (2004). "Expansive clay soil: A widespread and costly geohazard." *Geostrata*, Geo-Institute of the American Society Civil Engineers, Jan pp. 24-28.

Yisa, G. L. and Sani, J. E. (2014). "Reliability Estimate of Strength Characteristic of Iron Ore Tailing Stabilized Lateritic Soil for Road Pavement Sub-Base Materials." *Electronic Journal of Engineering*, 19:4177-4192, Bund. S

Appendix

PROGRAM FLOOR

C THIS PROGRAM EVALUATES THE RELIABILITY OF BLACK COTTON SOIL
C USING BAGASSE ASH AND CEMENT KILN DUST AS SUB-BASE MATERIAL
C BASED ON THE UNCONFINED COMPRESSIVE STRENGTH

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

EXTERNAL GFLOOR

DIMENSION X(8),EX(8),SX(8),VP(10,8),COV(8,8),ZES(3),

+ UU(8),EIVC(8,8),IV(2,8),des(8)

CHARACTER*10 PRT

COMMON/CFLOOR/E

DATA EX/1.72D3,1.58D1,1.138D0,5.0D0,4.0D0,1.91D2,1.31D2,1.73D0/,

+ SX/3.72D2,1.9D0,1.59D0,3.44D0,2.84D0,2.15D2,2.06D2,7.99D-2/,

+ N/8/,NC/8/,NE/8/,IRHO/0/

WRITE(*,*)'ENTER VALUE FOR E'

READ(*,*)E

WRITE(*,*)'ENTER THE COEFF. OF VAR. FOR X(1) IN %....>'

READ(*,*)VAR

SX(1)=VAR*EX(1)/100.

do 707 k=1,8

NAUS=7

ICRT=0

OPEN(7,FILE='BELO1.RES',STATUS='OLD',ERR=10)

GOTO 20

10 OPEN(7,FILE='BELO1.RES',STATUS='NEW')

20 CALL YINIT (N,IV,VP,IRHO,COV,NC)

IV(1,1)=3

IV(1,2)=3

IV(1,3)=3

IV(1,4)=2

```
IV(1,5)=2
IV(1,6)=3
IV(1,7)=3
IV(1,8)=3
DO 100 I=1,N
X(I) = EX(I)
VP(8,I)=1.D0
100 CONTINUE
V1=1.D0
BETA=1.D0
WRITE (NAUS,5000)
5000 FORMAT (////,6X,70('*'),/,30X,'F O R M 5',/,6X,70('*'),/,
+'SAFETY CHECK ON BLACK COTTON SOIL, 8 VARIABLES:')
CALL YKOPF (NAUS, N, IV, EX, SX, VP, IRHO)
WRITE (ICRT,*) ' START OF FORM5'
WRITE (ICRT,*) ' STOCHASTIC MODEL :'
CALL YKOPF (ICRT, N, IV, EX, SX, VP, IRHO)
PRT=' COV '
CALL YMAUS (NAUS,NC,N,COV,PRT)
CALL FORM5 (N, IV, EX, SX, VP, GFLOOR, IRHO, COV, NC,
+ EIVC, NE, V1, NAUS, BETA, X, UU, ZES, IER)
C
C POTENTIAL LOSS IS HERE DETERMINED
PF = YPHINF(-BETA)
PL = (0.95*(1.0-EXP(-50.*PF)))*PF*100.
C WRITE(*,*)'POTENTIAL LOSS =',PL
C WRITE(NAUS,*)'POTENTIAL LOSS =',PF
PRT=' UU '
CALL YFAUS (NAUS,N,UU,PRT)
PRT=' ZES '
CALL YFAUS (NAUS,6,ZES,PRT)
do 777 i=1,n
des(i)=x(i)/ex(i)
777 continue
write(naus,888)(des(i),i=1,n),E
WRITE(NAUS,504)
write(NAUS,505)(uu(i)/beta,i=1,n)
504 FORMAT(/,3X,'ALPHA VECTOR:')
505 format(3x,/3X,6(2X,E10.2)/)
888 format(3x,//7f10.2/3x,6f10.2/3x,'aspect ratio for joist =',f8.2/
+ 10x,10('*')/)
C
WRITE(NAUS,*)'POTENTIAL LOSS =',PL
WRITE(NAUS,*)'POTENTIAL FAILURE=',PF
707 continue

WRITE (ICRT,*) ' END OF FORM5 : IER =',IER
WRITE (ICRT,*) ' RESULTS SEE FILE BELO1.RES'
STOP
END

SUBROUTINE GFLOOR (N, X, FX, IER)
```



```
    IMPLICIT DOUBLE PRECISION (A-H,O-Z)
    DIMENSION X(N)
    COMMON /CFLOOR/E
C   CHECK FOR ERRORS, CALCULATE FX
    IF (X(1).GT.0.)THEN
    FX =(X(1))-(-2687.000-22.300*X(2)-58.400*X(3)+0.390*X(4)+
+   121.000*X(5)-21.200*E+2.64*X(6)+2.840*X(7)+
+   1863.000*X(8))
    IER = 0
    ELSE
    FX = 1.D+20
    IER = 1
    ENDIF
    RETURN
    END
```

IJSER