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# USE OF BIO-ENZYMES IN SOIL STABILIZATION, CONSTRUCTION AND SUSTAINABLE DEVELOPMENT

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## ABSTRACT

Strength developed in stabilized clay by progressive addition of urease bio-enzymes was evaluated in this paper. The soils were stabilized with 5, 10, 15 and 20% urease bio-enzymes. From the compaction tests, the OMC decreases from 13.1% to 9.20% with an increase in enzyme percentage from 0% to 20% for A-7-6. The same decrease was observed for sample A-7-5 from 17.1% to 13.0%. A-7-6 and A-7-5 samples recorded increase in MDD from 1.90g/cm$^3$ to 1.99g/cm$^3$ and from 1.69 to 1.75g/cm$^3$ respectively. The work further revealed improvement in California Bearing Ratio (115% increment) and a significant increment of 312% in Unconfined Compressive Strength of stabilized clay after 28-days curing with 0-20% urease bio-enzymes addition. Comparatively, the use of liquid concentrate bio-enzyme fermented from vegetable extracts for stabilization and other construction purposes, not only reduced the cost of construction (economy), but enhances improved handling, local content and sustainability.

**Keywords**: *Bio-Enzymes, Compaction, Clay Soil, Soil Stabilization, Triaxial compression*

## 1.0 INTRODUCTION

Weak clay is a problematic soil in geotechnical engineering practice. It is amongst wide spread soil types available for construction in Nigeria. Its vulnerability to severe shear strength loss I due to remoulding, which results from disturbance of its natural structure (Brand and Brenner, 1981). Weak clay cannot be safely and economically used for the construction of civil engineering structures without some measures of stabilization (Abolarinwa, 2010).

In construction industry, the challenge of maintaining a balance between performance/cost and satisfying environmental regulations has become a challenge for building material manufacturers, design engineers, and contractors. This challenge has led to identification and use of new construction materials and techniques. Geotechnical engineering projects are closely related to economic and environmental issues. Improving the geotechnical properties of weak clay materials, especially with locally sourced agent will help in attaining a sustainable development (Jefferis, 2008). Unfortunately, planning and design phases of most projects are dictated by financial interests and are even more affected by lack of knowledge about the effect of the geotechnical process on the environment (Abreu *et al.*, 2008).

Infrastructural development is crucial in the economic and sustainable development of every country, the cost of construction is influenced by different factors including the properties of the soil present in the construction site. Sometimes, it may be required to replace the soil completely due to poor engineering properties. Various techniques are used to increase the soil strength. Bryson and El Naggar (2013).

Manufacturing of readily used construction materials, such as cement and lime, has a deteriorating effect on the environment; the production of cement and lime is energy demanding, and production of only one ton of cement emits about one ton of $CO_2$ (Khedari *et al*., 2005).

Recently Bio-Enzymes have emerged as a new chemical for soil stabilization. Bio-Enzymes are chemical, organic, and liquid concentrated substances which are used to improve the stability of soil sub-base of pavement structures. It is a natural, non-toxic, non-flammable, non-corrosive liquid enzyme formulation fermented from vegetable extracts that improves the engineering properties of soil, facilitates higher soil compaction and increases strength (Joydeep and Jitendra, 2015)

Bio-Enzyme stabilization has shown little to moderate improvement in physical properties of soil. This little improvement may be due to chemical constituent of the soil, which has low reactivity with Bio-Enzyme, especially in high and medium plasticity clay (Velasquez *et al.*, 2005). Soil stabilization will improved the CBR and unconfined compression strength of clay. Bergmann (2000) concluded that the Bio-Enzymes require some clay content in the aggregate material in order to create the reaction that will strengthen the material. However, the work was silent or inexplicit on the optimum enzymes percent addition.

Kestler (2009), suggested that enzymes are proprietary of their supplier; unless they provide the composition, it is very difficult to determine the precise composition and stabilization mechanism. The enzymes are absorbed by the clay lattice and are afterwards freed upon exchange with metals cations. They have a significant role in the behaviour of the clay lattice, first causing them to get bigger and then to stiffen (Rauch *et al.*, 2003).

Scholen (1992), Peng *et al.* (2011) and Shankar *et al*. (2009) have all worked on enzyme soil stabilization with different level of success. However, moisture content and density, at the time of sample preparation and testing, which might have influenced the results were not mentioned in these studies.

The need for sustainable soil improvement methods, therefore, has led to the search of novel and innovative methods including using seemingly insignificant substance (enzymes), which was explored in this work.

## 2.0 MATERIALS AND METHODS

### 2.1 Materials

**Test Soil:** The soil sample used for this study was collected from borrow pits around Birgi village, near Lapai Gwari Community, a suburb of Minna, Niger State, Nigeria using disturbed sampling technique at depths of 0.5m, 1.0m, 1.5 and 2.0 meters from two clusters, A and B. The samples were pulverised and air-dried for further analysis as shown in Plate I.

**Plate I**: Air drying of samples for analysis

**Bio-Enzymes**: Urease Bio-Enzymes was produced in the Biology Laboratory of the Federal University of Technology Minna. It was extracted from the bacteria *Lysinibacillus fusiformis* Strain, cultured and grown in B4 medium according to the guidelines by James (1926).

Bio-enzymes are readily available and at low cost compared with other soil stabilizing materials. For large scale production of urease isolates, an inoculum of the isolates is prepared then a fermentation medium is formulated which is a composition of substrates to enhance the enzyme production. The Enzymes is environmentally safe.

### 2.2 Methods

**Index properties:** Natural moisture content, specific gravities, particle size analysis and Atterberg limits tests of samples were conducted in accordance with tests procedures specified in BS 1377: 1990.

**Compaction characteristics:** Compaction of clay soil stabilized with and without Bio-Enzymes specimens was conducted in accordance with the guidelines specified in BS 1377 (1990) to compute the required parameters. The Reduced British Standard light (RBSL) compactive effort was used. The RBSL compaction is the energy resulting from 2.5 kg rammer falling through a height of 30 cm onto three layers, each receiving 15 blows (ASTM D-1557, 1992).

**Unconfined compressive strength (UCS):** The UCS test was conducted in accordance with the procedure specified in BS, 1377: (1990). The clay soil was stabilized with varying percentages of 5, 10, 15 and 20% relative to OMC and compacted with Reduced British Standard Light (2.5 kg Hammer) compactive energy. The compacted specimens were cured for 28 days in the laboratory at temperature of 24 ± 2ºC.

**California bearing ratio (CBR):** The soaked CBR of stabilized clay specimens was conducted in accordance with the guidelines specified in BS 1377 (1990) to compute the required parameters as shown in Plate II. 6 kg of pulverized mixed samples divided to five parts were poured into CBR mould and rammed with 4.5 kg rammer in five layers, each receiving 62 blows. The attached upper and lower dial gauges measured the upper and lower penetrations of the plunger.

**Plate II:** California Bearing Ratio test of sample

**Free Swell Index:** Frees swell index is the increase in volume of a soil without any external constraints on submergence in water. The free swell index was conducted in accordance with the procedure specified in BS, 1377: (1990). And the value obtained from using the expression in Eqn. 3.1.

$$\text{Free Swell Index} = \frac{V_d - V_e}{V_e} \times 100 \qquad (3.1)$$

$V_d$ = Volume of sand in distilled water

$V_e$=Volume of sand in bio-enzyme

## 3.0 RESULTS AND DISCUSSION

### 3.1 Index properties of the natural Soil

The index properties of the natural clay soil and urease enzymes are shown in Figure 1.0 and Table 1.0. The fraction passing No 200 sieve is 62.1 and 82.2% for A-7-6 and A-7-5 soils respectively. An average value of 16.9% and 21.6% were obtained as natural moisture content for A-7-6 and A-7-5 soils respectively. The mean Specific gravity value for A-7-6 was 2.72g/cm$^3$ while that for A-7-5 soil was 2.76g/cm$^3$. The plasticity index of the soils (13.13% and 14.46%) indicates that the soils are suitable as sub-grade materials in road construction because they fell below the maximum 25% recommended for sub-grade tropical soils by (Simeon *et al*., 1973). The properties of the urease enzymes according to Peng *et al*. (2011) is shown in Table 1

Table 1: Physical properties of urease enzymes.

| Urease Enzymes | Properties |
|---|---|
| Hazardous Compound | None |
| Boiling point | $100^0$C |
| Specific Gravity | 2.70 |
| Evaporation Rate | Same as water |
| Melting Point | Liquid |
| Solubility in water | Complete |
| Cooler | Amber |
| Odors | Non-Obnoxious |

However the plasticity index of the soils are higher than 12% and hence will not be suitable for use as sub-base materials for roads and bridges as specified by (FMWH 2001;Ola (1975) indicated that the studied soils will exhibit low swelling potential based on plasticity index in the range of 0-15. Using Casangrade chart according to BS 1377, 1990 and ASTM D-4208(1992), the soil is of medium plasticity and hence compressible, Figure 3. Also, the grading curves from the sieve analysis is shown in Figures 1 and 2, while the summary of geotechnical properties of test samples is shown in Table 2.

Table 2: Geotechnical Properties of Natural Soils

| Properties (Average) | A<br>A-7-6 | B<br>A-7-5 |
|---|---|---|
| Specific gravity of soil | 2.72 | 2.76 |
| Natural moisture content (%) | 16.9 | 21.6 |
| **Atterberg Limits** | | |
| Liquid limit (%) | 41.22 | 50.50 |
| Plastic limit (%) | 28.09 | 36.04 |
| Plasticity index | 13.13 | 14.46 |
| % Passing BS No. 200 sieve | 62.10 | 82.20 |
| **Classification** | | |
| USCS | CL | CL |
| AASHTO | A-7-6 | A-7-5 |

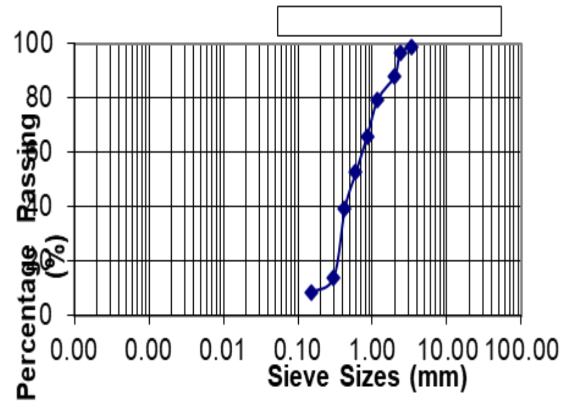


**Figure 1:** Sieve Analysis of A-7-5 Sample

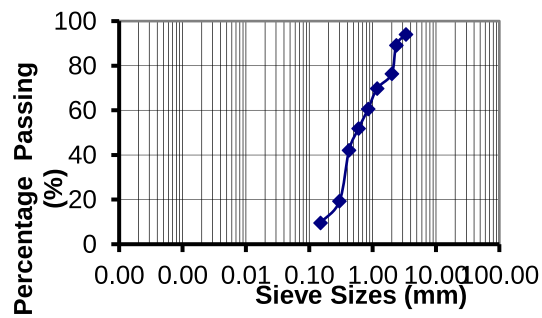


Figure 2:Sieve Analysis of A-7-6 Sample

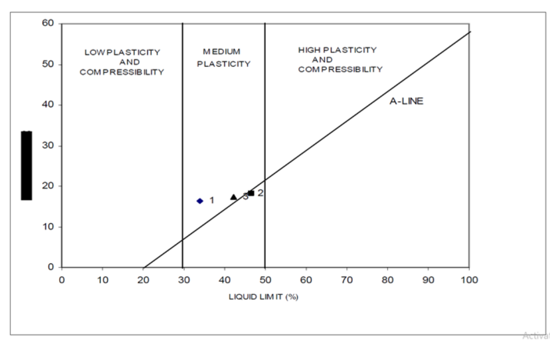


**Figure 3:** Casagrande chart classification of soils (Unified/ASTM D-4208, 1992)

## 3.2 Mineralogical composition of Clay

The average mineralogical composition of the soft clay soil samples from X-ray diffraction are: Quartz - 50.1%, Ankerite -

5.23%, Kaolinite - 4.82%, Calcium Silicide – 6.10%,Montmorillonite – 6.50%, Anorthite – 7.29%, Sodium Aluminium Silicate Hydrate – 6.22%,Anorthoclase – 6.28% and Orthoclase – 7.47%. From the X*ray fluorescent dispersion, the predominant oxides in both A – 7 – 5 and A – 7 – 6 are Iron oxide, Silicon oxide, Aluminium oxide and Titanium oxide. While, there are differences in the values of other oxides, both classes A-7-5 and A-7-6 Clay have the same value of $Cr_2O_3$.

### 3.3Compaction Characteristics of enzyme-stabilized clay

Compaction characteristics of sample clay soil (untreated) were determined using the standard compaction effort (ASTM D-698; ASTM D-1557), and the same procedure was used to identify any change in compaction characteristics due to enzymes. The result is shown in Table 3.0. Three important factors that affect the compaction of soil are *moisture content*, *soil type*, and *compaction effort*. The OMC and MDD for the compacted soil stabilized with 0% enzymes are 13.1% and 1.90g/cm$^3$ as well as 17.1% and 1.72g/cm3 for A-7-6 soil and A-7-5 clay soils respectively.

For A-7-6 soils, there is a decrease in OMC from 13.1 to 10.8 due to the addition of 5% enzymes which further increased to 10.2% OMC with an increase of 10% enzymes. This is accompanied with a considerable increase of MDD from 1.90 g/cm$^3$ to 1.99g/cm$^3$ for A-7- 6 soils. The same decrease in OMC and increase in MDD is observed with A-7-5 soils up to 20% enzymes. The variation in compaction parameters of stabilized soil is shown in Table 3.

**Table 3:**Compaction parameters of Urease Enzymes stabilized soil

| Enzyme % | A-7-6 OMC % | MDD(g/cm$^3$) | A-7-5 OMC (%) | MDD(g/cm$^3$) |
|---|---|---|---|---|
| **0** | 12.60 | 1.91 | 17.20 | 1.72 |
| **5** | 10.80 | 1.95 | 17.00 | 1.76 |
| **10** | 10.50 | 1.97 | 15.00 | 1.79 |
| **15** | 9.70 | 1.98 | 15.20 | 1.80 |
| **20** | 9.60 | 1.97 | 14.50 | 1.78 |

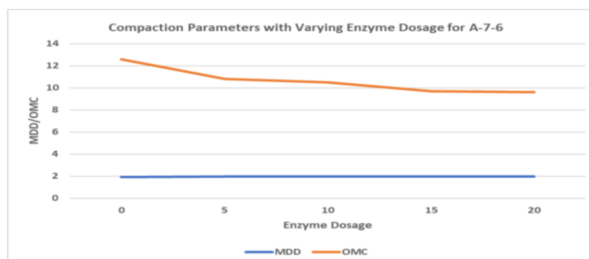


**Figure 4:** Compaction parameters with varying enzyme dosage for A-7-6

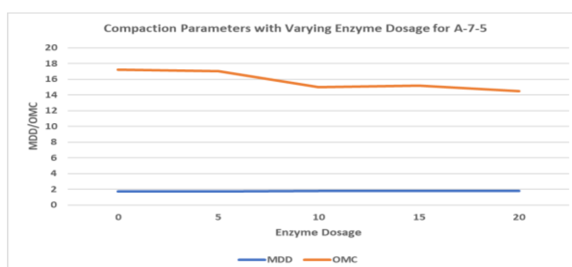


**Figure 5:** Compaction parameters with varying enzyme dosage for A-7-5

### 3.4California Bearing Ratio (soaked) of enzyme-stabilized clay

The results of the 28 days soaked CBR is shown in Table 4.Both the CBR and UCS are often used to estimate the bearing capacity of highway sub-grade and sub-base soils (Gidigasu, 1980). The CBR values are shown in Figure 3, where it is evident that the CBR values increases with the increase in urease dosage.

With the addition of 5% enzymes, the soaked CBR values increased to 29.01 and 17.48 % for A-7-6 and A-7-5 soils respectively. There is a progressive increase to 45.11 and 41.79 % with an increase to 20% enzymes for both A-7-6 and A-7-5 soils respectively. A general higher increase was observed in A-7-6 soils. Therefore enzyme stabilization increased the CBR of A-7-6 by 116.98% (from 20.79 to 45.11%), and A-7-5 by 315.41% (from 10.06 to 41.79%). With the CBR values of 45.11% and 41.79%, these enzyme-stabilized clay are suitable for road base and sub-base application according to FMWH (2001) and Nigerian General Specification (1997).

**Table 4:** Variation California Bearing Ratio (Soaked) of enzyme-stabilized clay

| Sample<br>Urease % | A-7-6<br>CBR % | Cum. Incr. CBR % | A-7-5<br>CBR % | Cum. Incr. CBR% |
|---|---|---|---|---|
| 0 | 20.79 | 0 | 10.06 | 0 |
| 5 | 29.01 | 28 | 17.48 | 42 |
| 10 | 31.81 | 37 | 20.17 | 55 |
| 15 | 38.07 | 53 | 32.32 | 93 |
| 20 | 45.11 | 69 | 41.79 | 116 |

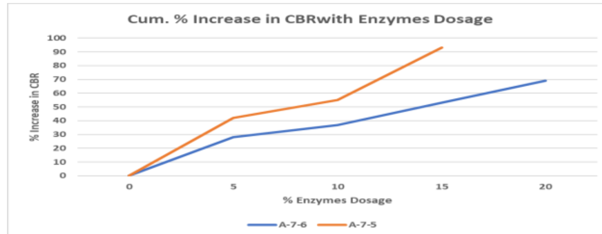


Figure 5: CBR values of enzyme-stabilized clay

### 3.4 Effect of urease enzymes addition on unconfined compressive strength (UCS)

The positive effect of curing is evident in the observed values of Unconfined Compressive Strength (UCS) as displayed in Table 5. The UCS was observed to increase with the increase in the enzyme percentage for samples A-7-6 and A-7-5 for 28 days curing. This phenomenon according to Adeyemi and Abolurin (2000) is as a resultof moisture affinity of grains of soil attributable to surface chemical reaction. Figure 4.0 presents the Unconfined Compressive Strength of A-7-6 and A-7-5 soils stabilized with and without urease.

The Unconfined Compressive Strength of 0% enzymes soil was 232.3 and 370.04 kN/m$^2$ for A-7-6 and A-7-5 soils respectively, There is a progressive increase from 349.40 to 407.73 kN/m$^2$ with 5-20% urease increase on A-7-6. A similar increase is observed on A-7-5 soil from 463.50 to 576.64 kN/m$^2$ with 5 to 20% increase in enzymes. The increment was noticed after the both samples were cured after 28 days as shown in Table 5 and Figure 6.

**Table 5:** UCS of enzyme-stabilized clay

| Sample<br>Urease % | A-7-6<br>UCS (kN/m$^2$ ) | Cum.% Incr. in UCS | A-7-5<br>UCS (kN/m$^2$ | Cum% Incr. in UCS |
|---|---|---|---|---|
| 0 | 232.30 | 0 | 370.04 | 0 |
| 5 | 349.40 | 34 | 463.50 | 20 |
| 10 | 357.58 | 36 | 529.60 | 32 |
| 15 | 372.27 | 40 | 553.97 | 36 |
| 20 | 407.73 | 49 | 576.64 | 40 |

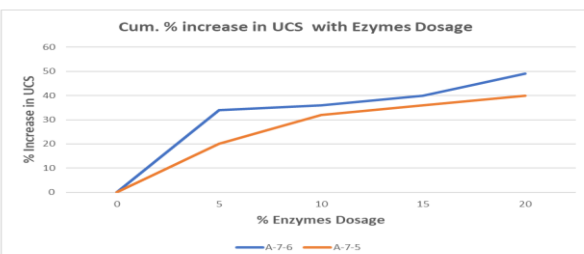


**Figure 6**: Increase in UCS with enzymes dosage

### 3.5 Free Swell Index (FSI)

The possibility of damage to structures due to swelling of soft clays should be identified at the onset of clay soil investigation. The Free Swell index (FSI) of the soils after 1 day curing was obtained as 113.6 and 83.3% for A-7-6 and A-7-5 soils respectively as shown in Table 6. The FSI of both samples is greater 50%which makes them expansive.

**Table 6:**Effect of liquid enzyme solutions on the swell percentage of the soils

| Sample | $V_d$(ml) | $V_e$(ml | FSI(%) |
|---|---|---|---|
| A-7-6 | 23.5 | 11 | 113.6 |
| A-7-5 | 16.5 | 9 | 83.3 |

## 4.0 CONCLUSION

From the results of investigation on the use of bio-enzymes in stabilization, construction and sustainable development, the following conclusions were drawn:

I. The dark-brown and reddish samples are classified as CL or A – 7 – 6 and A – 7 – 5 according to Unified Soil Classification and AASHTO soil classification systems respectively.

II. The plasticity index of test soils(>12%), indicating that, it is suitable for use as sub-grade materials in road construction.

III. Stabilization of the soils with biodegradable urease enzymes increased the MDD, CBR and thus produced denser and stronger samples while there was a reduction in OMC as the enzyme was progressively added.

IV. Urease bio-enzyme decreases the voids between the soil particles and thus increase the compaction and density of the soil with increase UCS and CBR.

V. The CBR value for the 0% enzymes stabilized soil was found to be 20.79 and 10.06% for A-7-6 and A-7-5 soils respectively. When soaked for 28 days with the addition of urease enzymes from 5% to 20%, there was an increase in the CBR value to 45.11 and 41.79% for A-7-6 and A-7-5 soils respectively. Enzyme stabilization increased the CBR of A-7-6 by 116.98% and A-7-5 by 315.41%. With the CBR values of 45.11% and 41.79%, these enzyme-stabilized clay are suitable for road base and sub-base applications.

VI. The Unconfined Compressive Strength of A-7-6 stabilized with urease showed higher improvement with increase in dosage. The Unconfined Compressive Strength of 0% enzyme soil was 232.3 and 370.04 kN/m$^2$ for A-7-6 and A-7-5 soils respectively. There is a progressive increase from 349.40 to 407.73 kN/m$^2$ with 5-20% increase of urease enzymes on A-7-6. A similar increase was observed on A-7-5 soil from 463.50 to 576.64 kN/m$^2$ with 5 to 20% increase in enzymes after 28 days curing.

VII. Comparatively, the use of liquid concentrate bio-enzyme fermented from vegetable extracts for stabilization and other construction purposes, not only reduced the cost of construction (economy), but enhances improved handling, local content and sustainability.

VIII. Thus, urease enzyme is a satisfactory agent for stabilization of clayey soils. The research in utilization of urease enzymes as an alternative to the other expensive stabilizing agents, is therefore a worthy course.

IX. Vegetable extract is locally available in Nigeria, so sustainability of the application of this research for developmental purposes is high.

**REFEERNCES**

Abolarinwa, A. (2010). Geotechnical Properties of Major Problem Soils of Nigeria Retrieved from http://engrdemol.hubpages.com/hub/geotechnical-properties-of-Nigeria, 13/03/2020

Abreu, D.G., Jefferson, I, Braithwaite, P. A. and Chapman, D.N (2008). Why is sustainability important in geotechnical engineering," in Proceedings of the Geocongress, Geotechnical Special Publication No. 178 on *Geosustainability and Geohazard Mitigation*, pp.821–828.

ASTM, D 4208 (1992). American Standards Testing Methods. Annual book of ASTM standards, Vol. 04.08, 1992. Philadelphia.

ASTM, D - 698 (1992). American Standards Testing Methods. Standard Proctor

Compaction Test of ASTM standards, Vol. 05.03, 1992. Philadelphia.

ASTM, D - 1557 (1992). American Standards Testing Methods. Modified Standard Proctor Compaction Test of ASTM standards, Vol. 05.05, 1992. Philadelphia.

AASHTO (1986). American Association of State Highway and Transport Officials. Standard Specifications for Transport Materials and Methods of Sampling and Testing. 14th Edition, AASHTO, Washington, D.C.

Adeyemi, G.O. and Abolurin, S.B. (2000). Strength characteristics of a chemically stabilized lateritic soil from kilometre 4, Ile-Ife/Sekona road, South-western Nigeria. *Journal of Mining and Geology* Vol.36 (1):113-119.

Brand, E. W., and Brenner, R. P. (1981). Soft clay engineering (Vol. 20). *Elsevier Science Ltd.*

Bergmann, R (2000). Soil stabilizers on universally accessible trails. USDA Forest Service, San Dimas Technology and Development Center.

Bryson, S. and ElNaggar, H. (2013). Evaluat ion of the efficiency of different ground improvement techniques. In proceeding of the 18th International Conference on Soil Mechanics and Geotechnical Engineering . Paris: The French Society for Soil Mechanics and Geotechnical Engineering (CFMS).

BS 1377 (1990). Method of Testing Soils for Civil Engineering Purposes. British Standard Institute, BSI, London.

Federal Ministry of Works and Housing (2001). General Specification for Roads and Bridges, Federal Highway Department, FMWH: Lagos, Nigeria, Vol. II, 317.

Gidigasu, M.D. (1980). Geotechnical evaluation of residual gravels in pavement construction. Engineering Geology, Amsterdam, 15:173-194.

James, B. S. (1926). Isolation of Urease Crystals. *Cornell University*, Ithaca, New York, USA.

Jefferis, S. A. (2008). Moving towards sustainability in geotechnical engineering, *Proceedings of the Geoenvironment Annual Congress of the Geo-Institute* of ASCE (GeoCongress), pp. 178–844

Joydeep, S. and Jitendra, P. S. (2015). Stabilization of Black Cotton Soil using Bio-Enzyme for a Highway Material. *IJIRSET*, 4(12):121-129.

Kestler, M.A (2009). Stabilization Selection Guide for Aggregate and Native-Surfaced Low Volume Roads, Forest Service, San Dimas Technology & Development Center USA, San Dimas, Calif, USA.

Khedari, J., Watsanasathaporn, P and Hirunlabh, J. (2005). Development of fibre-based soil-cement block with low thermal conductivity, *Cement and Concrete Composites*, 27(1): 111–119.

Nigerian General Specification (1997). Nigerian General Specification for Roads and Bridge Works, *Federal Ministry of Works*, Abuja, Nigeria.

Ola, S. A. (1975). Stabilization of Nigerian Lateritic soil with cement, bitumen and lime. Proceedings of the 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering. Vol. I .Pp.145-152.

Peng, H. T., Su, H.T., Zhang, X.P. and Wang, J (2011). An experimental comparison of compressive strengths of soils stabilized with enzyme and ground quicklime, *Advanced Materials Research*, vol. 280, 9–12.

Rauch, A. F., Katz, L.E. and Liljestrand, H.M. (2003). An Analysis of the Mechanisms and Efficacy of Three Liquid Chemical Soil Stabilizers, *Center for Transportation Research.* The University of Texas at Austin.

Simeon, A.B., Geisecke, J. and Bidlo, G., (1973). Use of Lateritic soils for Road Construction in North Dahomey. Engineering Geology. **7**: 197 – 218.

Scholen, D (1992) Non-standard stabilizers, Report FHWA-FLP-92- 011, *Department of Transportation.*

Shankar, A., Rai, H.K, and Mithanthaya. H. (2009), Bio- enzyme stabilized lateritic soil as a highway material, *Indian Roads Congress Journal*, vol. 70(2):124-130.

Velasquez, R., Marasteanu, M.O., Hozalski, R and Clyne, T. (2005). Preliminary Laboratory investigation of Enzyme solutions as a soil stabilizer. Research Report MN/RC-2005-25. University of Minnesota, USA.