*Proceedings of the 7th International Young Geotechnical Engineers Conference – Scott (Ed.)*
*© 2022 Australian Geomechanics Society, Sydney Australia, ISBN 978-0-9946261-5-8*

# Predicting the CBR of a lateritic soil for road construction from index properties using fractal analysis of grading

## Prédiction du CBR d'un sol latéritique pour la construction de routes à partir des propriétés de l'indice à l'aide de l'analyse fractale du nivellement

**Albert K. Ampadu**
*Civil Engineering Department, KNUST, Kumasi, Ghana.*

ABSTRACT: In tropical countries, laterites are abundant. They are selected for use as road construction materials for the pavement layers due to their unique formation conditions. Road base and subbase materials are selected based mainly on their index and strength properties. The index properties including the grading and Atterberg limits are the first line of tests conducted during material selection. The strength is usually measured after compaction by the four-day soaked CBR which is time consuming. This has created a desire to predict the CBR from these simple index property tests. Various researchers have attempted but found poor correlation between the index properties and CBR due to problematic modelling of the grading curve. Traditionally the grading curve has been represented by parameters such as $D_{50}$, $C_u$ and $C_c$. The Fractal analysis and dimensions have been established to successfully analyze and describe the whole grading curve, giving an advantage over the traditional methods of analyzing grading curves. This study aims to investigate whether the prediction of the CBR strength of a lateritic soil by its index properties can be improved if the grading curve is defined using fractal dimensions.

RÉSUMÉ: Dans les pays tropicaux, les latérites sont abondantes. Ils sont sélectionnés pour être utilisés comme matériaux de construction routière pour les couches de chaussée en raison de leurs conditions de formation uniques. Les matériaux de fondation et de fondation de la route sont sélectionnés principalement en fonction de leurs propriétés d'indice et de résistance. Les propriétés de l'indice, y compris la gradation et les limites d'Atterberg, constituent la première ligne de tests effectués lors de la sélection des matériaux. La résistance est généralement mesurée après compactage par le CBR trempé pendant quatre jours, ce qui prend du temps. Cela a créé un désir de prédire le CBR à partir de ces tests de propriétés d'index simples. Divers chercheurs ont tenté, mais ont trouvé une faible corrélation entre les propriétés de l'indice et le CBR en raison d'une modélisation problématique de la courbe de classement. Traditionnellement, la courbe de granulométrie était représentée par des paramètres tels que D50, Cu et Cc. L'analyse et les dimensions fractales ont été établies pour analyser et décrire avec succès l'ensemble de la courbe de classement, ce qui donne un avantage par rapport aux méthodes traditionnelles d'analyse des courbes de classement. Cette étude vise à déterminer si la prédiction de la résistance CBR d'un sol latéritique par ses propriétés d'indice peut être améliorée si la courbe de granulométrie est définie à l'aide de dimensions fractales.

KEYWORDS: Lateritic soils, CBR, Index Properties, Fractal analysis, Grading.

## 1 INTRODUCTION

In Africa and tropical countries upgrading gravel roads to a sealed standard even at relatively low traffic levels, has been found to be cost-effective. Therefore there is a move by Road Authorities to make optimum use of naturally occurring materials which are often rejected by traditional specifications. One such common naturally occurring material is laterite. Laterites and lateritic soils are abundant in tropical climate zone around the world including much of Central, Southern and Western Africa. Due to their unique soil-forming processes, they can behave quite differently from other types of soil (Ampadu, S.I.K. 2019). As a result of its favourable physical and engineering properties, they are often used in road construction as base, sub base or subgrade material for the pavement layers.

The acceptance criteria for road base and subbase material relies mainly on the index properties as defined by the grading and the Atterberg Limits and on the strength as measured by the CBR (MoT, 2007). The standard procedure of a soaked CBR test involves preparation of the sample at the optimum water content (OMC) to the maximum dry density (MDD) and soaked for 4 days before being crushed in the CBR test machine. This test is relatively expensive and time consuming. The test is done after the sample has met the initial index properties requirements. Thus in the process of evaluating material for road pavement construction, the index properties are a prerequisite for the CBR test.

These index properties control the engineering properties of compacted soils (Sridharan, 2002; Nagaraj et al., 2006; Gurtug and Horpibulsuk et al., 2008 and 2009). Based on work done by Bodman et al. (1965), the strength characteristics of soil depends on the particle size distribution as rearrangement of the particles through force applied creates a much denser and therefore stronger material thereby increasing the strength. In view of this, various attempts have been made to correlate the CBR to the index properties. However, various researchers (Vinod and Cletus 2008, Adamska & Zabielska-Sulewska, 2009) have reported poor correlation between CBR and grading. It must be pointed out that in these studies the grading curve has been described by single parameters such as $D_{50}$, $D_{10}$ or two parameters such as the uniformity coefficient $C_u$ and coefficient of curvature $C_c$. The question is would there be a better correlation if the grading curves were described over a large range of particle sizes?

The concept of fractal is used widely in several research fields. Mandelbrot (1983), observed that some objects when increased in scale magnitude were similar over a very large range displaying what are known as “self-similarity” and “scale-free”. This is known as fractals and it means they look similar at a greater variety of scales. However, this “scale invariance” only exists for a range of scales before it changes to a different shape. The fractal concept showed that observations of patterns at different scales could be related to each other by a power law function with an exponent termed the *fractal dimension, D.*

The CBR is known to depend on several factors including the dry density which in turn has been found to be greatly influenced by the grading especially during compaction before the crushing test. Hence the objective of this project is to investigate whether the CBR strength of lateritic soils used for construction can be predicted from the index properties by defining the grading curves using fractal dimensions. It has been shown by Boadu, (2015) that defining the grading in terms of fractal parameters resulted in a better prediction of compressibility and hydraulic conductivity of a soil than using specific diameters. A successful correlation between the CBR and grading implies reduced time and cost for evaluating materials for road construction.

## 2 MATERIALS AND METHODS

### 2.1 *Collection of Soil Samples*

Lateritic soil samples were collected from a borrow pit for a road construction at Yaabi close to Ahenema Kokobin Township in the Ashanti Region in the city of Kumasi in Ghana as shown in figure 1. The samples were airdried and packed into sacks and stored in the laboratory for further testing.

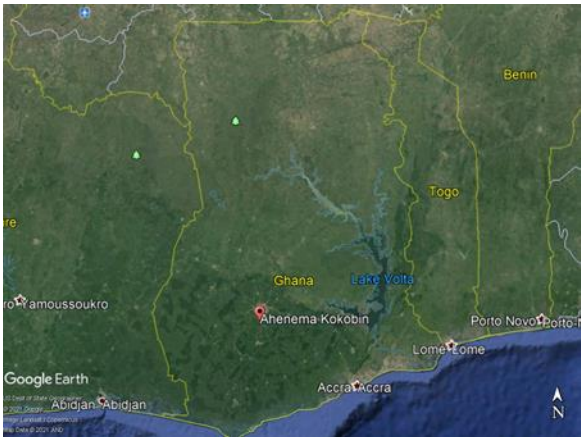


Figure 1 Google earth map showing borrow pit location in Ghana

### 2.2 *Preparation of Reconstituted Samples*

In order to obtain a range of CBR values for a sample with the same index properties for prediction, six new samples with different fines content were created from the same source bulk sample. The natural sample was first sieved through the 19mm sieve to obtain the dry sieved grading curve. Next, the natural soil sample (YN) was sieved through a nest of three sieves made up of 19mm, 4.75mm and 1mm sieves to create three portions falling into three distinct zones designated as: Zone A (19mm – 4.75mm), Zone B (4.75mm – 1mm) and Zone C (< 1mm). The portion retained on 19mm sieve was discarded since the Modified Proctor Compaction procedure specified 19mm as the maximum particle size. These 3 proportions were blended by percentages of weight of the total sample required for each test to obtain the six original samples with contrasting fine content using the percentages shown in Table 1.

Table 1 Summary of Proportioning for reconstituted samples

| Sample ID | Zone A (%) | Zone B (%) | Zone C (%) |
|---|---|---|---|
| **YN** | 54.3 | 32.0 | 14.0 |
| **YT L1** | 74.3 | 25.7 | 0 |
| **YTL2** | 64.3 | 26.9 | 8.8 |
| **YTM1** | 44.3 | 36.9 | 18.8 |
| **YTM2** | 34.3 | 41.9 | 23.8 |
| **YTH1** | 29.3 | 44.4 | 26.3 |
| **YTH2** | 14.3 | 51.9 | 33.8 |

### 2.3 *Determination of Index Properties*

The reconstituted samples along with the natural sample were graded to obtain the particle size distribution curves in accordance with BS 1377-2-1990 clause 9.3.1 and BS 1377-2-1990 clause 9.5 using wet sieving. The grading curves were used in the fractal analysis.

### 2.4 *Compaction and CBR Test*

The Modified AASHTO compaction characteristics were obtained for each reconstituted sample in accordance with the Modified AASHTO compaction procedure - ASTM D1557 and BS 1377-4-1990 clause 7.3.3. Then each sample was prepared at the OMC and subjected to the Modified AASHTO compaction effort to obtain the samples for the CBR test. For each reconstituted sample two samples were prepared for the unsoaked and soaked CBR test. The CBR test was performed in accordance with the ASTM standard (ASTM D 1883-99).

## 3 DISCUSSION OF RESULTS

### 3.1 *Index Properties of Sample*

The index properties of the natural sample (YN) are summarized in Table 2. The grading of YN is shown in Figure 2. According to the AASHTO classification system, the natural material is classified as clayey gravel belonging to A-2-6 which are rated as excellent to good material.

Table 2 Summary of Index and Compaction Properties

| LL | PI | Fines (%) | Gs | OMC (%) | MDD ($Mg/m^3$) |
|---|---|---|---|---|---|
| 38 | 17 | 17.33 | 2.695 | 7.27 | 2.25 |

### 3.2 *Grading of Reconstituted Sample*

Figure 2 shows the grading curves for each of the reconstituted materials. The plot shows a common maximum size of 19mm in accordance with Modified AASHTO compaction method (ASTM D1557-02 or T180). The curves are approximately parallel with gravel contents varying from 40% to 80% while fine contents vary from 12% to 44%. Also the $D_{50}$ vary from 0.4mm to 7mm.

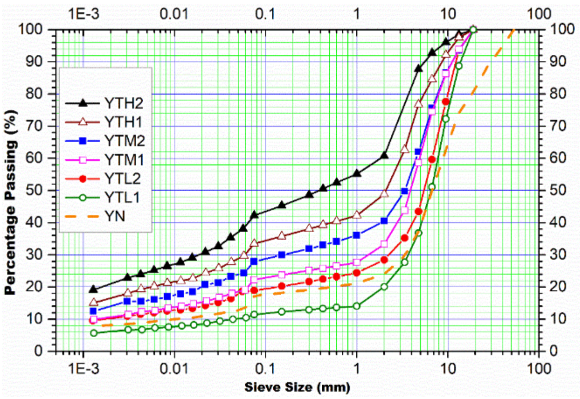


Figure 2 Grading Characteristics of reconstituted samples

### 3.3 *Compaction and CBR Properties*

#### 3.3.1 *Compaction Characteristics*

The compaction characteristics of the reconstituted samples are shown in Figure 3 with the saturation lines based on the Gs value of 2.695 and the projected true value (Oteng 2019) of 2.896.

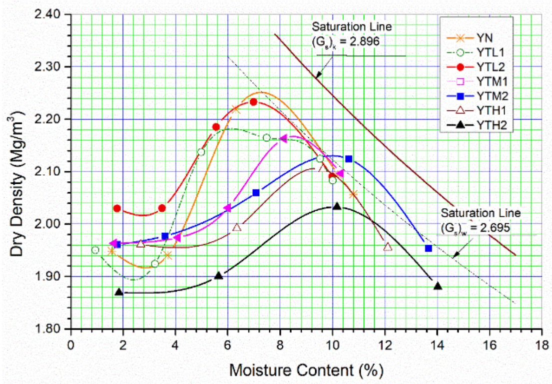


Figure 3 Compaction Characteristics of reconstituted samples

#### 3.3.2 *CBR Results*

Table 3 shows a summary of the unsoaked CBR tests results with their respective compaction characteristics while Table 4 shows the same for the soaked CBR test results. It can be seen that even though the samples targeted to be conditioned at the OMC, all the samples indicated some deviation. For all the samples except for YTM1 during the unsoaked test and YTH1 and YN during the soaked test, there was inevitable drying during the preparation. From both soaked and unsoaked CBR moisture conditioning, the largest deviation from the OMC was for YN with a deviation of 1.022% wetter than the OMC. All other deviations may be considered small.

Table 3 Summary of Unsoaked CBR test results

| Sample ID | Water Content | | Dry Density | | CBR |
|---|---|---|---|---|---|
| | w (%) | w-OMC (%) | MDD ($Mg/m^3$) | LC | |
| **YTL1** | 5.77 | -0.223 | 2.182 | 0.906 | 74 |
| **YTL2** | 6.63 | -0.35 | 2.233 | 0.958 | 56 |
| **YTM1** | 7.55 | 0.293 | 2.193 | 0.961 | 32 |
| **YTM2** | 7.9 | -0.59 | 2.167 | 0.963 | 20 |
| **YTH1** | 9.18 | -0.177 | 2.106 | 0.975 | 8 |
| **YTH2** | 9.64 | -0.44 | 2.033 | 0.966 | 28 |
| **YN** | 7.13 | -0.138 | 2.25 | 0.97 | 39 |

Table 4 Summary of Soaked CBR test results

| Sample ID | Water Content | | Dry Density | | CBR (%) |
|---|---|---|---|---|---|
| | w (%) | w-OMC (%) | MDD ($Mg/m^3$) | LC | |
| **YTL1** | 5.86 | -0.273 | 2.182 | 0.929 | 81 |
| **YTL2** | 6.23 | -0.75 | 2.233 | 0.953 | 40 |
| **YTM1** | 7.07 | -0.187 | 2.193 | 0.945 | 33 |
| **YTM2** | 8.10 | -0.39 | 2.167 | 0.958 | 17 |
| **YTH1** | 9.72 | 0.363 | 2.106 | 0.975 | 13 |
| **YTH2** | 9.32 | -0.76 | 2.033 | 0.973 | 20 |
| **YN** | 8.29 | 1.022 | 2.25 | 0.899 | 29 |

For each test, the ratio of the dry density achieved at the respective OMC to the MDD to the particular test is the level of compaction (LC). The values of LC achieved from the preparation of the sample for the CBR test show that except for YTL1 during the unsoaked CBR test and the YTL1 and YN during the soaked CBR test, the LCs were between 0.95 and 0.98. This is consistent with most compaction results on lateritic samples and it is due to the effect of using fresh samples instead of using recompaction. The large drop in YN may be due to the large deviation of 1.022% of the moulding water content from the OMC. For YTL1, the large drop may be due to the low fines content which doesn't allow proper densification to occur and hence a smaller quantity of material fills the mould resulting in a lesser dry density than the target MDD.

### 3.4 *Fractal Transformation of Grading*

Use of fractal models in characterizing PSD adopts the Tyler et al. (1992) conventional equation based on cumulative mass of soil grains of the form shown in Equation 1.

$$M(d < di) = cdi^{3-D} \quad (1)$$

where
M (d<di) is the cumulative mass of soil grains below an upper limit di.
D is the fractal dimension of the PSD
c is a composite scaling constant.

Taking the logarithmic transformation of Equation 1, the straight line equation, $y = mx + c$ is derived which results in Equation 2.

$$\log(M(d < di)) = \log c + (3 - D)\log(di) \quad (2)$$

The fractal dimension D is found by equating the expression 3-D to the slope of the log-log plot. This approach has been used to analyze PSD of soil samples studied with the objective of evaluating their possible fractal nature and by the relation to the slope, the fractal dimension D is obtained. It is noted that in this investigation, all the soil samples were sieved through the 19mm sieve size. This means that $d_L$ is 19mm. Figure 4 shows the fractal plot for sample YTL1.

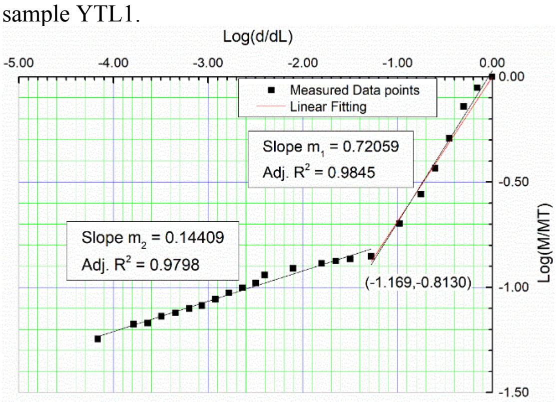


Figure 4 Double linear fitting to grading for YTL1

From the plots it is observed that two linear fits are required to best fit the logarithmic transformation of the grading curve. The key parameters that are required for the linear fitting are the slopes for linear fits $m_1$ and $m_2$, and the breakpoint between the two linear relationships ($C_2$, $P_2$). Table 5 is a summary of the fractal parameters derived using this approach.

Table 5 Fractal Grading Parameters

| Test No: | $D_1$ | $D_2$ | $P_2$ | $C_2$ | $D_1/D_2$ |
|---|---|---|---|---|---|
| **YTL1** | 2.2794 | 2.85591 | -0.8527 | -1.2788 | 0.7981 |
| **YTL2** | 2.3837 | 2.8521 | -0.537 | -0.9355 | 0.8358 |
| **YTM1** | 2.5106 | 2.83434 | -0.4924 | -1.0996 | 0.8858 |
| **YTM2** | 2.5755 | 2.83529 | -0.3587 | -0.9334 | 0.9084 |
| **YTH1** | 2.6762 | 2.8403 | -0.3182 | -1.1538 | 0.9422 |
| **YTH2** | 2.6411 | 2.8355 | -0.1669 | -0.8679 | 0.9314 |
| **YTN** | 2.4143 | 2.8282 | -0.4788 | -0.8784 | 0.8536 |

As proof of how well the fractal parameters fit the data, the percent passing for specified values of particle diameters were back calculated using Equation 2 to obtain a PSD curve. Figure 5 demonstrates the comparison between the actual PSD for the reconstituted sample YTL1 and the grading curved computed and demonstrates a close fit.

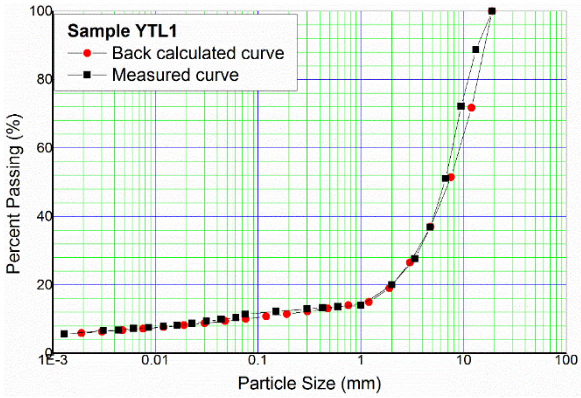


Figure 5 Comparison of actual and modeled grading curve

### *3.5 Correlation between Grading Fractal Parameters and CBR*

The main objective of this study is to show the possibility of predicting the CBR of lateritic material through correlation with the fractal parameters obtained from the grading curve of the sample. Research carried out by Boadu (2015) and Prosperini (2008) revealed that the fractal dimensions D correlated well with the soil textural parameters which are related some engineering properties influenced by texture. Table 6 summarizes the vital fractal and strength properties of the natural and reconstituted samples and the grading as defined by the conventional grading parameter $D_{50}$.

Table 6 Regression Parameters for CBR

| Sample | $D_{50}$ | $D_1/D_2$ | $CBR_{un}$ | $CBR_s$ |
|---|---|---|---|---|
| **YTL1** | 6.531 | 0.75823 | 74 | 81 |
| **YTL2** | 5.446 | 0.7991 | 56 | 40 |
| **YTM1** | 3.876 | 0.87021 | 32 | 33 |
| **YTM2** | 3.362 | 0.88871 | 20 | 17 |
| **YTH1** | 2.088 | 0.93741 | 8 | 13 |
| **YTH2** | 0.386 | 0.983 | 28 | 20 |
| **Natural** | 2.002 | 0.8536 | 39 | 29 |

To assess the relevance of fractal parameters in predicting the CBR, four regression models were developed. For the conventional grading parameter $D_{50,}$ two models one for the unsoaked and one for the soaked. The same was for using the fractal parameters whose independent parameter was $D_1/D_2$.

It was assumed that the CBR is a linear regression function of the grading parameter as shown in Equation 3.

Thus the regression model has only one independent variable $X_1$.

$$CBR = CBR_0 + \beta_1 X_1 \quad (3).$$

Then linear regression was performed using MicroCal Origin 9.0. Table 7 and 8 details the outputs in terms of the $CBR_0$ and $\beta_1$ of the regression model.

Table 7 Fitting Parameters for D1/D2

| | $CBR_0$ | $\beta_1$ | Adj-$R^2$ | RMSE |
|---|---|---|---|---|
| $CBR_{un}$ | 389.5 | -401.20 | 0.887 | 7.49 |
| $CBR_s$ | 375.4 | -389.10 | 0.750 | 11.53 |

Table 8 Fitting parameters for D50

| | $CBR_0$ | $\beta_1$ | Adj-$R^2$ | RMSE |
|---|---|---|---|---|
| $CBR_{un}$ | 9.70 | 7.983 | 0.4946 | 15.81 |
| $CBR_s$ | 3.64 | 8.758 | 0.5776 | 14.99 |

Based on each model, the soaked and unsoaked CBR values for each soil sample were predicted and compared with the measured values of the CBR parameters. The Adjusted R-squared and Root Mean Square Error (RMSE) were the factors utilized as performance assessment. The regression model using a single predictor $D_{50}$ had a weak correlation with the unsoaked CBR dataset recording an Adjusted $R^2$ of 0.49464. On the other hand, using $D_1/D_2$ showed a significant improvement in the correlation with an Adjusted $R^2$ of 0.887 indicating a very strong correlation with the CBR. The $D_{50}$ regression model recorded an RMSE of 15.81 much higher than the fractal regression model with an RMSE of 7.49. Both regression assessment parameters showed an almost two-fold performance improvement in the fractal dimensions regression model over the $D_{50}$ regression model.

A similar occurrence was observed in the Soaked CBR as seen with a higher Adjusted R-squared performance recorded with using $D_1/D_2$ than $D_{50}$ and smaller RMSE. It can be inferred that use of $D_1/D_2$ as an input variable for the regression model provides better prediction performance than use of the conventional grading parameter $D_{50}$.as shown graphically by Figure 6.

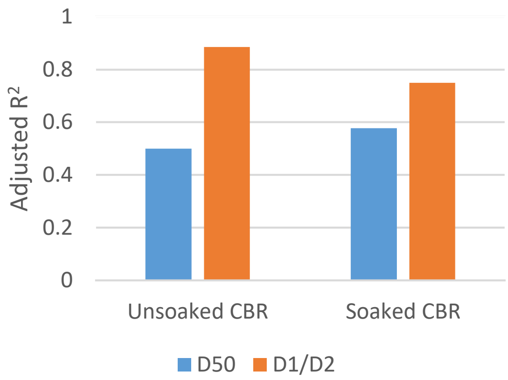


Figure 6. Bar chart comparing performance of $D_{50}$ and $D_1/D_2$ regression models

It is observed that use of only $D_1/D_2$ may not be enough to predict the CBR. Therefore, other index property parameters may be required to increase the predictive performance.

## 4 CONCLUSIONS AND RECOMMENDATIONS

### *4.1 Conclusions*

This study sought to investigate whether a better capturing of the grading curve will improve the prediction of the CBR value of laterite and lateritic soils from the grading curve. The overall conclusion is that there is the potential of using the fractal parameters of the grading curve for predicting the CBR values. The following are the key conclusions:

1. The use of two power law functions with fractal dimension $D_1$ and $D_2$ fully capture the features of the particle size distribution curves of the reconstituted laterite and lateritic samples.
2. A strong correlation was observed between the fractal dimension ratio $D_1/D_2$ and both the soaked and unsoaked CBR with Adjusted $R^2$ values of 0.75 and 0.89 compared with corresponding values of 0.49 and 0.58 for the conventional $D_{50}$ and soaked and unsoaked CBR, respectively.
3. The correlation performance was found to be 31% and 78% better than that obtained using the traditional $D_{50}$ as the independent variable.

### *4.2 Recommendations*

- This study involves only one type of lateritic material and it involved six data points. A larger dataset would provide a clearer insight into the use of fractal dimensions to predict the CBR.
- Further investigation should be made into the influence of other fractal parameters including $C_2$ and $d_L$ and how they influence the predictive model.


## 5 ACKNOWLEDGEMENTS

I am grateful to Dr. Frederick Owusu Nimo and Dr. F.J. Ayeh who were my supervisors. I am also grateful to Prof. S.I.K. Ampadu for his advice and support.

## 6 REFERENCES


Ampadu, S.I.K. (2019), The Unique Properties of Laterites and lateritic soils and their influence inn Construction, Unsaturated Soils Course, $17^{th}$ African Regional Conference of ISSMGE, Durban South Africa.

ASTM D 1883-99, Standard Test Method for CBR of laboratory-compacted soils, In Annual Book of Standards, Vol 04-08

Boadu, F., (2015).Models for predicting compression index of soils using fractal scaling of particle size distributions. *International Journal of Modern Engineering*, *16*(1), pp.78-88.

Bodman, G. and Constantin, G., (1965). Influence of particle size distribution in soil compaction. *Hilgardia*, *36*(15), pp.567-591

Horpibulsuk, S., Katkan, W. and Apichatvullop, A., (2008). 'An approach for assessment of compaction curves of fine grained soils at various energies using a one point test'. *Soils and Foundations*, *48*(1), pp.115-125.

Lyon Associates Inc. and Building and Road Research Institute (1971), 'Laterite and Lateritic Soils and Other Problem Soils of Africa, An Engineering Study for Agency for International Development'. AID/esd-2164, Kumasi Ghana

Mandelbrot, B. B. (1983). The fractal geometry of nature. New York, WH Freeman and Co., 1983.

MoT, (2007), Standard Specification for Road and Bridges. Republic of Ghana Ministry of Transportation

Nagaraj, T.S., Lutenegger, A.J., Pandian, N.S. and Manoj, M. (2006), 'Rapid Estimation of Compaction Parameters for Field Control', *Geotechnical Testing Journal* 29, no. 6 (2006): 497-506.

Oteng, R. (2019), Factors influencing the specific gravity of lateritic soils, Proceedings of the $6^{th}$ International Young Geotechnical Engineers Conference, Durban, South Africa

Prosperini, N. and Perugini, D., (2008). 'Particle size distributions of some soils from the Umbria Region (Italy): fractal analysis and numerical modelling'. *Geoderma*, *145*(3-4), pp.185-195.

Sridharan A., Gurtug Y. (2002), 'Prediction of compaction characteristics of fine-grained soils', *Geotechnique* 52, No. 10 (2002), 761-763.

Sridharan, A. and Gurtug, Y., (2004). 'Swelling behaviour of compacted fine-grained soils'. *Engineering Geology*, *72*(1-2), pp.9-18.

Tyler, S.W. and Wheatcraft, S.W., (1992). 'Fractal scaling of soil particle-size distributions: Analysis and limitations'. *Soil Science Society of America Journal*, *56*(2), pp.362-369.

Vinod, P. and Reena, C. (2008). 'Prediction of CBR Value of Lateritic Soils Using Liquid Limit and Gradation Characteristics Data'. *Highway Research Journal*, IRC.

Zabielska-Adamska, K. and Sulewska, M.J., (2009). 'Neural Modeling of CBR values for compacted Fly Ash'. In *Proc. 17th Intern. Conf. on Soil Mechanics and Geotechnical Engineering,* pp. 781-784.