Strength Characteristics of Compacted Tropical Deltaic Lateritic Fills

George Rowland Otoko
Civil Engineering Department,
Rivers State University of Science and Technology,
Port Harcourt

ABSTRACT
Laterites are generally being used as fills for embankments in Nigeria taking into consideration its various geotechnical characteristics. However, economy usually dictates that the expected soil strength over the service life of the embankment soil, be inferred from behaviour characteristics usually developed in the laboratory. This paper is aimed at improving the predictability of such field post-compaction strength behaviour.

From statistical examination of the magnitude and variation of soaked strength of the laboratory compacted laterite, it is concluded among other things, that quantitative relationships can be established which will allow the prediction of properties as well as the determination of the compaction variables to produce a desired behaviour.

1.0 INTRODUCTION
The importance of the environment of deposition in the development of soil texture, structure, and mineralogy have been emphasized by various investigators. Lateritic weathering products derived from rock types of various parts of Nigeria may not be the same. The laterites of the geological zone 1 (Dry flat country) of the Niger Delta, Nigeria (see fig. 1) is the subject of this study.

Fig. 1 Geomorphological Zones of the Niger Delta, Nigeria.
Previous work on the geological study of laterites in Nigeria dwells mainly on their distribution, classification, depth extent, general nature and formation (Faniran 1970, 1972, 1974 and 1978, Adekoya et al 1978). The study of soils for agricultural purposes has also contributed to the knowledge of laterites. Although much work has been done on the geotechnical study of laterites (Ola 1978, 1980a, 1980b, and Alao 1983) most especially in connection with foundation problems, little or no attention has been paid to the strength characteristics of compacted laterites (Omine and Yasufuku 2005; Oota and Iba 2009).

Otoko (1985, 1987, 1988a 1989b, 1997, 2000) has shown that the soils design engineer requires the strength of the field compacted soil for analysis in the design of an embankment. The soil design engineer must select or estimate the expected soil strength over the service life of the embankment soil. Economy in present day practice usually dictates that this strength behaviour of the field compacted soil be inferred from behavioural characteristics developed in the laboratory. This inference process at times leaves much to be desired. The objective of this paper is the improvement of the predictability of the field post-compaction strength behaviour.

Field compaction is specified not in terms of the behaviour property, but, rather, in terms of unit weight. The reasons for this are historical. However, the consequences include the need to infer such behaviour as strength from some relationship with unit weight, assuming there is one.

Studies have been reported that examine the qualitative trends in the behaviour of laboratory compacted clays show that there is no seeming direct relationship between strength and unit weight of the compacted soil. Strength and unit weight appear to have different relations with compaction water content for both field and laboratory compaction. Both of these sets of data place doubt on the validity of inferring strength from unit weight.

This study assumes that the field strength – field compaction data relations can be related to the laboratory strength – laboratory compaction data relations. Once the transfer relations are established, prediction is possible from the more easily obtained laboratory relations.

In this study the laboratory magnitude and variability of soaked undrained strength as function of the placement variables for the same laterite are reported. Although the data are limited to tropical deltaic laterites, the procedure can serve as a model for developing such procedures for other soils and other properties.

### TABLE 1 – Classification Test Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit. As a percentage</td>
<td>22</td>
</tr>
<tr>
<td>Plastic limit, as a percentage</td>
<td>15</td>
</tr>
<tr>
<td>Plasticity index, as a percentage</td>
<td>7</td>
</tr>
<tr>
<td>Specific gravity of solids</td>
<td>2.71</td>
</tr>
<tr>
<td><strong>15-Blow Proctor Test</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum dry unit weight (kN/m$^3$)</td>
<td>19.1</td>
</tr>
<tr>
<td>Optimum water content, as percentage</td>
<td>12.5</td>
</tr>
</tbody>
</table>
### Standard Proctor Test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum dry unit weight (kN/m$^3$)</td>
<td>19.4</td>
</tr>
<tr>
<td>Optimum water content, as percentage</td>
<td>11.5</td>
</tr>
</tbody>
</table>

### 25-Blow Proctor Test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum dry unit weight (kN/m$^3$)</td>
<td>19.9</td>
</tr>
<tr>
<td>Optimum water content (%)</td>
<td>9.5</td>
</tr>
<tr>
<td>Unified soil classification</td>
<td>CL – ML</td>
</tr>
<tr>
<td>AASHTO soil classification</td>
<td>A – 4 (5)</td>
</tr>
<tr>
<td>Description</td>
<td>Reddish brown silty clay</td>
</tr>
</tbody>
</table>

2.0 **EXPERIMENTAL PROCEDURES**

**Laboratory Testing Programme** – The soil used for testing was obtained from a borrow pit after the Emohua Local Government Area Council Headquarters, Emohua, Rivers State (see fig.2). Classification test results are summarized in Table 1, as are the optimums for the various compaction curves produced for the soil.

![Map of the Niger Delta of Nigeria showing the location of Emohua, Rivers State.](image)

Three different energy levels were used for the compaction: they are referred to as: (1) the 15 Blow (24.5-N) hammer falling 300mm Proctor; (2) the standard Proctor; and (3) the 25 Blow (445-N) hammer falling 450mm Proctor.

Samples were obtained after compaction by simultaneously pressing three sharpened thin-walled stainless steel tubes of 37.7mm diameter into the compacted soil. The tubes were then dug out of the mould. Samples were extruded from the tubes, ends were trimmed, diameter and height measurements were made, and the samples were weighed. The samples were then put into small plastic bags, sealed, and stored in a container at a room temperature of 36°C (± 2°C) for 5 days.
Soaking of specimens was performed in triaxial cells so prepared that a cell pressure of 347 Kpa and a back pressure of 345 Kpa were concurrently applied [see corps of Engineers (1970)]. Two of the three specimens from each compaction mould were soaked while the third was used for water content determinations. All storing, soaking, and testing were performed at a temperature of 36\(^0\)C ± 2\(^0\)C. A period of 48 hours (± 2 hrs) was required to produce degrees of saturation in excess of 95%.

3.0 ANALYSIS OF RESULTS

**Statistical Analysis:** The statistical analysis performed depended on whether the actual magnitude of the dependent variable or the magnitude of its variation was under examination. If the actual magnitude was desired then all the data obtained were used in the analysis. If the magnitude of the variability was desired, then the data were divided into subsets and the statistical analysis was performed using this reduced set of data. The subsets were obtained by dividing data into 1% water content intervals with respect to the optimum water content for the particular energy level under consideration. Means and variances were calculated within each subset.

Regression analysis was used to examine and isolate the effects of independent variables on a chosen response or dependent variable. Several of the better models were selected, and regression equations were developed.

An inherent assumption in the least square regression analysis is that the residuals, i.e. differences between the observed and correspondingly predicted values, are independent normally distributed random variables with mean zero and constant variance.

**Statistical Results:** The data were divided into three water content ranges. These were

1. All water contents
2. All water contents less than the optimum water content
3. All water contents greater than the optimum water content.

The all-possible regressions procedure was performed on the magnitude and variability of dry unit weight and soaked strength using the three water content ranges.

Table 2 shows the results of the unit weight, variation in unit weight, soaked strength, and variation in soaked strength relationships. These regression relationships were developed from models with the lowest order and lowest number of independent variables meeting the significance criteria. When all criteria were met by more than one model, the model with the lowest number of variables was used, provided higher variables models did not appreciably increase the coefficient of determination.

4.0 DISCUSSION

**Magnitude of soaked strength** - For compaction dry of optimum, the magnitude of soaked strength is described by the energy level, the interaction of dry unit weight and energy, and the interaction of water content and energy. The magnitude of the soaked strength compacted wet of optimum is controlled only by the moulding water content. Fig. 3 shows the soaked strength regression relationships. The regression
relationships are shown by the lines while the points represent the average values of the 1% water content intervals.

The regression relationship for soaked compacted dry of optimum indicates that for a given energy, the strength will increase as the dry unit weight increases. Also, an increase in strength occurs as the water content increases for specimens compacted dry of optimum.

The regression relationship for soaked strength compacted wet of optimum indicates that the strength decreases linearly as the moulding water content increases. This relationship is less complex and contains fewer variables than the relationship for specimens compacted dry of optimum.

**Magnitude of soaked strength variability:** The variation in soaked strength can be effectively described by a single relationship for the entire range of water contents used in this investigation. Table 2 shows that the resulting regression relationship involves only the magnitude of the soaked strength and the interaction of the water content and soaked strength. Relationships that met the statistical acceptance criteria were also developed for moisture ranges dry and wet of the optimum water content. However, these relationships were either of higher order or contained more terms than the two-term model for all water contents.

Fig.4 shows the regression relationship for the variation in soaked strength. The regression relationship is shown by the lines while the points represent the values for the 1% moisture content intervals. The largest variation in soaked strength for all three energy levels occur near the optimum water content for the particular effort level. Thus, one can expect that the in-service strength of

![Graph showing variation in soaked strength](image)

**Fig.4:** Moisture-variation in soaked strength Relationship for laboratory compaction
a compacted soil prepared in the laboratory will have the highest variation when compacted near the optimum water content.

Fig. 4 also shows that the variation in soaked strength increases as the compactive effort increases for a given moulding water content. However, for specimens compacted at a water content of about 12% or greater, the variabilities of soaked strength for all three compactive efforts are quite similar indeed.

**Table 2 – Regression Results**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Moisture Range</th>
<th>Regression relationship</th>
<th>R&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry unit weight</td>
<td>All Moistures</td>
<td>( \gamma_d = 2.7100w - 0.105w^2 + 1.565E - 0.122we + 1.704 )</td>
<td>0.657</td>
</tr>
<tr>
<td></td>
<td>Dry of optimum</td>
<td>( \gamma_d = 0.511w + 0.524E + 12.854 )</td>
<td>0.811</td>
</tr>
<tr>
<td></td>
<td>Wet of optimum</td>
<td>( \gamma_d = 1.037E - 0.173wE + 0.00129w^2 + 20.228 )</td>
<td>0.519</td>
</tr>
<tr>
<td>Variation in dry unit weight</td>
<td>All Moistures</td>
<td>No models significant</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dry of optimum</td>
<td>( S(\gamma_d) = 3.874w - 0.0317wE + 0.0000636\gamma_d^2 - 11.448 )</td>
<td>0.686</td>
</tr>
<tr>
<td></td>
<td>Wet of optimum</td>
<td>( S(\gamma_d) = 8.071E + 0.0264E^2 - 0.0551wE - 0.0653 \gamma_d E + 0.892 )</td>
<td>0.788</td>
</tr>
<tr>
<td>Soaked strength</td>
<td>All Moistures</td>
<td>( q'_w = 180.408w - 1.226E^2 + 0.00730\gamma_d^3 - 0.000537wE^2 + 4077.433 )</td>
<td>0.553</td>
</tr>
<tr>
<td></td>
<td>Dry of optimum</td>
<td>( q'_w = 90.879E^2 + 0.00468\gamma_d^3 - 0.265wE^2 + 24.322 )</td>
<td>0.715</td>
</tr>
<tr>
<td></td>
<td>Wet of optimum</td>
<td>( q'_w = -32.452w + 478.352 )</td>
<td>0.605</td>
</tr>
<tr>
<td>Variation in soaked strength</td>
<td>All Moistures</td>
<td>( S(q'_w) = 8.909 q'_w + 0.519E - 1.502 )</td>
<td>0.911</td>
</tr>
<tr>
<td></td>
<td>Dry of optimum</td>
<td>( S(q'_w) = 2.115 q'_w + 0.0779 q'_w + 2.480 )</td>
<td>0.995</td>
</tr>
<tr>
<td></td>
<td>Wet of optimum</td>
<td>( S(q'_w) = -4.623E - 12.809E^2 + 4.436\gamma_d - 49.808 )</td>
<td>0.904</td>
</tr>
</tbody>
</table>

*Notes: \( \gamma_d \) and \( q'_w \) are in kN/m<sup>2</sup> and kPa respectively*

**Fig. 3 Moisture – Soaked strength regression relationship for laboratory compaction**

The regression equation fit the data quite well except for the lowest energy level (15 Blow Proctor). The maximum soaked strength for all three energy levels studied was obtained within ±1% of the optimum water content for the particular energy level.

The soaked strength decreases as the moulding water content moves away to either side of the optimum water content. In addition, soaked strength decreases much more rapidly on the dry side of optimum than on the wet side.
**Water content change upon soaking:** Fig. 5 shows the change in water content that occurred during the soaking process for the standard proctor energy level. As was expected, the specimens compacted dry of optimum experienced a larger change in water content upon soaking than those compacted wet of optimum. Specimens compacted dry of optimum exhibited a larger strength loss than those compacted wet of optimum. This occurred for all three energy levels used. The water content after soaking was a minimum for samples compacted at about the optimum water content for each respective energy level.

![Fig. 5: Change in Water Content after Soaking, (Standard Proctor)](image)

**Strength and strength variability prediction**

The statistical results developed for soaked magnitude and variability presented in table 2, is useful in predicting soaked strength magnitude and variability. They serve as a model for the field operation and other soils as well. In this way, the development of compaction specification can be improved as the uncertainty about behaviour properties is reduced.

### 5.0 CONCLUSIONS

For compaction dry of the optimum water content, the variables that control the unconfined soaked strength are the energy level, the interaction of dry unit weight and energy and the interaction of water content and energy. The wet of the optimum water content, the magnitude of the unconfined soaked strength is controlled solely by the moulding water content.
All energy levels show that the soaked strength decreases much more rapidly on the dry side of optimum than on the wet side. The variation in soaked strength can be described by the magnitude of soaked strength and the interaction of water content and soaked strength for the entire range of water contents used in this investigation.

Quantitative relationships can be established which will allow the prediction of properties as well as the determination of the compaction variables to produce a desired behaviour.

Acknowledgements
The author is grateful to Optima Engineers, Port Harcourt for their financial support of this study as part of the Geotechnical needs of the proposed Ogbia-Nembe Road being carried out for them.

REFERENCES


