

# Modeling of Compaction Curves for Corn Cob Ash-Cement Stabilized Lateritic Soils

O. A. Apampa, Y. A. Jimoh, K. A. Olonade

**Abstract**—The need to save time and cost of soil testing at the planning stage of road work has necessitated developing predictive models. This study proposes a model for predicting the dry density of lateritic soils stabilized with corn cob ash (CCA) and blended cement - CCA. Lateritic soil was first stabilized with CCA at 1.5, 3.0, 4.5 and 6% of the weight of soil and then stabilized with the same proportions as replacement for cement. Dry density, specific gravity, maximum degree of saturation and moisture content were determined for each stabilized soil specimen, following standard procedure. Polynomial equations containing alpha and beta parameters for CCA and blended CCA-cement were developed. Experimental values were correlated with the values predicted from the *Matlab* curve fitting tool, and the Solver function of *Microsoft Excel 2010*. The correlation coefficient ( $R^2$ ) of 0.86 was obtained indicating that the model could be accepted in predicting the maximum dry density of CCA stabilized soils to facilitate quick decision making in roadworks.

**Keywords**—Corn cob ash, lateritic soil, stabilization, maximum dry density, moisture content.

## I. INTRODUCTION

COMPACTION is defined as the densification of soil through the application of mechanical energy to pack the soil particles more tightly, reducing voids to a minimum. Compaction of soils is mostly required in building up of embankments for roadworks, dams and sundry foundation works. Attempts are therefore continuously being made to develop appropriate models for predicting the behaviour of soils, by producing a family of compaction curves applicable to specific soils. Knowledge of the family of compaction curves makes it possible to predict a compaction curve from a single laboratory compaction test and thus determine the maximum dry density and optimum water content for soils, when certain parameters are known. The concept, called one point method, has been in use for many years and is a recommended method by AASHTO [1].

The parabolic shape of the standard compaction curve suggests that it should be easily modeled with a 2-degree polynomial, and indeed this is done frequently. However, the polynomial equations are limited in their capacity to describe a compaction curve because the regression parameters change by up to three orders of magnitude and the equations perform

well only over a limited moisture range [2]. Also, while a normal compaction curve runs parallel to the zero-air-voids (ZAV) line at moisture contents above the optimum moisture content; polynomial fit equation would violate this constraint. However, an equation developed by [1] from observation of some clay soils in the United States overcomes these identified shortcomings. However, the equation has not been tested on lateritic soils commonly used for road works in Nigeria and many other tropical regions of the world.

## II. AIM AND OBJECTIVES

The aim of this work is to test the applicability of (1) to predict the dry density and optimum moisture content of lateritic soils, using the computer based approach of [2] and to propose a modified form of (1) that will make it applicable to CCA stabilized lateritic soils and thereby develop a set of compaction curves that could be used to predict the response of stabilized soils to compaction. Through these curves maximum dry density and optimum moisture content of the stabilized soil could be predicted, given the corresponding values of the natural soil.

## III. MATERIALS AND METHODS

### A. Lateritic Soil

Lateritic soil was obtained from Kobape area in Abeokuta (7.03°N, 3.45°E), Southwest Nigeria. Characterisation tests conducted showed that it can be classified as an A-2-6 material. The grading analysis curve of the soil is presented in Fig. 1.

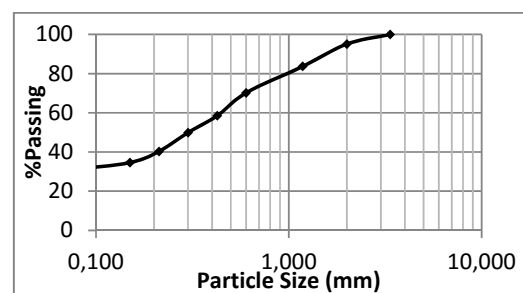


Fig. 1 Particle size distribution of lateritic soil sample

### B. Compaction Tests

Compaction test was carried out using the 2.5kg rammer in a 0.001m<sup>3</sup> cylindrical mould in accordance with the procedures specified in BS 1377-4:1990.

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### C. Modeling Equation for Dry Density and Optimum Moisture Content of the Natural Lateritic Soil

The original equation relates the dry density of some clay soils in the United States with its moisture content, using as parameters the specific gravity of the soil sample, maximum degree of saturation and the corresponding moisture content, the shape factor of the moisture content versus degree of saturation curve; and the compactible moisture range. The equation is presented thus:

$$\gamma_d = \frac{G_s \gamma_w}{1 + \frac{w G_s}{S_m \left\{ 1 - \left( \frac{w_m - w}{w_m} \right)^{n+1} \left( \frac{w_m^n + p^n}{(w_m - w)^n + p^n} \right) \right\}}} \quad (1)$$

where  $\gamma_d$  is the dry density of the soil;  $G_s$  is the specific gravity of soil solids;  $\gamma_w$  is the unit weight of water;  $S_m$  is the maximum degree of saturation;  $w_m$  is the moisture content corresponding to  $S_m$ ;  $n$  is the shape factor of the moisture content versus degree of saturation curve; and  $p$  is the compactible moisture range, which is taken as the difference between maximum and minimum moisture contents at which the soil is compactible. In applying this equation to lateritic soils, initial values were chosen for the coefficients  $S_m$ ,  $w_m$ ,  $n$  and  $p$  and together with the known values of  $G_s$  and  $\gamma_w$ , the initial dry densities  $\gamma_d$  corresponding to each moisture content,  $w$ , were calculated as  $\gamma_{dcalc}$ . Having earlier determined in the laboratory how the dry density ( $\gamma_{dlab}$ ) varies with moisture content for the soil, optimization techniques were employed to determine the most appropriate values of the coefficients  $S_m$ ,  $w_m$ ,  $n$  and  $p$  that bring the value  $\gamma_{dcalc}$  as closely as possible to  $\gamma_{dlab}$ . Using the solver function of Excel 2010, the command was given thus:

Minimize  $\Sigma(\gamma_{dlab} - \gamma_{dcalc})^2$ , by changing the values in the cells containing the coefficients  $S_m$ ,  $w_m$ ,  $n$  and  $p$ ; subject to the following constraints:

- $0.8 \leq S_m \leq 0.99$  (the maximum degree of saturation will never exceed 100%)
- $w_{max} + 0.5 \leq 30$  ( $w_{max}$  is the maximum moisture content of input data for the curve)
- $4 \leq n \leq 12$  (the range of values of  $n$  as proposed by [1])
- $0.03 \leq p \leq 0.15$  (the typical compactible range of moisture content for most soils)

As suggested by [2], the initial values were chosen near the midpoint of the range of values to which they are constrained, thus: 0.90 for  $S_m$ , 0.2 for  $w_m$ , 8.0 for  $n$  and 0.10 for  $p$ .

### D. Modeling Equation for Dry Density and Optimum Moisture Content of CCA-OPC Stabilized Lateritic Soil

The compaction curves for modified soils are always shifted downward right of the natural soil [2]-[5]. The laboratory compaction curves in this study also followed this trend. On the basis of this, alpha and beta parameters were introduced as coefficients of  $\gamma_d$  and  $w$ , respectively for the natural soil so that the observed dry density and moisture content values of the natural soil are as close as possible to those of the stabilized soil. These parameters were formulated as functions

of the binder contents,  $a$  and  $b$ , for CCA and blended cement-CCA, respectively as shown in (2).

$$\gamma'_d = \gamma_d [\alpha^{(a+b)}] \quad (2)$$

when  $\gamma_d$  is substituted, it becomes (2a);

$$\gamma'_d = \frac{G_s \gamma_w [\alpha^{(a+b)}]}{1 + \frac{w G_s}{S_m \left\{ 1 - \left( \frac{w_m - w}{w_m} \right)^{n+1} \left( \frac{w_m^n + p^n}{(w_m - w)^n + p^n} \right) \right\}}} \quad (2a)$$

$$w' = w + [(a+b) \cdot \beta] \quad (3)$$

where  $\gamma'_d$  and  $w'$  are the dry density and corresponding moisture content of the stabilized soil respectively;  $a$  and  $b$  are the respective percentage contents of CCA and OPC in the stabilized soil; and  $\alpha$  and  $\beta$  are coefficients of the polynomial equation. The coefficients  $\alpha$  and  $\beta$  were obtained by the standard linear programming technique using the Solver to minimize  $\Sigma(\gamma'_{dlab} - \gamma'_{dcalc})^2$ ; and  $\Sigma(w' - w)^2$ ; where  $\gamma'_{dlab}$  and  $\gamma'_{dcalc}$  are the respective dry densities obtained in the laboratory and by calculation; and  $w'$  and  $w$  are the respective moisture contents corresponding to  $\gamma'_{dlab}$  and  $\gamma'_{dcalc}$ . The optimization constraints and initial values were same as previously adopted for the natural soil. The alpha and beta parameters so obtained at different percentage binder inputs were then subjected to regression analysis using the curve fitting tool of *MATLAB R2011*; this is to ensure that the alpha and beta parameters as functions of the percentage binder inputs, are calculated automatically according to the respective percentages of CCA and OPC used to stabilize the soil.

## IV. RESULTS AND DISCUSSION

The result of the regression analysis obtained from *Matlab R2011* for the alpha and beta parameters are as in Figs. 2 and 3.

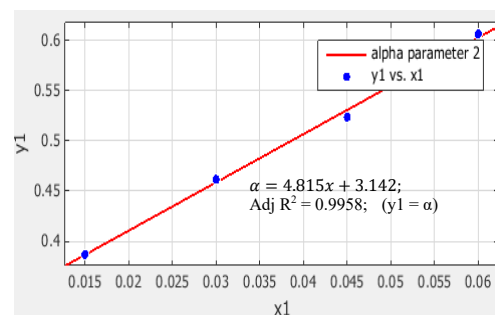


Fig. 2 Regression equation for alpha parameter

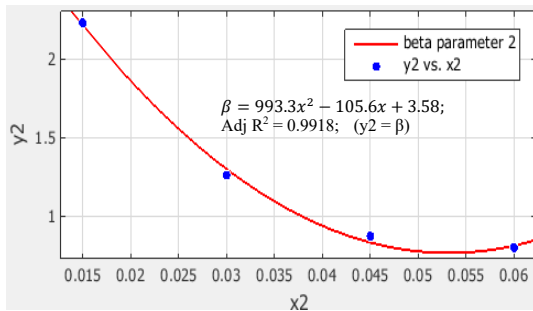


Fig. 3 Regression equation for beta parameter

As shown in Fig. 2, the alpha parameter was determined as:

$$\alpha = 4.815x + 3.142; \quad \text{Adj } R^2 = 0.9958 \quad (4)$$

Given that  $x_1 = (a+b)$ , total binder content, (4) becomes:

$$\alpha = 4.815(a + b) + 3.142; \quad (4a)$$

Similarly in Fig. 3, the beta parameter was determined as:

$$\beta = 993.3x^2 - 105.6x + 3.58; \quad \text{Adj } R^2 = 0.9918; \quad (5)$$

Given also that  $x_2 = (a+b)$ , total binder content, (5) becomes:

$$\beta = 993.3(a + b)^2 - 105.6(a + b) + 3.58; \quad (5a)$$

Equations (2a) and (3) can therefore be more completely written as:

$$\gamma'_d = \frac{G_s \gamma_w [(4.815(a+b) + 3.142)(a+b)]}{1 + \frac{w G_s}{S_m \left( 1 - \left( \frac{w_m - w}{w_m} \right)^{n+1} \left( \frac{w_m^n + p^n}{(w_m - w)^n + p^n} \right) \right)}} \quad (6)$$

$$w' = w + [(a+b) * (993.3(a + b)^2 - 105.6(a + b) + 3.58)] \quad (7)$$

The complete compaction curve is therefore a plot of  $\gamma'_d$  versus  $w'$ , which reduce to  $\gamma_d$  and  $w$  respectively, when the binder content is zero (natural soil).

The coefficients  $S_m$ ,  $w_m$ ,  $n$  and  $p$  obtained from the optimization process varied slightly as the moisture content of the soil was incrementally varied in the process of the standard Proctor compaction test. The results and the arithmetic mean are presented in Table I.

Table I and Fig. 4 indicate that the correlation coefficient is close to 1 (0.999), which is comparable to that of Li and Sego equation [1] developed in the US for fine grained soils. Thus, these results suggest that the model could also be used for lateritic soils in the tropical regions provided the key coefficients  $S_m$ ,  $w_m$ ,  $n$  and  $p$  are determined for the particular soil type under investigation as was done in this study for the A-2-6 lateritic soil.

The compaction curves for the CCA stabilized soil are shown in Figs. 5 and 6 for the model and the actual laboratory

values respectively. The  $R^2$  value of 0.86 indicate that our proposed model gave a fairly good fit of the compaction behaviour of CCA stabilized lateritic soil. The implication of this result is that it is possible from the control test of a lateritic soil to determine the optimum moisture content at which the soil can be compacted to achieve maximum dry density. Also, the procedures adopted in this study can be adapted to derive alpha and beta values applicable to Portland cement stabilized lateritic soils and blended cement-CCA stabilized lateritic soils.

TABLE I  
TABLE OF COEFFICIENTS

w	$S_m$	$w_m$	n	p	$\gamma_d$ model g/cm <sup>3</sup>	$\gamma_d$ lab g/cm <sup>3</sup>
0.055	0.823315	0.187	7.9999	0.106	1.823874	1.823803
0.068	0.801278	0.175	8.0045	0.094	1.870444	1.870363
0.091	0.88053	0.188	8.004	0.093	1.904755	1.904727
0.11	0.947069	0.199	7.9999	0.086	1.879915	1.879923
0.125	0.945319	0.189	8.0024	0.059	1.832194	1.832148

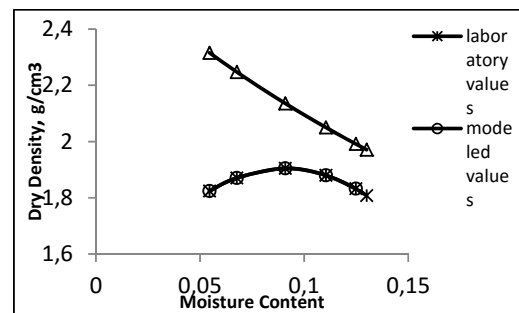


Fig. 4 Compaction curve for modeled and laboratory values for the natural soil

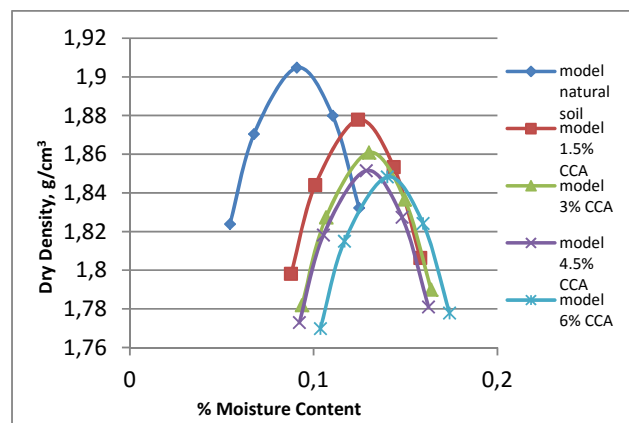


Fig. 5 Compaction curves from proposed model for CCA stabilized lateritic soil

The significance of this study is the introduction of the alpha and beta parameters that extended the application of the original Li and Sego equation to both the natural lateritic soil and the blended cement-CCA stabilized lateritic soil. The parameters, being functions of the percentage binder content

reduce to zero or unit multipliers as the case may be, where the binder content is zero i.e. normal soil.

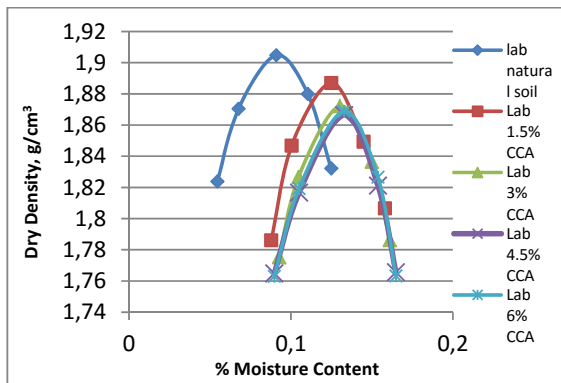


Fig. 6 Compaction curves from laboratory values for CCA stabilized lateritic soil

## V. CONCLUSION AND RECOMMENDATION

### A. Conclusion

A model developed by [1] for fine grained soils in the United States was tested on the A-2-6 lateritic soil of Kobape Abeokuta and upon the determination of the key coefficients, it was found to be a perfect fit with an  $R^2$  value of 0.999. The model was extended to CCA stabilized lateritic soil with the introduction of alpha and beta parameters and the family of compaction curves derived were fairly good fits with an  $R^2$  value of 0.86.

### B. Recommendation

The results of this study are considered useful in the preliminary planning and design of pavement works, particularly as an aid to timely decision making while avoiding extensive soil tests at the preliminary stage. Further studies are recommended to test the model on other binders such as lime, and ashes of various wastes.

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