Journal of Basic Physical Research ISSN: 2141-8403 Prints, 2141-8411 Online
Vol.14, Issue 1, March, 2025, pp. 19 - 26. Available online at https://journals.unizik.edu.ng/jbpr/

ENGINEERING PROPERTIES OF SOILS DEVELOPED OVER ENUGU SHALE: IMPLICATIONS FOR CONSTRUCTION AND DURABILITY.

Chidiebere H. Nnamani, Chigozie I. Aganigbo and Ejiofor C. Ezike
Department of Geology and Mining, Faculty of Physical Sciences
Enugu State University of Science and Technology
**Email: henry.nnamani@esut.edu.ng*

Abstract
Assessment of engineering properties of soils developed over Enugu Shale for their sustainability, durability and workability for engineering construction is highly needed in this time of massive infrastructural development in Enugu and environs. Proper characterization will assist developers and policymakers to obtain the desired and sustainable engineering development in the study area. Thirty soil samples were collected from varying depth ranging from 0.5m to 1.0m. The collected soil samples were sent to laboratory to ascertain their engineering properties such as consolidation, permeability and shear strength. The consolidation test was determined through oedemeter test. Through the test, we obtained the values of compression index (Cc), coefficient of volume change (Mv) and coefficient of consolidation (Cv) which range from 0 – 0.25, 0 – 1.19m^2/MN and 0 – 3.56m^2/yr respectively. The coefficient of permeability ranges from 1.52 – 331.13m/yr. The shear strength parameters of cohesion and internal friction range from 1.42 – 38.08KN/m^2 and 3.10 – 14.85^0 respectively. The results show that the study area is dominated with medium coefficient of volume change and the soils are poorly drained. The study area has good cohesion but low angle of internal friction and low to medium undrained compressive strength especially in the eastern part. These results imply that special foundation would be needed in the eastern part of the study area for the sustainability and durability of engineering structures in the area.
Keywords: *consolidation, permeability, shear strength, sustainability and durability*

Introduction

Soil is a product of rock weathering which contains primarily the mineral grains of the weathered rock and sometimes fragments of the parent rock as well. It is formed through the process of physical, chemical and biological weathering (Balasubramaian, 2017). Soil properties are impacted by the parent rock minerals, weathering process, topography, climatic conditions of the area, environmental factors and both the surface and subsurface water of the area (Nnamani and Igwe, 2020). Soil serves both as a foundation and, in some cases, as construction material. Geologists see soil as material in the relatively thin zone of the Earth crust which has been impacted by weathering processes. In engineering construction, soil must possess some of the good properties for it to be used as site for engineering construction as well as a material for construction. Some of these properties include consolidation, permeability and shear strength. When a saturated soil is subjected to a compressive stress, its volume decreases. The compression of the soil mass can be due to one or more of the following reasons; compression of solid particles and expulsion of water in the voids. The process of compression of a saturated soil mass under a steady static pressure is known as consolidation. When a load such as foundation footing is applied to a mass of saturated soil, the water drains to the extent compatible with the magnitude of load. This leads to a reduction in the volume of voids, as well as the thickness of the soil mass and consequent settlement of the footings. This is a time-dependent process. The amount of settlement that occurs to the footing is related to the compression index (Cc) or coefficient of volume change (Mv). The good knowledge of the rate at which the compression of the soil layer occurs is important to understand the type and nature of the footings for the proposed engineering structure. Soils are permeable for they consist of solid particles, and a good network of interconnected pore spaces. The degree of permeability of soil depends on soil type, grain size distribution, and soil stress history. The permeability of soil is characterized by the coefficient of permeability (K) which is a product of Darcy's law (Arora, 2008). Permeability is a critical engineering property. A good knowledge of permeability is key towards the understanding of some soil engineering problems such as settlement and consolidation. Shear strength of soil results from an angle of internal friction which is the interlocking of the particles and bonding at the particle surface contact. The shear strength parameters of soil mass comprises of cohesion and angle of internal friction as stated by Mohr Coulomb's theory. Shear strength of soil mass depends on the effective stress, drainage conditions which can be determined by the coefficient of permeability, density of the particles, and rate of strain and direction of strain. Therefore, the shear strength is controlled by the consistency of the soil materials, mineralogy, grading of soil materials, initial void ratio and features such as layers, joints, fissures and cementation (Nnamani, 2022). This study assesses the geotechnical properties of soils developed over Enugu Shale to evaluate their suitability for engineering construction

Geological Setting

Enugu Shale overlays the Agbani Sandstone/Awgu Shale (Coniacian). It is a member of Nkporo group (Campanian) and lateral equivalent of Nkporo Formation and Owelli Sandstone. Enugu Shale is one of the oldest deposit of Anambra Basin (Nwajide, 1990). It consists of fissile, grey shale with extra formational clast and capped on top by Ironstone with presence of pyrite. The shale is associated with extensive synsedimetary and post-sedimentary deformational structures (Nwajide and Reijers, 1999) and lies in the eastern part of Anambra Basin. Enugu Shale which is now well known as Enugu Formation is well exposed along Enugu-Onitsha Express Way by New-Market flyover and along Enugu-Port Harcourt Express Way by Ugwuaji flyover. The highly weathered Enugu Shale consists of reddish brown lateritic and non-lateritic soils that are porous and varies significantly up to a maximum depth of 20 m, depending on the topography and drainage conditions (Nnamani and Okonkwo, 2022).

Materials and Methods

The study involves field observations, samplings and laboratory experiments. Prior to the field work, desk study of topographic map of Enugu urban and environs were thoroughly studied for the purpose of understanding the topography of the area in view of variations in engineering properties with change in topography.

Field Observations and Samplings

With aim of determining the variations in engineering properties with change in topography, soil samples were collected from 30 different locations by careful observing the variations in the elevations, topography and active engineering foundation and pavement challenges in the study area. Bearing in mind that prevailing geology and climatic conditions in the study area are the same. The fieldwork lasted for two days. Samples were collected at the varying depth of 0.5m to 1.0m depending on the depth to fresh soil sample with minimal weathering impact.

Laboratory experiments

Consolidation tests

Consolidation tests were carried out in accordance with (BSI 1377, 1990). Soil sample was extruded into a pre-weighted ring of 50mm internal diameter and 19mm thickness. The ring with extruded soil sample was weighed and placed between two porous stones inside a circular cell chamber containing water. A dial gauge, with a least count of 0.002mm, is mounted on the top of the pressure pad to obtain the compression of the soil sample. An initial load of 5KPa called the seating load was applied on the soil sample to create a flat surface of the soil sample. The seating load was maintained for 24hrs and was later relaxed. Subsequently, the loads were applied by placing standard weights on the loading arm of the odometer to cause the needed final stress of 12, 25, 50, 100. 200, and 400KPa on the soil sample in successive load increments.

Compression Index (Cc): This is equal to the slope of a linear portion of the void ratio versus Logσ' plot

i.e. $Cc = \frac{-\Delta e}{\log_{10} \sigma' / \sigma'_{0}}$ ……… $eqn1$

Where σ'_0 = initial effective stress

σ'= final effective stress

△e = change in void ratio.

Coefficient of volume change (Mv): This is defined as the volumetric strain per unit increase in effective stress.

i.e. $Mv = \frac{\Delta V/Vo}{\Delta\sigma'}$ ……….eqn 2

where Vo = initial volume

△V = change in volume

△σ' = change in effective stress

Coefficient of consolidation (Cv) in M^2/S can be expressed as

i.e. $Cv = \frac{k}{\mathrm{MvYw}}$ ……….eqn 3

where; k = hydraulic conductivity (m/s)

Mv = coefficient of volume change (m^2/KN)

Yw= unit weight of pore fluid (KN/m^3)

Empirical Prediction of Coefficient of Consolidation

Various engineering properties of soils are correlated with index properties. Researchers have done great works in an attempt to predict coefficient of consolidation (Raju Narasimha, *et al*. 1995 and Sridharan and Nagaraj, 2004). (Carrier, 1985) provided a coefficient of consolidation Cv (in m^2/s) as follows;

$$Cv = \frac{9.09x\ 10^{-7}(1.192 + ACt^{-1})^{6.993}(4.135IL + 1)^{4.29}}{\mathrm{IP}(2.03\mathrm{IL} + 1.192 + \mathrm{ACT}^{-1})^{7.998}} \ \ldots\ldots\ldots.eqn\ 4$$

Where; Act = activity
IL = liquidity index
Ip = Plasticity index

It can be noted from equation 4 that Cv is inversely proportional to the plasticity index. While (Raju Narasimha, *et al*. 1995) came up with an equation to predict Cv (in Cm^2/s) for a normally consolidated clay in terms of the void ratio at the liquid limit (LL) and the in situ effective overburden pressure, Q^IV (Kpa) as

$$Cv = \frac{1 + LL(1.23 - 0.276\, log\, Q^{i}v)}{\text{LL}}\ X\ \frac{1}{Q'v(0.353)}\ X\ 10^{-3} \ldots\ \ldots\ldots\ldots.eqn\ 5$$

(Sridharan and Nagaraj, 2004) provided an empirical correlation of coefficient of consolidation as;

$$Cv = \frac{3}{100\ (Is)^{3.54}} \ldots\ \ldots\ldots\ldots.e\text{qn } 6$$

Where, cv = coefficient of consolidation in m^2/s

Is = shrinkage index

Unlike plasticity index used by (Carrier, 1985), equation 6 proposed shrinkage limit.

Permeability of Soil

Darcy derived an empirical relation through his experiment on the flow of matter through a porous medium. He stated that Q = KiA ……eqn7

Where Q = flow rate
i = hydraulic gradient
A = cross sectional area of the flow
K = coefficient of permeability

Table 1: Typical values of the coefficient of permeability (Arora, 2008)

Soil type	Coefficient of permeability in (mm/sec)	Drainage properties
Clean gravel	10^{+1} to 10^{+2}	Very good
Coarse and medium sands	10^{-2} to 10^{+1}	Good
Fine sands, loose silt	10^{-4} to 10^{-2}	Fair
Dense silt, clayey silts	10^{-5} to 10^{-4}	Poor
Silty clay, clay	10^{-8} to 10^{-5}	Very poor

Shear Strength

Triaxial tests were carried out on the soil samples by means of applied stress. In a consolidated drained condition, a known stress was applied to the soil sample being tested for in a way that the resulted stresses along one axis were different from the stresses in the perpendicular direction. This was achieved by means of triaxial apparatus which has two parallel platens and the soil sample was placed in between the platens. This allowed applied stress in one direction (vertical direction) and fluid chamber allowed another applied stress to the soil sample in the perpendicular directions. The applied stresses in the triaxial apparatus caused shear stress to develop in the sample. The stress was increased and deflections monitored until the fracture of the soil sample occurred. Angle of internal friction and cohesion were obtained through semi Mohr circle plot. Mohr Coulomb's theory stated the shear strength (s) of a soil at a point on a particle plane is a linear function of the normal stress on the plane as s = c + ɕtanØ --- eqn8. Where c is cohesion which is independent of normal stress, ɕ is shear stress and Ø is angle of internal friction.

Results and Discussions

The aim of the consolidation test on the study area is to obtain soil data which were used in predicting the rate and amount of settlement of a structure founded on the soils of the study area. The lowering of water table and dewatering of saturated or partially saturated soils are the known cause of massive settlement. The rate at which dewatering occurs depend on the inherent properties of soils as well as its mineralogical composition. Materials and methods section have elaborated on the principle and prevailing factors of consolidation. Table 2 shows the values of coefficient of consolidation (Cv), coefficient of volume change (Mv) and compression index (Cc) in the soils of study area. Table 3 is the classification of these parameters by (Bell, 2011). The results of coefficient of volume change in Table 2 show that about 33.33% of the samples have high coefficient of volume change and 63.33% of the samples have a medium coefficient of volume change based on (Bell, 2011) classification. This implies that the soils of study area if used as foundation materials without treatment will probably undergo a reasonable settlement with time and differential settlement due to heterogeneous nature of soils and probably shorten the life span of engineering structures in the area. The results were used to generate the map of study area in terms of coefficient of volume change (Fig. 1). Table 2 shows that samples were made up of 50% high compression index, 33.33% medium compression index and 10% low compression index on the basis of (Bell, 2011) classification in Table 3. The obtained results were used to generate the map of study area in terms of compression index (Fig.2).

Table 2: Engineering properties of the studied samples in the study area

STATION	C (KNM^{-2})	Ø(°)	UNDRAINED COMPRESSIVE STRENGTH (KNM^{-2})	Cv (m^2/yr)	Mv (m^2/MN)	Cc	K (m/yr)	Geotechnical Attributes
2	30.21	4.42	62.13	1.24	0.22	0.19	2.83	Unfavourable
3A	13.49	7.84	71.95	2.75	0.2	0.23	5.64	Unfavourable
3B	22.37	5.49	61.97	0.65	0.25	0.24	5.33	Unfavourable
4	30.55	5.22	69.47	1.21	0.16	0.16	9.81	Unfavourable
5	30.36	5.14	67.33	0.35	0.19	0.08	3.53	Unfavourable
6	27.53	6.32	75.71	0.62	0.32	0.21	30.30	Favourable
7A	27.86	5.85	71.81	0.54	0.29	0.20	15.45	Favourable
7B	26.82	5.85	68.15	0.62	0.24	0.21	15.64	Favourable
8	32.52	7.21	90.59	0.52	0.4	0.12	2.24	Favourable
9	4.51	6.89	18.30	0.37	1.11	0.05	14.48	Favourable
10A	6.07	7.02	20.61	0	0	0	4.89	Favourable
10B	28.34	11.72	136.63	1.05	0.26	0.20	1.54	Favourable
11A	30.22	3.12	51.86	0.75	0.39	0.13	4.57	Favourable
11B	1.42	10.62	24.30	1.21	0.85	0.11	6.34	Favourable
12	25.05	4.93	60.31	1.1	1.19	0.04	47.62	Favourable
13	27.28	5.3	66.24	1.08	0.22	0.04	331.13	Favourable
14	28.74	11.67	136.56	2.19	0.2	0.23	5.99	Favourable
15	38.03	3.1	60.40	1.75	0.26	0.16	5.52	Unfavourable
16	27.8	6.91	81.61	1.29	0.17	0.11	2.41	Favourable
17	33.66	5.53	75.97	1.96	0.22	0.08	68.75	Favourable
18	37.75	4.03	67.29	1.63	0.13	0.16	8.83	Favourable
19	12.19	14.85	154.84	0	0	0	1.83	Unfavourable
20	28.74	6.69	80.70	1.56	0.11	0.21	41	Favourable
21	26.97	10.8	122.92	0.34	0.76	0.24	17.09	Favourable
22	30.58	5.93	75.87	0.96	0.7	0.17	11.32	Unfavourable
23	22.83	10.51	113.36	3.56	0.2	0.25	50.77	Favourable
24	27.6	7.08	82.99	0.23	0.2	0.08	7.38	Favourable
25	36.15	7.4	97.19	0.45	0.87	0.12	30.50	Unfavourable
26	36.94	5.58	80.42	0.102	0.14	0.10	6.34	Unfavourable
27	26.97	6.83	79.79	0.19	0.22	0.20	1.52	Unfavourable

***Table 3:** Bell classification of coefficient of volume change and compression index*

Mv(m^2/MN)	Degree of compressibility	Cc	Degree of compressibility
>1.5	Very high	>0.3	Very high
0.3-1.5	High	0.3-0.15	High
0.1-0.3	Medium	0.15-0.075	Medium
0.05-0.1	Low	<0.075	Low
<0.05	Very		

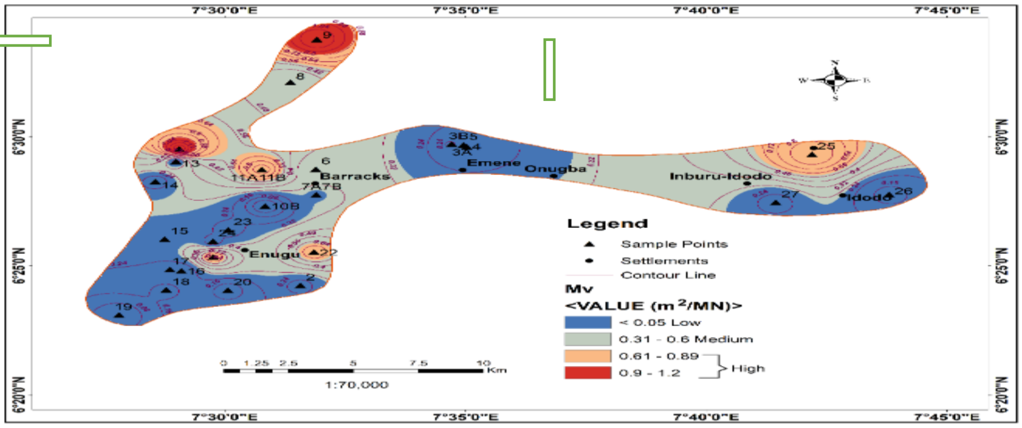

Figure 1: *Map of coefficient of volume change in the study area showing expected variations in the settlement*

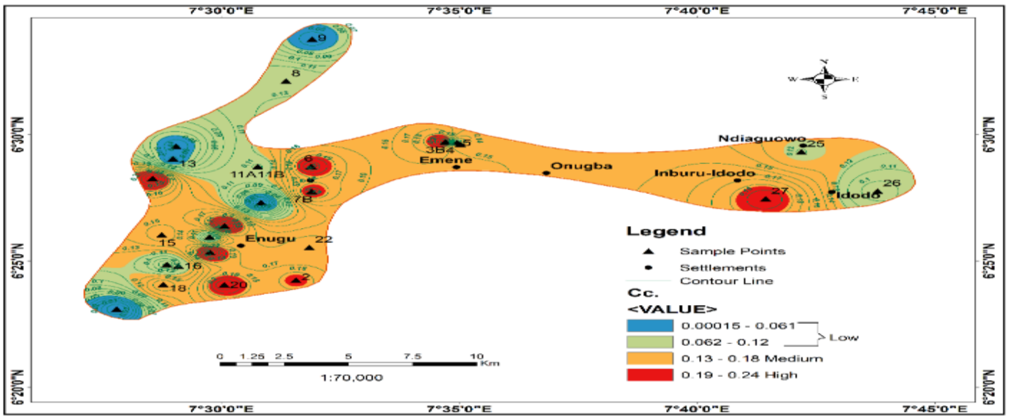

Figure 2: *Map of compression index in the study area*

Permeability

The rate at which water flows in the soil mass has an important role on the properties and behaviour of soil mass. Understanding the principle of fluid flow, as groundwater conditions are frequently encountered on the construction site, is a good step in solving geotechnical problems in the construction area. The rate of consolidation of compressible soils under load depends on its permeability. And the rate of drainage of water through wells and excavated foundation pits depends on the coefficient of permeability of the soils. Soil shear strength also depends indirectly on its permeability, because dissipation of pore pressure and effective stress principle are controlled by soils permeability. Table 1 is typical values of coefficient of permeability, which was compared to the samples of the study area. Table 2 shows the coefficient of permeability (k) of the studied soil samples. Low permeability suggests poor drainage, which can elevate pore pressure and cause differential settlement (Arora, 2008). Figure 3 shows distributions of values of coefficient of permeability in the study area. The excessive water stored in the soils due to poor permeability exert excessive pore pressure when loaded with engineering structures in the study area. The effect can be seen on the shear strength of soils in the study area.

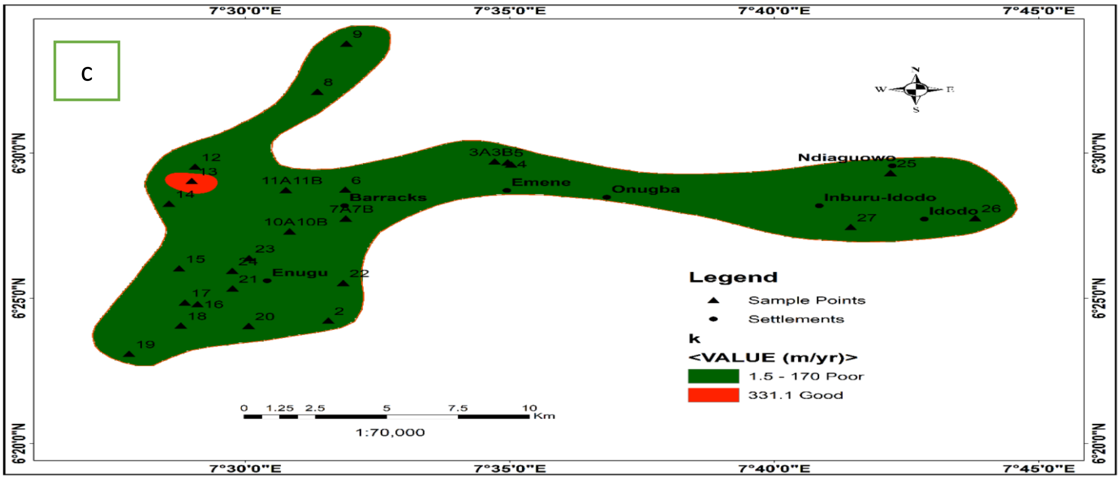

Figure 3: Map of Coefficient of permeability in the study area.

Shear Strength

The studied samples are dominated by kaolinite (Nnamani and Igwe, 2020), with good cohesion Table 2 and low angle of internal friction (Ø) Table 2, poor grading and near horizontal layering, good cementation by (Nnamani and Okonkwo, 2022), poor permeability Table 2 and Figure 3, and poorly connected joint sets near the surface. Kaolinite has low plasticity and thus low swelling potential. The study area is dominated by soft soil with low to medium undrained compressive strength (Fig.4) and Table 2. The above results show similarity with works of (El-Sayed and El-Sharif, 2008), and (Sharma and Fahey, 2003) on factors influence the shear strength of soils. The capability of a soil mass to support a loading from an engineering structure or sustain a slope in equilibrium is governed by its shear strength. The study area by nature of its inherent properties requires a special foundation design, especially in the eastern part for sustainability of engineering structures.

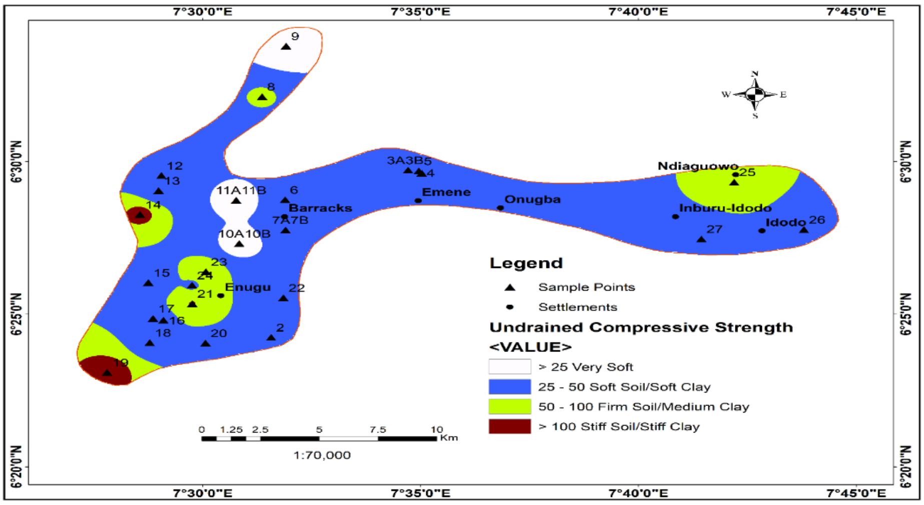

Figure 4: Map showing the distribution of undrained compressive strength in the study area.

Conclusions

1. Samples results showed that the study area will exhibit differential settlement due to variations in coefficient of volume change in the area.
2. The studied samples showed poor permeability for the study area. The classification of permeability of the study area based on the work of Arora (2008) showed that samples were poorly drained.
3. The studied samples had good cohesion, low angle of internal friction and low to medium undrained compressive strength especially in eastern part of the study area. These findings indicate that the soils require special geotechnical consideration before construction.

References

Arora, K. R. (2008). Soil mechanics and foundation engineering (Geotechnical Engineering) 7th edition. Standard Publishers Distributors, NaiSarak, Delhi, 953p.

Balasubramaian, A. (2017). Engineering properties of soils. Centre for Advance Studies in Earth Science, Technical Report, p. 1-7.

Bell, F.G. (2011). Engineering Geology. 2nd edition Elsevier, New Delhi, India, 581p.

British Standard Institution (BSI) 1377. (1990). "Methods of testing soils for civil engineering purposes". British Standards Institution, London.

Carrier, W. D. (1985). Consolidation parameters derived from index test. Geotechnique, 35(2):211-213.

El-Sayed, S. A. S. and El-Sharif, M. A. (2008). Geotechnical factors governing shear strength of Quseir Shale in Dakhla Oasis Western Desert, Egypt. J. Engr. Sci., 36(1):131-145.

Nnamani, C. H. (2022). The chemical and mineralogical composition and their effects on strength parameters of cohesive soil developed over Enugu Shale. European Journal of Environment and Earth Sciences, 3(1):28-35.

Nnamani, C. H. and Okonkwo, A. C. (2022). The lateritic potential of soils developed over Enugu Shale for civil engineering construction in Enugu and environs. European Journal of Engineering and Environmental Sciences, 6(3):1-8.

Nnamani, C. H. and Igwe, O. (2020). Estimation of swelling potential of Enugu Shale using cost effective methods. International Journal of Physical Sciences, 15(1):10-21.

Nwajide, C. S. (1990). Cretaceous sedimentation and paleogeography of the Central Benue Trough. In: Ofoegbu, C.O., (Ed.), The Benue Trough Structure and Evolution International Monograph Seriesw, Braunschweigh. p.19-38

Nwajide, C. S. and Reijers, T. J. A. (1999). Geology of the southern Anambra Basin. In: Reijers TJA(Ed), Selected chapter on Geology SPDC Warri, p. 133-148.

Raju Narasimha, P. S. R., Pandian, N. S. and Nagaraj, T. S. (1995). Analysis and estimation of coefficient of consolidation. Geotechnical Testing Journal, 18(12):252-258.

Sharma, S. S. and Fahey, M. (2003). Evaluation of cyclic shear strength of two cement calcareous soils. J. Geotech. Geoenvironmental Engr., 129(7):608-618.

Sridharan, A. and Nagaraj, H. B. (2004). Coefficient of consolidation and its correlation with index properties of remolded soils. Geotechnical Testing Journal, 27(5):1-6