CARITAS UNIVERSITY AMORJI-NIKE, EMENE, ENUGU STATE

Caritas Journal of Engineering Technology

CJET, Volume 3, Issue 1 (2024)

Article History: ***Received: 20th December 2023 Revised: 12th February, 2024 Accepted: 2nd March, 2024***

Influence of Bentonite Slurry Modifier on the Elastic Properties of Lateritic Soil

[1]Ntegun I. Erasmus,
[1]Scott. B. Akpila,
[1]Godfrey. W. T. Jaja
[1]Department of Civil Engineering (Geotechnical Engineering Options)
Faculty of Engineering, Rivers State University,
PMB. 5080 Port Harcourt, Rivers State.
engineeringbrain4live@yahoo.com

Abstract

The influence of bentonite slurry on the elastic properties of lateritic soil was investigated. Various amounts of bentonite slurry (2%, 4%, 6%, 8% and 10%) were mixed with the lateritic soil from six (6) different boreholes to ascertain its effect on the elastic modulus and Poisson's ratio of the soil. The results revealed that an increase in bentonite slurry yielded an increase in the elastic modulus of the soil by an average of 83.41% while an increase in bentonite slurry on the lateritic soils resulted in a decrease in Poisson's ratio by an average of 23.79%. This result shows that the bentonite slurry modification with lateritic soil improves the lateritic soil from a state of very soft soil to medium soil in relation to the elastic properties, especially the elastic modulus and Poisson's ratio. Based on the results, bentonite slurry has a positive influence on the elastic properties of lateritic soils and is suitable for foundation works when mixed with lateritic soils.

Keywords: ***Bentonite Slurry, Elastic Modulus, Poisson's Ratio, Lateritic Soil.***

1. Introduction

Lateritic soils are a common and significant type of soil in tropical and subtropical climate zones, such as Southern Nigeria. In the classification system, lateritic soils are highly weathered soils. It is challenging to dig very far into the soil structure without running across lateritic soils. The lateritic soils are notable for their distinctive colour, high amount of clay content, reduced cation exchange capacity, and low fertility (Shaw, 2001). Other characteristics of lateritic soils are the fact that they have significantly large amounts of iron and aluminium oxide (Shaw, 2001). Since 1807, when Buchanan first encountered a substance he called laterite in India and described it as "soft enough to be readily cut into blocks by an iron instrument, but which upon exposure to air quickly becomes as hard as brick, and is reasonably resistant to the action of air and water," laterite has been recognized as an earth material with special properties (Yoshinaka & Kazama, 1973). The unusual engineering characteristics of laterite soils, which are extreme products of soil genesis, call for a thorough investigation and potential elucidation from a purely scientific standpoint. Though it is still more or less qualitative, the development of the science of soil stabilization has provided a scientific foundation for an understanding of soil behavior in civil engineering constructions (Firoozi *et al*., 2017).

Due to the critical nature of civil infrastructure to be placed on lateritic or other compressible soils, thorough examination must be carried out on the geotechnical characteristics of the compressible soil (lateritic soil), especially its elastic properties. Geotechnical engineers are very concerned about the lateritic soil's elastic behavior, which causes it to compress on load application and subsequent stress release on unloading.

It is necessary to put stabilizers or additives on lateritic soil to improve its elastic capabilities to combat the failure issues that would result from the application of repetitive loads. Since lateritic soils in Nigeria typically contain a high percentage of clay, stabilization is required before they can be utilized for construction or as a foundation (Olaniyan, 2011). Soil stabilization refers to the various techniques used to alter a soil's characteristics to enhance its engineering performance. To improve the strength and stiffness of the initially weak soils, binders or stabilizers are added to soft soils, modifying their chemical properties either under wet or dry conditions. In addition to its environmental and economic advantages, soil stabilization has recently evolved into innovative techniques that make use of locally accessible industrial and environmental waste products to enhance the engineering characteristics of weak or clayey soil (Yilmaz & Civelekoglu, 2009; Choi et al., 2017; Rosa et al., 2017; Bazne et al., 2017; Arulrajah et al., 2017a; Awarri & Otto, 2022). Over time, there has been a significant advancement in the use of solid waste in civil engineering projects.

When considering the usage of bentonite slurry modifier as an improvement admixture, the elastic properties of lateritic soil are important. This is because there are issues with sample disturbance, nonlinear and inelastic load deformation, and the relative stiffness of the surface layer when assessing the stress distribution throughout the deposit. If one wants to prevent the collapse of the civil engineering structure, one must also take into account the parameters of the soil and the resultant effects related to stiffness defects. The elastic modulus and Poisson's ratio of lateritic soils are being taken into consideration. The use of bentonite slurry to enhance the elastic properties of soil, such as elastic modulus and Poisson's ratio, is vital. This study aims to investigate the influence of various percentages of bentonite slurry on the elastic characteristics of lateritic soils.

2.0 Materials and Methods

2.1 Materials

The lateritic soil samples used in this study were taken from six (6) distinct boreholes in the Oduoha Community in Ogbakiri of Emohua, Rivers State, Nigeria. The bentonite was purchased at Mile 3 Market in Port Harcourt, Rivers State.

2.2 Methods

The depths of disturbed samples collected were within the range of 0.5 and 2.0 meters below the surface of the ground. Both lateritic and bentonite samples were sent to the laboratory for experiments and tests at Rivers State University's Civil Engineering Laboratory.

Test standards of the American Society for Testing and Materials (ASTM D4767, 2011), presented in Table 1 and British Standards (BS 1377, 1990) codes of practice for site investigation were followed for all laboratory tests and data analysis. The specific gravity, moisture content, Atterberg limit, Particle-size distribution, and Triaxial tests were performed first on the lateritic soil. Next, the specific gravity of the bentonite was determined. To blend with the lateritic soil, several trial bentonite content percentages (2% - 10%) at intervals of 2% were used for the mixture and were subjected to a Triaxial test. Table 1 lists the Bentonite materials' physical and chemical characteristics, while Table 2 lists the tests, standards used, and parameters measured for the various laboratory works.

Table 1: Physical and Chemical Properties of Bentonite

Property	Value
Ph	10.90
CaO (%)	8.51
SiO_2 (%)	57.98
Al_2O_3 (%)	22.07
Fe_2O_3 (%)	2.85
MgO (%)	2.39
Cl_2O (%)	1.15
LOI (%)	12.21
Na_2O(%)	1.93
K_2O(%)	2.85
TiO_2 (%)	0.14
Density	1.05
Granulometry (µm)	2 to 1
Capacity swelling Cg	8.29
Conductance (µS)	66.6
CEC (meq/g)	0.92

2.2.1 Triaxial Test for Bentonite Modified Slurry (BMS)

The shear characteristics of all types of soils are assessed using the triaxial test under various drainage conditions. In this test, axial symmetry is maintained when stressing a cylindrical specimen. First, an all-around confining pressure of σ_c is applied to the specimen, acting in mutually orthogonal directions. A liquid pressure is supplied around the specimen, applying the major principal stress σ_1 vertically from the top and the other two principal stresses σ_2 and σ_2 (σ_2=σ_3) in the horizontal directions perpendicular to one another. Keeping σ_3 constant, σ_1 is gradually increased until the sample fails in shear.

The shear failure Coulomb equation also applies:

$$\tau = c + \sigma_n \tan\Phi \qquad (3.1)$$

Where;

τ = Shear strength

c = apparent cohesion

σ_n = normal stress

Φ= angle of shearing resistance

The apparatus used to carry out the test were: a Transparent triaxial cell, a Specimen trimmer, a Wire saw, a Vacuum source, a drying oven, Callipers, a Strain-controlled compression machine, an evaporating dish, a Membrane stretcher, a Weighing balance, porous plates, a Rubber membrane, Rubber rings, and a stopwatch.

Each borehole's soil sample was combined with 2%–10% Bentonite at intervals of 2%. First, the sample's bulk density and initial moisture content were calculated. The specimen has a height of 7.6 cm and a diameter of 3.8 cm. The first test used a cell pressure of 100 kN/m^2. The specimen was fixed on the base of the triaxial cell, covered with a rubber membrane, and given solid end caps at either end. Next, the pressure cap was set at the top. Rubber rings were then used to seal the membrane to the caps, and the cell was carefully put together with the top cap's piston elevated. The air release valve was opened to allow water to enter the triaxial cell; once water had escaped, the valve was then closed. The triaxial cell was then placed in the compression machine. The hydrostatic pressure was then increased to the necessary level and maintained there until the test's conclusion. By manually operating the compression machine, the proving ring was lowered to rest on the cell piston and shifted slightly downward. After deducting the reading required to drive the piston against the friction force and the cell pressure, the proving ring dial gauge was then reset to read zero. The proving ring was then brought back into contact with the piston after the piston was manually lowered to rest on the pressure cap. After mounting, the strain dial gauge was set to zero. Then, the axial loading was initiated at a steady strain rate of about 2% per minute. There were readings collected every 20 mm of deformation. The test was carried out until an axial load recession was noticed. Afterwards, the stress-strain curve was established. The specimen was unloaded, and the cell was disassembled. The rubber membrane was taken off, the sample was weighed, and then the moisture content was determined. The test was then conducted again for 200 and 300 kN/m^2 cell pressures, respectively.

The following steps were used for the analysis once the test result was obtained:

- The axial load imposed on the specimen, in addition to that caused by the cell pressure, is the difference between the initial pressure and the subsequent reading of the load measuring device.
- At any point throughout the test, the area A of the specimen is determined by;

$$A = \frac{A_0}{1-\varepsilon} \qquad (3.2)$$

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L_0 - L}{L_0} \qquad (3.3)$$

Where;

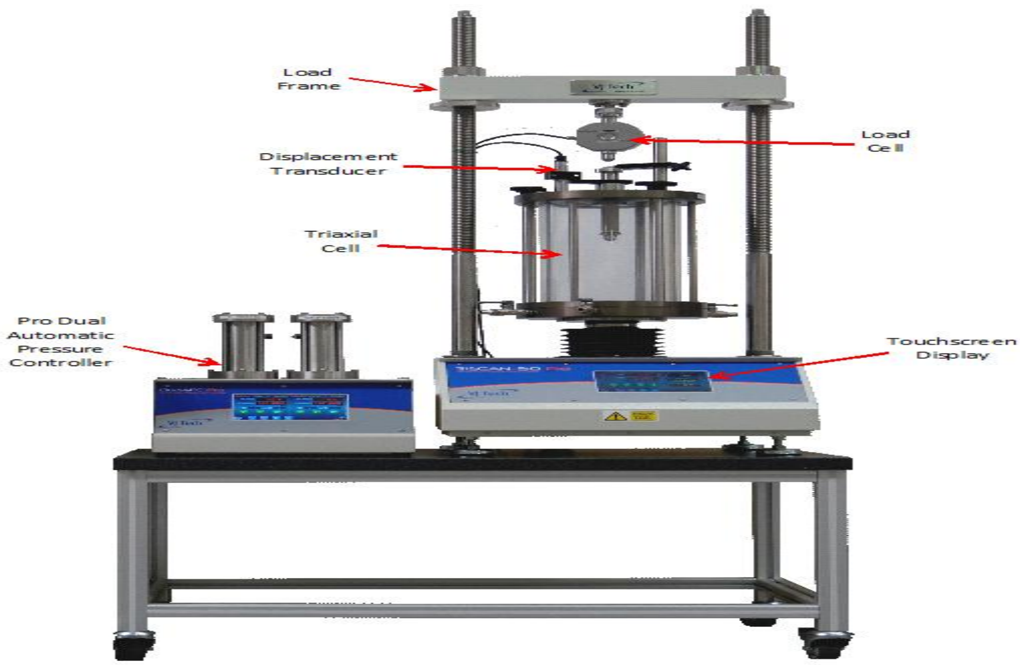
A_0 =initial area of specimen

L_0 = initial length of specimen

L = Length of specimen at the stage of the test at which area A is to be determined

- The deviator stress (σ_1- σ_3) or the principal stress difference at any stage of the test is determined by dividing the additional axial load by the area A.
- Draw a stress-strain graph. From this graph, obtain the value of $\Delta\sigma$ at failure ($\Delta\sigma = \Delta\sigma_f$).
- The cell pressures are σ_3 (i.e., the chamber confining pressure). The major principal stress (total) at failure as $\sigma_1 = \sigma_3 + \Delta\sigma_f$ (3.4)

Plate 1: Triaxial Equipment Set Up Test Preparation on Samples



2.2.2 Sample Preparation for Investigation

A total of 90 samples (3 cell pressures per bentonite percentage) of varying mixed proportions were prepared for the triaxial test and represented as shown in Table 3.

Table 3: Number of Bentonite Stabilized Soil Samples for Triaxial Test

No. of Boreholes	Bentonite (%)	No. of Samples
1	2, 4, 6, 8 and 10 (x3)	15
2	2, 4, 6, 8 and 10 (x3)	15
3	2, 4, 6, 8 and 10 (x3)	15
4	2, 4, 6, 8 and 10 (x3)	15
5	2, 4, 6, 8 and 10 (x3)	15
6	2, 4, 6, 8 and 10 (x3)	15
	Total Samples	90

2.2.2 Determination of Elastic Properties of Soil

The following are the elastic properties that required investigation upon the addition of varying quantities of bentonite slurry modifier to the lateritic soil;

2.2.2.1 Elastic or Young's modulus, E:

The determination of Young's modulus E from the initial elastic zone of the stress-strain curve measured in a drained triaxial test of the soil. Put it differently, it is the slope of the stress-strain curve's initial portion where the soil appeared elastic in nature that is used to calculate the elastic or Young's modulus of the soil (Wichtmann *et al.,* 2017)

Mathematically,

$$Elastic\ modulus\ , E = \frac{Stress}{\text{Strain}} \qquad (3.5)$$

2.2.2.2 Poisson's ratio, μ:

The lateral strain to axial strain ratio within the elastic limit is known as Poisson's ratio.

Mathematically,

$$Poisson's\ ratio,\ \mu = \frac{Lateral\ strain}{Axial\ strain} \qquad (3.6)$$

The Poisson's ratio was obtained from the graph showing the relationship between angle of internal friction and Poisson's ratio using the soil, rock mass classification systems by Bieniawski (1976).

3.0 Results and Discussion

3.1 Index properties of the Lateritic soil

The properties of soil known as "index properties" help in identifying and categorising soil for general engineering purposes. These properties were established in the laboratory. The index properties and soil classification of the lateritic soil are shown in Table 4.

Table 4: Summary of the Preliminary Test of Natural Lateritic Soil Sample

Index Properties	BH1	BH2	BH3	BH4	BH5	BH6
Moisture Content (%)	23.40	22.0	23.7	19.6	23.7	21.6
Bulk Density (kN/m^3)	18.40	18.50	18.70	18.80	18.40	18.50
Specific Gravity-Soil	2.90	3.06	2.64	2.86	2.93	2.89
Specific Gravity-Ben.	2.55	2.55	2.55	2.55	2.55	2.55
Liquid Limit (%)	42.80	41.20	55.20	45.00	50.0	45.10
Plastic Limit (%)	22.50	23.70	27.20	27.30	33.1	24.70
Plastic Limit (%)	20.30	17.50	28.00	17.80	16.9	20.40
Cohesion (kN/ m^2)	56.93	57.27	60.89	88.68	119.39	66.47
Angle of int. Friction (^{0})	3	2	3	2	4	3
Elastic modulus (kN/m^2)	2789.13	2806.52	3317.14	2828.76	2754.94	2569.81
Poissions ratio	0.48	0.47	0.47	0.48	0.47	0.48
Shear modulus (kN/m^2)	942.27	954.60	1128.28	955.66	937.05	868.18
Bulk modulus (kN/m^2)	23242.78	5591.76	18428.56	23573.00	15305.22	21415.08
Stiff. modulus (kN/m^2)	24499.14	16864.56	19932.93	24847.22	16554.64	22572.66

3.2 Elastic Modulus or Young's Modulus of Bentonite Slurry Modified Lateritic Soil

The triaxial test results for various mixtures of bentonite slurry (2%–10%) stabilized lateritic soil for the six (6) boreholes are shown in Figure 1. The behavior of the lateritic soil in its natural state and the bentonite-stabilised soil is shown therein.

The natural soil from the six (6) boreholes (BH1-BH6) had elastic modulus values of 2789.13 kN/m^2, 2806.52 kN/m^2, 3317.14 kN/m^2, 2828.76 kN/m^2, 2754.94 kN/m^2 and 2569.81 kN/m^2 for the respective boreholes. These suggest that they fall into the very soft clays category (Punmia, 2005). The elastic modulus increased and improved gradually with the addition of bentonite slurry content. However, with the addition of up to 10% Bentonite slurry, the soil improved from very soft clay to medium clay.

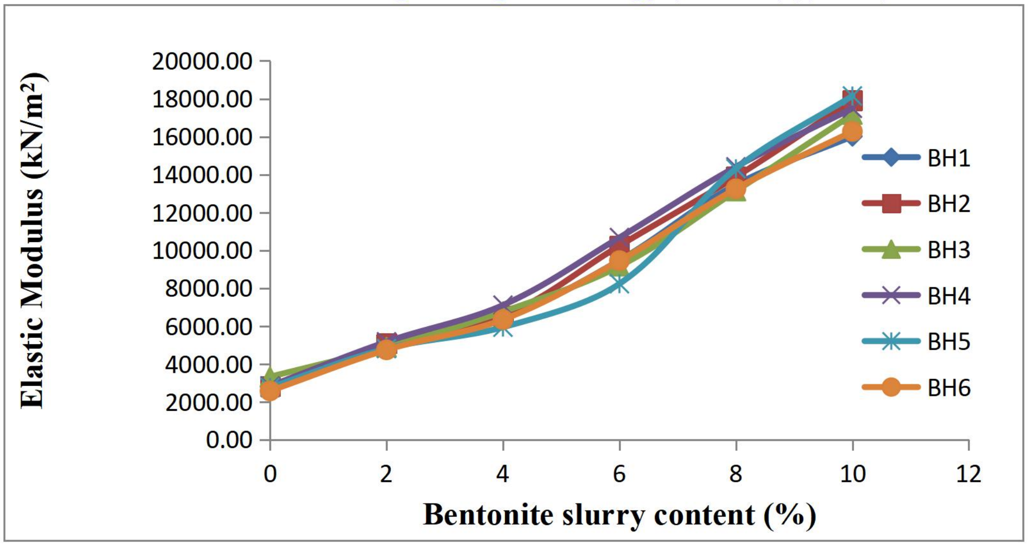


Figure 1: Elastic Modulus of Bentonite Slurry Modified Lateritic Soil

3.3 Poisson's Ratio of Bentonite Slurry Modified Lateritic Soil

The Poisson's ratio for various mixtures of bentonite slurry (2%–10%) stabilized lateritic soil for the six (6) boreholes was obtained from the relationship between angle of internal friction and Poisson's ratio graph (Bieniawski, 1976). The behavior of the lateritic soil however, is depicted in Figure 2 for each percentage of bentonite slurry content.

The Poisson's ratio decreased with an increase in bentonite slurry content. This means that the addition of bentonite slurry improved the lateritic soil's Poisson's ratio from a state of soft clays to stiff clays.

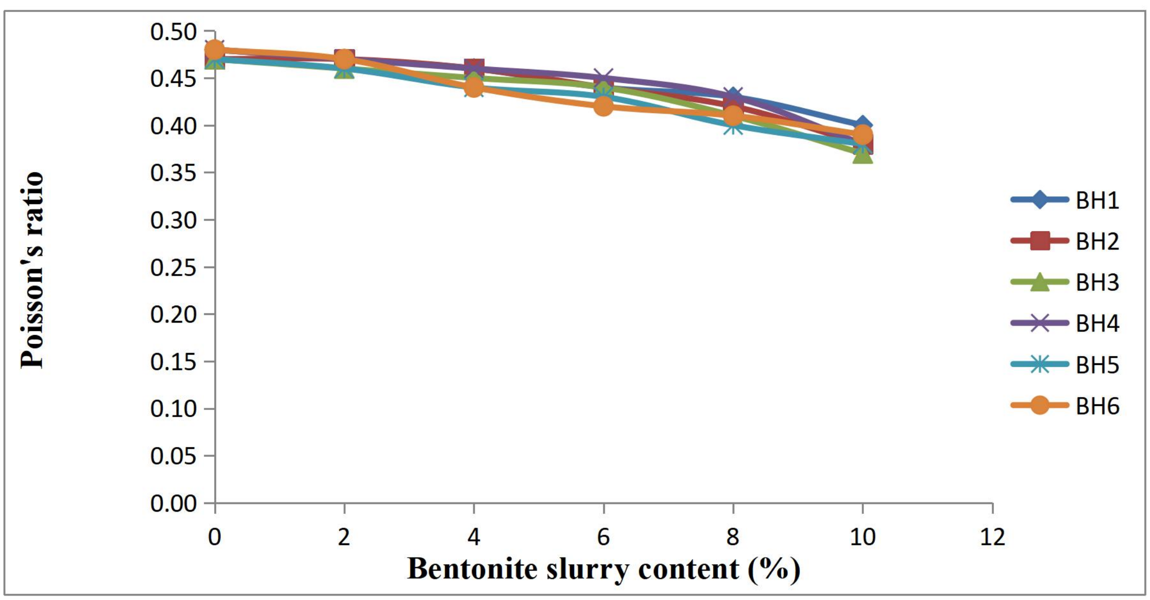


Figure 2: Poisson's Ratio of Bentonite Slurry Modified Lateritic Soil

4.0 Conclusions

In light of this research, the accompanying conclusions can be drawn

1. At 10% bentonite slurry to the lateritic soil, the elastic modulus of the lateritic soil has increased by 82.59%, 84.34%, 80.68%, 83.83%, 84.82% and 84.21% for the various boreholes. Making the modified soil perform better than the unmodified soil sample.
2. At 10% bentonite slurry addition to the lateritic soil, the Poisson's ratio of the lateritic soil decreased by 20.00%, 23.68%, 27.03%, 26.32%, 23.68%, and 23.08% for the various boreholes. Making the modified soil perform better than the natural state soil sample.
3. Based on this investigation, it is now a fact that up to 10% bentonite slurry, when blended with lateritic soil, significantly improved the elastic properties of lateritic soils, leading to the improvement of the soil from very soft to medium lateritic soil.

Declarations

Credit authorship contribution statement

N.I.E: J G.W; and S.B.A: Conceptualization. Wrote the original draft, Methodology, Validation, Resources, project administration, and review of manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

Funding

The author received no funding for this research.

Consent for publication

Not applicable

Ethics and Consent to Participate

Not applicable

Acknowledgement

The authors wish to thank the management and technical staff of the Department of Civil Engineering, River State University**,** for their administrative and technical support.

References

Arulrajah, A., Kua, T. A., Horpibulsuk, S., Mirzababaei, M. & Chinkulkijniwat, A. (2017a). Recycled Glass as a Supplementary Filler Material in Spent Coffee Grounds Geopolymers. *Construction and Building Materials, 151*(1), 18–27.

ASTM D4318-17e1 (2017). ''Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils''

ASTM D4767 (2011). ''Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils''

ASTM D4959-16 (2016). ''Standard Test Method for Determination of Water Content of Soil by Direct Heating''

ASTM D6913/d6913M-17 (2017). ''Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve''

ASTM D7263-21 (2021). ''Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil''

Awarri, A. W. & Otto, C. G. (2022). Settlement Analysis of Cement and Residue from Spent Calcium Carbide Stabilized Cohesive Soils‖. *IOSR Journal of Mechanical and Civil Engineering,* 19(4), 45 – 51.

Bazne, M. O. A., Howard, I. L. & Vahedifard, F. (2017). Stabilized very High Moisture Dredged Soil: Relative Behavior of Portland-Limestone Cement and Ordinary Portland Cement. *Journal of Materials in Civil Engineering, 29* (9), 1- 10.

Bieniawski, Z. T. (1976). Rock Mass Classification in Rock Engineering. Symposium Proceedings of Exploration for Rock. *Engineering, 1,* 97 - 106.

British Standards (B.S 1377), 1990. *Methods of Test for Stabilized Soils.* British Standards Institution: London, UK.

Choi, S. G., Park, S. S., & Chu, J. (2017). Methods for Calcium Carbonate Content Measurement of Bio-cemented Soils, Journal of Civil Engineering, 29 (11), 1 - 4.

Firoozi, A.A., Olgun, C.G., Ali, A.F. & Mojtaba, S.B (2017). "Fundamentals of Soil Stabilization".Engineering 8, 26.

Olaniyan, O.S., Olaoye R.A,, Okeyinka, O.M., & Olaniyan D.B, (2011). Soil Stabilization Techniques Using Sodium Hydroxide Additives.*Internal Journal of Civil & Environment Engineering,* 11(6).

Olaniyan, O.S., Olaoye R.A,, Okeyinka, O.M., & Olaniyan D.B, (2011). Soil Stabilization Techniques Using Sodium Hydroxide Additives.*Internal Journal of Civil & Environment Engineering,* 11(6).

Punmia, B.C., Ashok, K. J. & Arun, K. J. (2005). *Elements of Elasticity, Soil Mechanics and Foundation,* 16th Edition, 279 – 294.

Rosa, M. G., Cetin, B. T., Edil, B. & Benson, C. H. (2017). Freeze-thaw Performance of Fly Ash-Stabilized Materials and Recycled Pavement Materials. *Journal of Materials in Civil Engineering, 141 (5),* 938-943

Shaw J.N. (2001). "Iron and Aluminum Oxide Characterization for Highly-Weathered Alabama Ultisols," *Communications in Soil Science and Plant Analysis, 32(1-2)* 49–64.

Wichtmann T., Kimmig I., & Triantafyllidis T.H. (2017). ''Soil Dynamics & Earthquake. *Engineering, 98*,72-83.

Yilmaz, I., & Civelekoglu, B. (2009). Gypsum: An additive for stabilization of swelling clay soils, *Applied Clay Science*, 44 (1), 166 –172.

Yoshinaka, R. & Kazama, H (1973). ''Microstructure of compacted kaolin clay, *Soils and Foundations, 13*, 19-34.