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Effect of Iron Ore Tailing on Compressive Strength of Manufactured Laterite Bricks and Its Reliability Estimate

Yisa, G. L.[1] Akanbi, D. O.[1] Agbonkhese, O. Ahmed, M. K[1] Sani, J. E[2]
1.Nigeria Building and Road Research Institute, Ota, Ogun state
2.Department of Civil Engineering, Nigerian Defence Academy, Kaduna

Abstract
In recent years there is a significant demand of building materials in Nigeria. It is therefore imperative to use mining and mineral wastes in the production of bricks, paving blocks and other value added products since some of these waste materials possess potential characteristics, which can be tapped for various uses. Varying grams of IOT were mixed with constant measured portion of laterite sample and cast into lateritic brick cubes, which were later subjected to compressive strength test at 7 days interval for 21 days. The result of the compressive strength test revealed that the lateritic mix containing varying grams of IOT had higher strength value of 27 N/mm^2 when compared with laterite having compressive strength of 14 N/mm^2 both for 7 days curing. Reliability of estimates of the compressive strength values from laboratory results for specimens was developed by incorporating data obtained from compressive strength 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 quantity, hydraulic modulus, iron ore tailing, water cement ratio produced acceptable safety index value of 1.0 at the energy levels of all curing period i.e. 7 days, 14 days and 21 days respectively and they were achieved at COV ranges of 10-100 %. The use of iron ore tailing which is a waste material will serve as an alternative source of building material when used as an admixture or replacement of fine aggregate ratio and also possible reduction in quantity of cement. It will also help reduce environmental problems associated with iron ore tailing disposal problems.
Keywords: Building Bricks, Compressive Strength, Reliability Analysis, Reliability Index, Iron Ore Tailing, Pozzolana, Utilization

1 INTRODUCTION

As a result of the increasingly high demand for building materials and also cost of these building materials in Nigeria and other parts of the world, it has become necessary to conduct research into the use of mining and mineral wastes in the production of bricks, paving blocks and other value added products. This is because some of these waste materials possess potential characteristics which can be tapped for various uses.

The exploitation of mineral resources would promote the development of economy and society, but it will also generate massive overburden, mill tailings, silt etc. that may pollute the environment heavily. Therefore, comprehensive utilization of waste/tailings is important in saving resources, improving the environment and contributing to sustainable development. Iron ore tailing is a waste product of the mining industry. Tailings are waste silica and quartz particles, as well as fine-grained ore that are unable to be recovered within the existing concentration processes. Storage and handling of these tailings is a serious environmental concern (Ghose, 1997). Tailings embankment are susceptible to rapid erosion, cutting down and complete breaching (Toland,1977; Sen and Ghose, 1997).

Laterites are commonly found in the leached soils of the humid tropics. They are formed under weathering system through the process of laterization, where the decomposition of ferro-alumnino silicate minerals and permanent deposition of sesquioxides (Al_2O_3 and Fe_2O_3) takes place within the soil profile to form the horizon of laterite. The present study is a research into the suitability and reliability of using iron ore tailings as fine aggregate in the manufacture of paving blocks.

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). 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 iron ore tailing in the compressive strength of manufactured laterite bricks

2.0 LITERATURE REVIEW

Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils (Lambe and Whitman, 1979). They are characterized by the presence of iron and aluminium oxides or hydroxides, particularly those of iron, which give the colour to the soils (Amu et al., 2011). The term laterite may be correctly applied to clays, sands, and gravels in various combinations while "lateritic soil" refers to materials with lower concentrations of oxides. Bridges (1970) states that the correct usage of the term laterite is for "a massive vesicular or concretionary ironstone formation nearly always associated with uplifted peneplains originally associated with areas of low relief and high groundwater". Fookes (1997) named laterites based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminium-rich cemented crusts, "calcrete" for calcium carbonate-rich crusts, and "silcrete" for silica rich cemented crusts.

The geotechnical characteristics and field performance of laterite are considerably influenced by the mode of formation (genesis), morphological characteristics, degree of weathering and the chemical and mineralogical composition, all of which can in turn be related to the weathering system determined by the joint effects of the pedogenic factors (parent materials, climate, vegetation, etc) (Dumbleton et al., 1966; Gidigasu, 1976). These factors also influence and are influenced by topography and drainage conditions so that soils having similar mineralogical and geotechnical characteristics can often be associated with particular topographical areas (Dumbleton and Newill, 1962).

Iron ore is being beneficiated around the world to meet the raw materials requirements of the iron and steel industries. Iron ore has its own peculiar mineralogical characteristics and optimum product extraction at any site requires tailoring of the metallurgical treatment and specific beneficiation process selection for use. The choice of beneficiation technique depends on the nature of the gangue and its association with the ore structure. The prime function of beneficiation of iron ore is to improve the content of the finished iron. Beneficiation proceeds mainly from washing, sizing by classification, jigging and then magnetic separation (Mohanty et al., 2010).After beneficiation, the rejected portion of the iron ore may include coarse and fine particulates in the wash water, and these particulates may form a slurry known as wet tailings. Ponds are utilized for disposal of tailings.

Laboratory characterization of iron-ore tailings or slimes has indicated that they are largely made up of extremely fine materials. More than 60% of the particulates in such slimes have diameters that are <20μm (Das et al. 1992, 1993). Moreover, the silica and alumina content of the tailings is quite high, which requires both beneficiation and agglomeration treatment prior to their use in steel making. The iron ore tailings are also contaminated with parts per million levels of heavy metal ions such as Cu, Pb, Zn, Cr, Sn, Mo and U, as well as lower levels of macronutrients. Many of these potentially toxic elements reach and become pollutants of water.

The Itakpe iron ore deposit has a reserve of about 200 million tonnes with an average iron ore content of 36%. Itakpe iron ore processing plant produces a waste material of about 64% of its capacity; Ajaka, (2009).Soframine, (1987) showed that the Itakpe project was designed to treat a minimum of 24,000 tonnes of ore per day and operate 300 days per year. The waste to ore ratio is 4:1 (Adebimpe and Akande, 2011).If the tailings are not disposed of, the land will be seized, the environment will be polluted, and the useful resources cannot be fully used.

However, some of these waste materials possess potential characteristics, which can be tapped for various uses (Hussain, 1995). Hammond (1998) in his study critically reviewed the usage of mining waste as building material. He identified many mining wastes as concrete aggregates and pigments for paints. Das et al. (2000) developed new techniques for converting iron ore tailings into value added products such as ceramic floor and wall tiles for building application. It was proved that such tiles have high strength and hardness compared to conventional tiles. The investigation also revealed other benefits like energy economy and lower production costs.

Kumar et al. (2006) demonstrated the usage of fly ash, blast furnace slag and iron ore tailings in the preparation of floor and wall tiles. It was concluded that partial addition of iron ore tailing, fly ash and blast furnace slag in suitable combination in ceramic tiles will improve its scratch hardness (>6 on Mohr's scale) and flexural strength (>25 MPa).

The experiment carried out by Jian et al. (2011) on sintered wall materials reveals that the iron ore tailings and waste can be used very effectively as construction material. The study also showed that due to higher iron content in iron ore tailings and waste rock, the products reduce the sintering temperature and decreased energy consumption.

2.1 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

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

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 β = I/Vs (Kottegoda and Rosso, 1997).

2.1.1 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:

$$g(t) = g(x1, x2....Xn) = r - s \quad (4)$$

Where x1 for I = 1.2….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. The compressive strength is taken to be the basic parameter for design of laterite bricks. Bricks 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 laterite brick admixed with iron ore tailing failure would occur when the compressive strength less than the minimum value of 5 N/mm^2 specified by NBRRI. The probability of failure (P_f) can then be formulated as:

$$P_f = P\{S_c - S_o(WQ, HM, IOT, W/C) \le 0\} \quad (7)$$

where:

S_c = Expected Compressive Strength

S_o = Specified regulatory minimum compressive strength

WQ = Water quantity

HM = Hydraulic modulus

IOT = Iron ore tailing

W/C = Water cement ratio

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

3 MATERIALS AND METHOD

3.1 Materials

3.1.1 Soil

Samples of soil were collected at a depth of between 1.5 and 2.0 m corresponding to the B – horizon which is usually characterized by the accumulation of material leached from the overlying A – horizon. Disturbed samples were obtained from a borrow pit located in Shika area of Zaria (Longitude 7° 36′ E Latitude 11° 4′ N). A study of the geological map of Nigeria after Akintola (1982) and the soil map of Nigeria after Areola (1982) reveals that the sampled soil belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks. From previous studies, soils from this area contain kaolinite as the dominant clay mineral (Ola, 1975; Osinubi, 1998).

3.1.2 Iron ore tailing

The iron ore tailing (IOT) used was collected from the National Iron Ore Mining Company, Itakpe (Longitude 6° 16′ E Latitude 7° 39′ N) in Kogi state, Nigeria. The oxide composition of the IOT was determined by X-ray fluorescence (XRF) analysis. The specific gravity of the IOT was determined to be 3.77, which is higher than the 2.59 recorded for the lateritic soil used in the study.

3.2 Methods

3.2.1 Batching and mixing

2000 g of laterite was mixed with varying quantities of IOT i.e 250 g, 500 g and 750 g. Mixing was done manually in the laboratory and the cube cast was into a 50 mm by 50 mm mould.

3.2.2 Curing

The laterite bricks were cured for 7, 14 and 21 days by arranging them in a way that they are not broken and polythene sheet is used to cover them. This is a more saver way for the bricks to gain strength. When moist Curing is interrupted, the strength increases for a short period and stops. This is the method of curing employed in this research.

3.2.3 Compressive strength test

Three standard cubes of 50mm by 50mm were cast from each mix. A 36 cubes cylinder were cast and tested after 21 days of curing. Compressive strength was measured by subjecting the prepared 50mm cubes to compression test according to ASTM C109. The mean compressive strength was then determined.

3.3 Database and Statistical Analysis

A database was compiled by extracting data gotten from the laboratory test as shown in table 3 to 7. The statistical characteristics of the material composition and compressive strength of laterite bricks are shown in Table 1.

3.3.1 Set-up of Numerical Experiments Reliability Analysis

The results of all laboratory experiments on compressive strength and the parameters associated with compressive strength were measured during the laboratory work. The various parameters measured include the following compressive strength, water quantity, (WQ), hydraulic modulus HM, iron ore tailing IOT, water cement ratio W/C. These results were used to run a regression model for predicting laboratory compressive strength results. The statistical analyses were carried out using the tools of analysis Mini-tab R15 software.

Reliability analysis is intended to assess the suitability of iron ore tailing in the compressive strength of manufactured laterite bricks. This becomes necessary due to the variability that might exist from lateritic soil obtained from one location to another and the compositional content of the additives (iron ore tailing). The statistical characteristics of the relevant lateritic soil – iron ore tailing as well as physical properties of their probability distribution functions types were established.

The relevant statistical properties for lateritic soil – iron ore tailing mixtures were then incorporated into FORTRAN programmes for a field based predictive model in order to evaluate reliability levels and to predict compressive strength 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.

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 four independent variables evaluated that affect strength are: Water quantity (WQ), Hydraulic modulus (HM), Iron ore tailing (IOT) and Water cement ratio (W/C) at W/C ratio of 0.5, 0.55 and 0.6 were obtained.

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

S/No	Variables	Distribution type	Mean E(x)	Standard Deviation S(x)	Coefficient of Variation COV (%)
1	Compressive Strength	Lognormal	2.227E1	5.40E0	24.25
2	Water quantity (WQ)	Lognormal	2.705E2	5.86E1	21.70
3	Hydraulic modulus HM	Lognormal	5.18E-1	3.63E-1	70.08
4	Iron ore tailing (IOT)	Normal	1.75E1	1.292E1	73.83

4 RESULTS AND DISCUSSION

4.1 Oxide Composition

The oxide compositions of the materials used in the study are presented in Table 2. The results show that iron ore tailing contains a high amount of silica, which if present in amorphous chemically reactive state, could enable the IOT exhibit pozzolanic properties. The iron ore tailing was classified as a class N pozzolana according to the ASTM C618 – 78 specifications for pozzolanas, based on its oxide composition.

Table 2: Oxide compositions of iron ore tailing and lateritic soil

Oxide	Concentration (%)	
	IOT	Laterite*
CaO	0.607	0.28
SiO_2	45.64	35.60
Fe_2O_3	47.70	24.0
Al_2O_3	3.36	27.40
MnO	0.067	0.067
MnO_2	-	2.0
TiO_2	0.240	-
K_2O	0.607	-
PbO	0.415	-
Na_2O	0.405	-
MgO	0.393	-
SO_3	-	0.85
LOI	3.0	14.6

*After Osinubi, 1998

4.2 Compressive strength

Three standard cubes of 50 mm by 50 mm were cast from each mix. A total of 36 cubes were cast for a 4 cube set and the average compressive strength were determined for 7 days, 14 days, and 21 days cured samples. These were done by subjecting each 3 samples of a cube set to a compression test according to ASTM C109. The standard compressive strength of a lateritic brick is 5 N/mm^2 for a 7 day curing; the average compressive strengths of the cast cubes were compared with standards.

Table 3: Cube set 1 (lateritic brick containing 250g of iron ore tailing)

Qty. of material (g)(fine aggregate)	Qty. of cement (g)	Qty. of water (litres)
2250	450	0.27
2250	450	0.27
2250	450	0.27

Note: Constant quantity (vol.) of laterite = 2000g; Ratio of material to cement = 5:1

Table 4: cube set 2 (lateritic brick containing 500g of iron ore tailing)

Qty. of material (g) (fine aggregate)	Qty. of cement (g)	Qty. of water (litres)
2500	500	0.30
2500	500	0.30
2500	500	0.30

Note: Constant quantity (vol.) of laterite = 2000g; Ratio of material to cement = 5:1

Table 5: cube set 3 (lateritic brick containing 750g of iron ore tailing)

Qty. of material (g) (fine aggregate)	Qty. of cement (g)	Qty. of water (litres)
2750	550	0.33
2750	550	0.33
2750	550	0.33

Note: Constant quantity (vol.) of laterite = 2000g; Ratio of material to cement = 5:1

Table 6: cube set 4 (lateritic brick containing no iron ore tailing)

Qty. of material (g) (fine aggregate)	Qty. of cement (g)	Qty. of water (litres)
1500	300	0.18
1500	300	0.18
1500	300	0.18

Note: Constant quantity (vol.) of laterite = 1500g; Ratio of material to cement = 5:1

Table 7: Average compressive strength of the set cubes

	7 days (N/mm^2)	14 days (N/mm^2)	21 days (N/mm^2)
Cube set 1	**24**	**33**	**38**
Cube set 2	**26**	**36**	**40.5**
Cube set 3	**27**	**37.5**	**42**
Cube set 4(control)	**14**	**24**	**29**

Maximum compressive strength of 42 N/mm^2 was obtained from the mix containing 750 g of iron ore tailing followed by that containing 500 g and then 250 g respectively (see Figure 1). This result shows that the higher the iron ore tailing content, the stronger the bricks. The control mix has a strength value of 14 N/mm^2 for a 7 days curing period and a maximum of 29 N/mm^2 for 21 days which shows the gain in strength over curing days; although, the 7 days value is a lot higher as compared with the standard strength of 5 N/mm^2 for lateritic bricks.

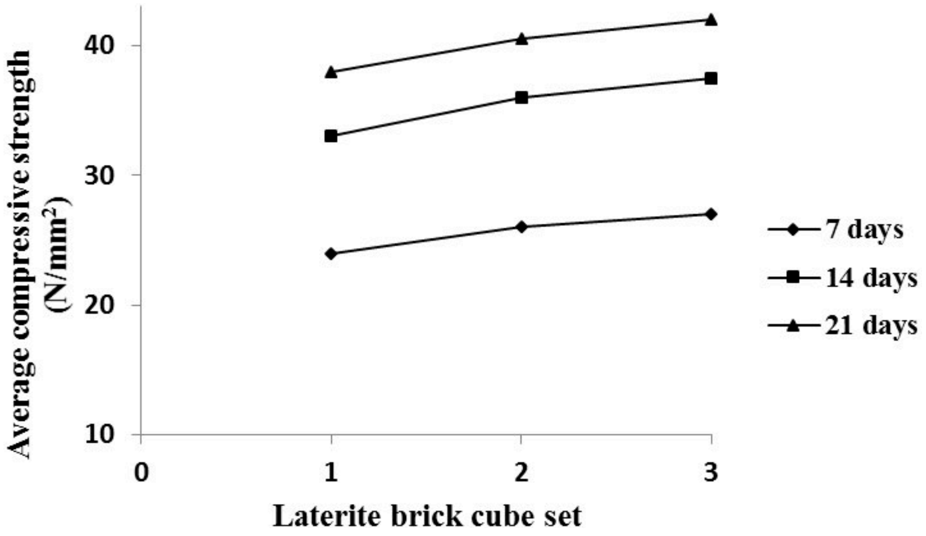

Figure 1: Compressive strengths (N/mm^2) against set cubes

4.2.1 Reliability index on compressive strength of concrete

Figure 1 shows that as the curing period increases the safety index increases which shows a gain in strength of bricks which is as a result of increases activity of the pozzolanic reaction that occurs within a long period of time. For a 10 % COV the safety index recorded are 1.90, 2.87 and 4.67 for 7 days, 14 days and 21 days curing period respectively.

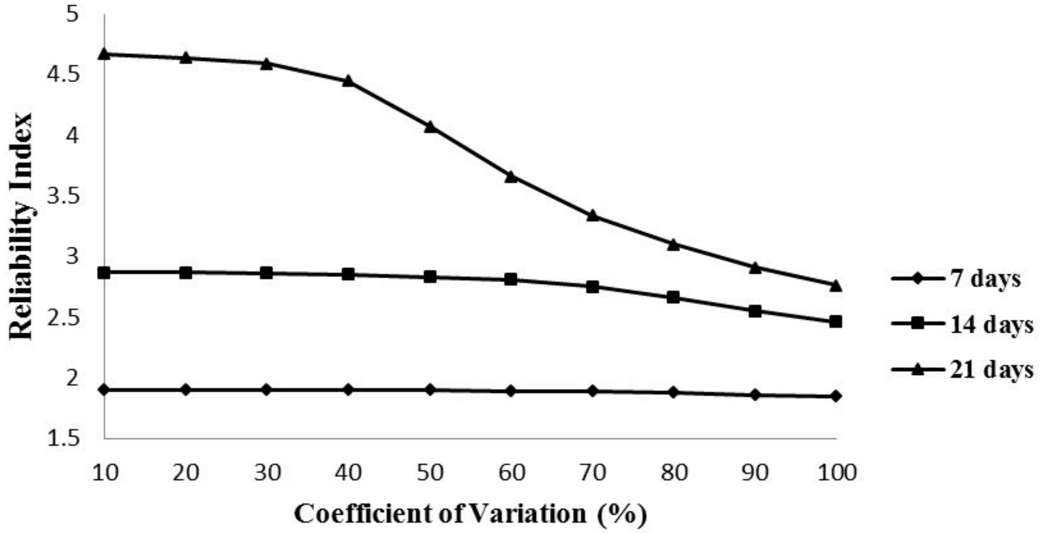

Figure 2: Variation of reliability index compressive strength

Effect of Water Quantity on Reliability Index of the compressive strength

The effect of water quantity on reliability index as the coefficient of variation is varied is shown in Fig.3. Higher safety indices were recorded for higher curing period. Water quantity produced a constant value for 7 days curing period and a linear decreasing relationship for 14 and 21 days curing period with coefficient of variation in the ranges 10-100 % respectively. Safety index varied considerably which is an indication that variability of WQ has drastic influence on the safety index for bricks. As COV increased from 10-100 %, β value decreased from 1.90-1.85, 2.87 to 2.46 and 4.67 to 2.76 for 7 days, 14 days and 21 days curing period, respectively.

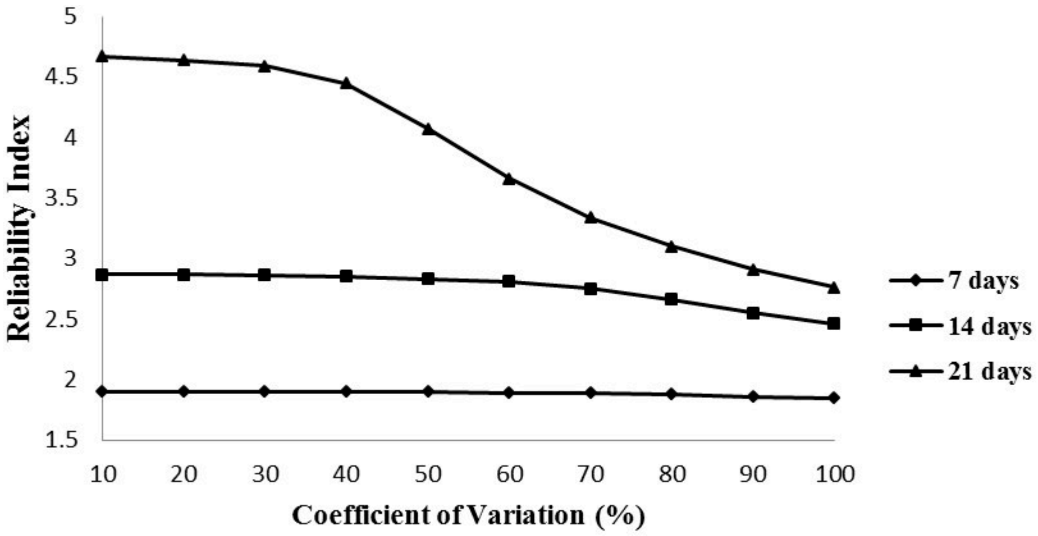

Figure 3: Variation of reliability index compressive strength

Effect of Hydraulic modulus and Iron ore tailing on Reliability Index of the compressive strength

For the hydraulic modulus and iron ore tailing, the same safety index values were obtained as that of water quantity. The effect of hydraulic modulus and iron ore tailing on reliability index as the coefficient of variation is varied is shown in Fig.4. Higher safety indices were recorded for higher curing period. Water quantity produced a constant value for 7 days curing period and a linear decreasing relationship for 14 and 21 days curing period with coefficient of variation in the ranges 10-100 % respectively. Safety index varied considerably which is an indication that variability of WQ has drastic influence on the safety index for bricks. As COV increased from 10-100 %, β value decreased from 1.90-1.85, 2.87 to 2.46 and 4.67 to 2.76 for 7 days, 14 days and 21 days curing period, respectively.

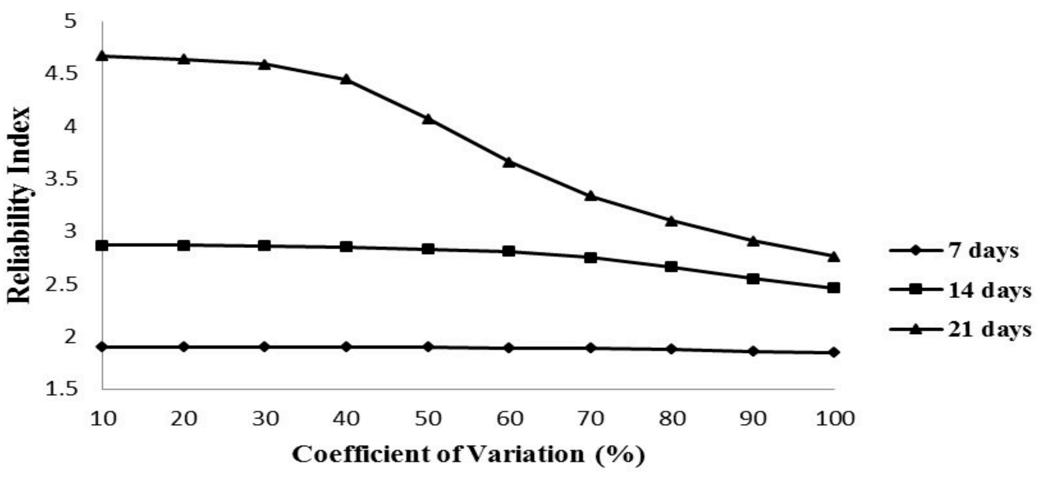

Figure 4: Variation of reliability index compressive strength

Stochastical Model Assessment on the 7 days unconfined compressive strength

The safety index obtained for the three curing periods 7 days, 14 days, and 21 days compressive strength are higher than the value stipulated by NKB Report (1978). 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.

6 CONCLUSION

Results were incorporated into a FORTRAN-based first-order reliability program and safety index values obtained. Generally, the safety index produced satisfactory beta value of 1.0 as specified for serviceability limit state design at all the curing period. Compositional factor and compound formations based on admixture combination ratio such as WQ, HM, IOT, W/C ratio produced acceptable safety index value of 1.0 at the three curing periods at COV ranges of 10-100 % respectively. Observed trends indicate that the IOT and WQ is greatly influenced by the COV and therefore must be strictly controlled in lateritic bricks for building construction.

The compressive strength of laterite bricks with iron ore tailing mix increases with increase IOT content, as compared with that made by laterite only. The results show that the utilization of IOT as an admixture is gainful considering that IOT is a waste and a pozzolanic material. Thus, by using these wastes instead of conventional materials, we would not only be preserving the natural precious resources, but also solving the problems of disposal of the waste, which has become a national problem. The IOT is an alternative material as aggregate in the manufacture of laterite bricks. The utilization of IOT will also promote the economy of the built industry by giving Nigerians the opportunity of affordable housing.

REFERENCES

Adebimpe,R.A. and Akande, J.M. (2011).Engineering Economy Analysis on the Production of Iron Ore in Nigeria, *Geomaterial Journal of Scientific Research*, 1: 14-20.

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.

Ajaka, E.O. (2009). Recovering Fine Iron minerals from Itakpe Iron-ore process Tailing. *Asian Research Publishing Network Journal of Engineering and Applied Sciences*, 4(9): 17-28.

Akintola, F.A. (1982). Geology and Geomorphology. In: *Nigeria in Maps* edited by K.M. Barbour, Hodder and Stoughton, London, United Kingdom.

Amu, O.O., Owokade O.S. and Shitan O. I. (2011).Potentials of Coconut Shell and Husk Ash on the Geotechnical Properties of Lateritic Soil for Road Works.*International Journal of Engineering and Technology*, 3(2): 87-94.

Areola, O. (1982). Soils In: *Nigeria in Maps*. Barbour, K.M. (Ed), Hodder and Stoughton, London, United Kingdom.

ASTM C618-78(1978).Specification for Fly Ash and Raw Calcined Natural Pozzolana for use as a Mineral Admixture in Portland Cement Concrete..*American Society for Testing and Materials*, Philadelphia.

Bridges, E.M. (1970). World soils Cambridge, University Press, London, pp25.

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.

Das B., Ansari M. I. and Mishra D. D. (1993). Effective Separation of Barsua Iron Ore slimes using Hydrocyclone. *Miner Metallurgical Process*, 52: 52-55.

Das B., Prakash S., Mohapatra B. K., Bhaumik S. K. and Narasimahan K. S. (1992). Beneficiation of Iron Ore Slimes using Hydrocyclone.*Miner Metallurgical Process,* 9(2): 101-103.

Das, S. K., Sanja, K., RamachandraRao, P. (2000). *Exploitation of Iron Ore Tailing for the Development of Ceramic Tiles*, Waste Management, 20(8), 725-729.

Dumbleton, M.J. and Newill, D. (1962).A study of properties of 19 Tropical clay soils and the relation of these properties with the mineralogical constitution of the soils.*British Road Research Laboratory*,Note, 44:14pp.(unpublished).

Dumbleton, M.J., West, G. and Newill, D. (1966).The mode of formation, mineralogy and properties of some Jamaican soils.*Engineering Geology,* 1(3): 235-249.

Fookes G. (1997). Tropical residual soils; A geological society engineering group working party revised report, The Geological Society, London.

Ghose, M.K. (1997). Environmental Management for the Disposal of Spoils and Tailings from Mines.*Enivironment and Ecology*, 15(1): 206-210.

Gidigasu, M. D. (1976). Laterite Soil Engineering: Pedogenesis and Engineering Principles. *Elsevier Scientific Publication Company, Amsterdam, the Netherlands.*

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

Hammond, A. A. (1998). *Mining and Quarrying Wastes: A Critical Review,* Engineering Geoology*, 25(1), 17-31.*

Hussain, A. (1995). *Deforestation and Mining Industry*, The Indian Mining & Engineering Journal, 47(3), 29-30.

Jian, S., Yuan, L., Yang, L., Tan, H., Xiang-guo, L., Bao-guo, M. (2011).*Study on Sintered Wall Materials*

Made Use of Iron Tailings and Waste Rock, Advanced Material Research, 243-249, 7036-7040.
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*.
Kotegoda M. and Rosso, R. (1997). *Statistics, probability, and reliability for civil and environmental engineers*. New York, McGraw-Hill.
Kumar, S., Kumar, R., Amitava, B. (2006).*Innovative Methodologies for the Utilization Waste from Metallurgical and Allied Industries*, Resources, Conservation and Recycling, 48(4), 301-314.
Lambe T.W. and Whiteman V.R. (1979).*Soil Mechanics*, S.I version, New York: John Wiley and Sons, Inc.
Mohanty, M., Dhal, N.K., Patra, P., Das, B. and Reddy, P.S.R. (2010). Phytoremediation: A novel approach for utilization of iron ore wastes.*Institute of Minerals and Materials Technology* (CSIR), Bhubaneswar 751013, Orissa, India
NKB - Report No. 36. (1978) Recommendation for loading and safety regulations for structural design. Nordic Committee on Building Regulation.
Ola, S.A. (1975). Stabilization of Nigerian lateritic soils with cement, bitumen and lime.*Proceedingof6th RegionalConferenceforAfrica on Soil Mechanics and Foundation Engineering,* Durban, 1: 145-152.
Osinubi, K. J. (1998). 'Influence of compactive efforts and compaction delays on lime-treated soil.' *Journal ofTransportation Engineering*, ASCE, 124 (2): 149 - 155.
Sen, P.K. and Ghose, M.K. (1997).Sitting of Tailings Pond for Safe Disposal of Tailings from Iron-Ore Beneficiation plants- A case Study.*Mine Technology*., Vol. 18, No.1 and 2, pp. 63-67.
Soframine (1987).Evaluation of the National Iron ore mining project, Itakpe. National Steel Development Agency (NSDA) – personal communication
Toland, G. (1977). Case history of failure and reconstruction of Mike Horse tailings dam near Lincoln, Montana.*Proceedings of 15th American Engineering Geology and Soil Engineering Symposium,* Idaho State University.

APPENDIX

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      PROGRAM  FLOOR
C     THIS PROGRAM EVALUATES THE RELIABILITY OF IRON ORE TAILING
C     WITH CEMENT ON COMPRESSIVE STRENGH OF LATERITIC BRICKS
C     BASED ON THE REGULATORY MINIMUM COMPRESSIVE STRENGTH
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      EXTERNAL GFLOOR
      DIMENSION  X(4),EX(4),SX(4),VP(10,4),COV(4,4),ZES(3),
     +          UU(4),EIVEC(4,4),IV(2,4),des(4)
      CHARACTER*10 PRT
      COMMON/CFLOOR/E
      DATA EX/5.0D0,2.7D2,5.18D-1,1.75D1/,
     +  SX/5.40D0,5.86D1,3.63D-1,1.292D1/,
     +   N/4/,NC/4/,NE/4/,IRHO/0/
      WRITE(*,*)'ENTER THE COEFF. OF VAR. FOR X(4) IN %....>'
      READ(*,*)VAR
      SX(1)=VAR*EX(1)/100.
       do 707 k=1,8
      NAUS=7
      ICRT=0
      OPEN(7,FILE='LAZHI1.RES',STATUS='OLD',ERR=10)
      GOTO 20
10    OPEN(7,FILE='LAZHI1.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
      DO 100 I=1,N
      X(I) = EX(I)
      VP(8,I)=1.D0
100   CONTINUE
      V1=1.D0
      BETA=1.D0
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      WRITE (NAUS,5000)
5000  FORMAT (////,6X,70('*'),/,30X,'F O R M 5',/,6X,70('*'),/,
     +'SAFETY CHECK ON TREATED FOUNDRY, 4 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,
     +           EIVEC, 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,*)'POTENTIONAL FAILURE=',PF
707   continue

      WRITE (ICRT,*) ' END OF FORM5 : IER =',IER
      WRITE (ICRT,*) ' RESULTS SEE FILE LAZHI1.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
C      IF (X(1).GT.0.AND.X(2).GT.0.AND.X(3).GT.0.AND.X(4).GT.0.AND.X(5).
C     2GT.0.AND.X(7).GT.0.AND.X(8).GT.0.AND.X(9).GT.0)THEN
      IF (X(1).GT.0.)THEN
      FX =-(X(1))+(26.700-0.0708*X(2)+9.280*X(3)+0.590*X(4))
      IER = 0
      ELSE
       FX = 1.D+20
       IER = 1
      ENDIF
      RETURN
      END
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