The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 04 || Series I || Pages || PP 50-57 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Consolidation Characteristics of Expansive Soils from Parts of Anambra Basin, Southeastern Nigeria

OKEKE O.C., IWUOHA, P.O., EBERENDU, C. J., OMOKO, E.N., AMADI C.C. AND NWACHUKWU, H.G.O.

Department of Geology, Federal University of Technology, Owerri, Nigeria.
Corresponding Author: OKEKE O.C

Abstract

Atterberg limits and consolidation tests were carried out on samples of expansive soils derived from Imo Shale (Amuro-Okigwe and Ozu-Abam) and Mamu Formation (Asaga), Anambra Basin, in order to infer their consolidation behaviour. The liquid limits range from 33-56% while the plasticity index value range from 30-31%. The samples used in the test were found to have a dry densities of 1.11Mg/m^3 to 1.58Mg/m^3. The consolidation swell test on these samples has indicated that the moisture content ranges from 33-51% with an average value of 38% and compression index of the expansive soil falls within the range of 0.73-0.68 (Amuro-Okigwe, 0.73: Asaga, 0.68: Ozu-Abam, 0.73). The results have shown that the samples fall into clay of high plasticity (both) soils with corresponding medium (soil derived from Mamu Formation) and high swelling potentials, (soils derived from Mamu Formation and soils derived from Imo Shale, respectively), and moderate compression index (both soils). Soils with high/medium swelling potentials tend to have moderate/high compression index. Compression index of expansive soils may therefore be used to estimate foundation settlement in expansive soils.

Keywords: *Consolidation, Expansive Soils, Atterberg limits, Swelling potential, and Compression index.*

Date of Submission: 07-04-2020 Date of Acceptance: 22-04-2020

I. INTRODUCTION

Expansive soils are clayey soils that swell or increase in volume when in contact with water and shrink or decrease in volume when the water is removed (Nelson and Miller, 1992).

Expansive soils with swelling and shrinking behavior prove to be challenging for construction and pavement activities (Kartikey et al., 2012). These expansive soils contain clay mineral that absorbs water molecules as a result of its diffuse layer. Thermal and X-ray diffraction pattern analysis have shown that montmorillonite mineral is predominant in expansive soil (Prasad et al., 2008). They are mostly found in the arid and semi-arid regions and they cover very large area of the world. For swelling to occur, these soils must be initially unsaturated at some water content (Radhey, 1998). If the unsaturated soil gains water content, it swells. On the other hand, if a decrease in water content occurs the soil shrinks.

Swelling and consolidation of expansive soils are phenomenal, which take place due to moisture change and effective stress change in the soil mass, respectively (Nelson and Miller,1992). Swelling of expansive soils takes place under change in the environment of the soil (Chen, 1988). Environmental change can consist of pressure release due to excavation, desiccation caused by temperature increase, and volume increase because of the introduction of moisture. By far the most important element and of most concern to the practicing engineer is the effect of water on expansive soil. There must be a potential gradient, which can cause water migration and a continuous passage through which water transfer can take place. The potential gradient in expansive soils can be due to seasonal moisture fluctuation or thermal gradient, which can cause vapor and liquid moisture transfer. It is well recognized that the heaving of expansive soils may take place without the presence of free water. Vapor transfer plays an important role in providing the means for the volume increase of expansive soils.

On the other hand, consolidation takes place when there is change in volume of the soil mass due to pore water pressure dissipation (Arora, 2004). Any structure built on the ground causes increase of pressures on the underlying soil layers. The soil layers are unable to spread laterally as the surrounding soil strata confines them. Hence there must be adjustment to the new pressure by vertical deformation. The compression of the soil mass leads to the decrease in the volume of the mass, which result in the settlement of the structure, built on the mass.

However, engineering construction such as highways, airports, seaports and residential buildings has necessitated for evaluation of good soil conditions for proper safety of the structures Madurwar et al., 2013.

Several research works are being carried out to study the behavior of expansive soil, which says that structures, when built over such expansive soil are subjected to serious threat due to its alternative swelling and shrinkage behavior. To protect the structures, built over the expansive soil, from damage and to increase its design life, it is necessary to modify the properties of the sub soil. Thus the aim of this paper is to present a review on characteristics, behavior, stabilization of expansive soil, its effects on the structures and possible remedial measures.

II. LOCATION AND GEOLOGY OF THE STUDY AREA.

The study areas Amuro-okigwe, Asaga-Ohafia and Ozu-Abam are located in Anambra Basin Southeastern Nigeria. The areas are bounded between latitude 5^0 15^1N to 5^0 65^0N and longitude 7^0 13^1E to 7^0 81^1E. The tectonic evolution of the Anambra Basin may be traced back to the late Jurrassic when convention currents in the asthenosphere caused the break-up of the Gondwana Supercontinent. The separation of the African and south American plates left the Benue Trough as an aulacogen, a failed arm of an RRR Triple Junction (Burke, 1972; Olade, 1975).The Benue Trough is itself a part of the very expansive west and central African rift system in which it opened as an extensive sinistral wrench complex (Emery *et al*., 1975; Whiteman, 1982; Genik, 1993). A reconstruction by Murat (1972) shows the southern part of the Benue Trough as longitudinally faulted, with its eastern half subsiding preferentially to become the Abakiliki depression. During the filling of the Abakiliki-Benue sector of the Benue Trough in the Albian-Santonian times, the proto-Anambra Basin was a platform that became only thinly sediment-draped (Nwajide and Reijers, 1997). Basin subsidence in the southern Benue Trough was spasmodic. It was at a high rate in pre Albian time, low in lower Cenomanian, and very high in Turonian; the latter was an important phase of platform subsidence (Ojoh, 1990). This is thought to be the actual time of initiation of the Anambra Basin; a process that gained momentum in the Coniacian and climaxed during the Santonian thermotectonic event (Nwajide, 2005).

Sediment deposition in the Southeastern Nigeria started in the Campanian with a short marine transgression followed by a regression. The Nkporo Shale and its lateral equivalents, the Enugu Shale and Owelli Sandstone (Nkporo Group), constitute the basal beds of the Campanian period. The broad shallow sea gradually became shallower because of gradual subsidence, initiating regressive phase during the Maastrichtian that deposited deltaic foresets and flood plain sediments of the Mamu Formation (Lower Coal Measures). The Mamu Formation is overlain by the continental beds of Ajali Sandstone (False bedded Sandstone), followed by a return to partially paralic conditions and the deposition of the Nsukka Formation.

The Nsukka Formation marks the onset of the Sokoto transgression (Murat, 1972) and documents a return to paludal conditions. Sedimentation was mainly of fluvial origin. The Imo shales reflect shallow-marine shelf conditions in which foreshore and shoreface sands are occasionally preserved (Petters et al., 1981). The Imo Formation consists of blue-grey clays and shales and black shales with bands of calcareous sandstone, marl, and limestone (Reyment, 1965).

It is quite possible that the basal beds of the Ogwashi-Asaba Formation are partly Oligocene in age (Kogbe, 1985). During the Miocene, the Niger Delta continued to build up and prograde seawards. There was a lowering of sea level during the Pleistocene. The River Niger cut wide valleys through its own delta. These troughs are being filled today as the sea level gradually rises. Fig. 1: shows the geologic map of Southeastern Nigeria and the location of the study area, while Table 1 shows stratigraphic sequence of sedimentary rocks in Southeastern Nigeria.

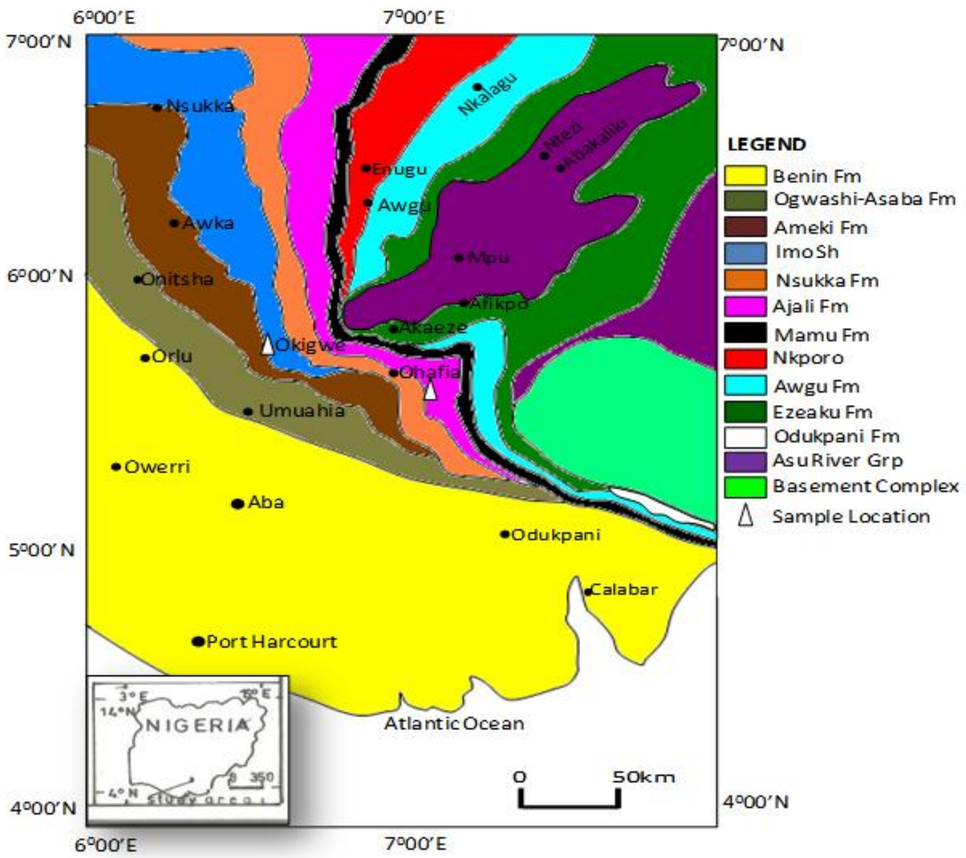


Fig 1. Geologic map of Southeastern Nigeria (Adapted from Peters, 1978 and Mode, 2004)

Table 1: Generalized regional stratigraphy of Southeastern Nigeria (Modified from Reyment, 1965 and Offodile, 1975)

	Age	Formation	Lithology
Tertiary	Recent	Recent Sediments	Alluvium/Deltaic Plains
	Miocene-Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
	Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsoliddated sandstones, mudstone, clay and lignite seams.
	Eocene	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone units
Upper Cretaceous	Paleocene	Imo Formation	Blue to dark grey shales and subordinate sandstone members (Umuna and Ebenebe)
	Maastritchian	Nsukka Formation	Alternating sequence of shale, sandstone and coal seams
		Ajali Formation	Friable sandstone with iron stains
		Mamu Formation	Sandstone, shale, siltstone with coal seams
	Campanian	Nkporo Formation/Enugu Shale	Mudstone and shale with thin beds of sandstone
	Santonian Coniacian	Awgu Formation (Awgu Shale)	Shale with intercalations of sandstones and shaly limestones
	Turonian	Ezeaku Formation (Ezeaku Shale)	Siltstone and shale with sandstone lenses
	Cenomanian	Odukpani Formation	Alternating sequence of sandstone, shale and limestone
Lower Cretaceous	Albian	Asu River Group, Abakaliki Shale and Awi Formation	Sandy shales, sandstone and sandy limestone lenses
	Precambrian	Basement Complex	Older granites and gneisses

III. MATERIALS AND METHODS

Soil samples were collected from three different geological locations within the study area (Amuro-Okigwe, Asaga and Ozu-Abam). Each of the samples was collected at a depth of about 3 ft. The samples were properly packaged in polythene bags inorder to retain its natural moisture content. The samples were taken to the laboratory to determine some vital geotechnical properties that will affect the engineering potential of the soil. These characteristics include:

Natural Moisture Content: This is achieved by

$W = W_w/W_s \times 100/1$. . . . . (1)

Where W = Natural moisture content of soil

W_w = Weight of water in soil sample (initial weight of soil W_1 minus weight of oven dried soil W_2).

Ws = Weight of solid soil in sample (weight of even dried soil).

Atterberg Limits: This indicates the moisture content variation of the soil as it gradually changes from one state to another (BSI, 1981). Three different parameters where determined namely the plastic limit, liquid limit and the shrinkage limits. The Casagrande methods were used to determine the parameters.

Plasticity Index: This is the difference between the liquid limit and plastic limit. It is expressed as:

$PI = LL – PL$ . . . . (2)

Where PI = Plasticity Index

LL = Liquid limit

PL = plastic limit.

Density: This comprises the determination of the bulk density and dry density. The bulk density (LD) is given by

Bulk density (LD) = $(A – B)/C$. . . . . (3)

Where A = weight of mould and sample

B = weight of mould only

C = volumw of mould

Dry density = $100w/(100 + 10Mg/m^3)$ . . . . . . (4)

Specific Gravity: This is the ratio of a unit weight of material to the unit weight of water. It is derived as follows

$Gs = Ms/(Vs.Lw)$

Where Gs = Specific gravity of the soil sample.

Ms = mass of soil particles.

Vs = volume of soil particles.

Lw = density of water.

Oedometer Test: The test measures the magnitude and rate of one dimensional consolidation of a saturated soil in the form of a disc, confined laterally, subjected to vertical axial pressure and allowed to drain freely from top and bottom surfaces. The compression index was estimated from void-log pressure graph.

That is,

$$C_c = \frac{e_o - e}{\log_{10}(\sigma'/\sigma'_o)} = \Delta e/\ \Delta\log_{10}(\sigma'/\sigma'_o) \quad . \quad . \quad . \quad . \qquad (5)$$

where: C_c= compression index (slope of straight line portion of compression part of the graph)

e_o = initial void ratio

e = void ratio corresponding to increase in effective stress

σ' = effective stress due to consolidation (change in effective stress)

σ'_o = initial effective stress

IV. RESULTS AND DISCUSSION

Table 2 represents the geotechnical properties of the studied clay samples from parts of Anambra Basin, Southeastern Nigeria while table 2 represents the relationship between the plasticity index and the swelling potentials (Ola, 1981).

Table 2. Summary of the Geotechnical properties of the studied clay samples.

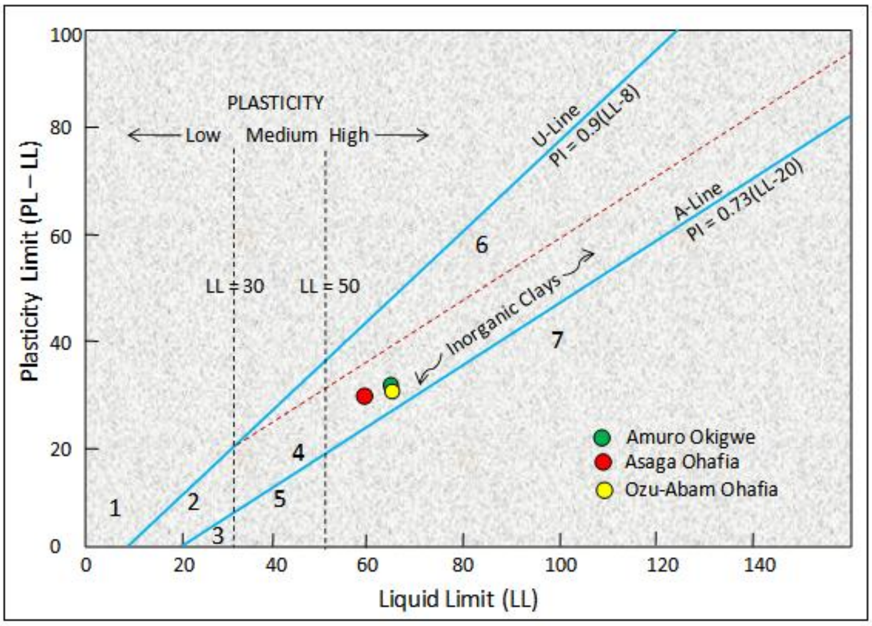
Location and Parameters	Amuro Okigwe (Imo Shale)	Asaga Ohafia (Mamu Formation)	Ozu-Abam Ohafia (Imo Shale)
Liquid Limit (%)	65	56	65
Plastic Limit (%)	35	29	34
Plasticity Index (%)	30	25	31

Moisture Content (%)	33	30	51
Bulk Density (Mg/m^3)	1.83	1.97	1.66
Specific Gravity	2.65	2.65	2.65
Dry Density (Mg/m^3)	1.37	1.58	1.11
Void Ratio	0.93	0.68	1.39
Compression Index	0.73	0.68	0.73
Swelling potential classification of the soils	High	Medium	High

Table 3. Relationship between plasticity and swelling potential (Ola, 1981)

Plasticity Index	Swelling Potential
0-15	Low
15-25	Medium
25-35	High
>35	Very high

The use of Atterberg limits as a tool for recognition of problem soils for construction purposes and estimating the swelling potential and shrinkage is now widely acknowledged. The studied clay samples from parts of Anambra Basin, Southeastern Nigeria shows that the moisture content ranges from 33-51% with an average value of 38% Table 2. These values are higher than the average range (5-15%) specified for engineering construction (Underwood, 1967). Natural moisture content also influences the shrink-swell potential of soils and also clay bulk density and consistency (Nelson and Miller, 1992). The moisture content indicates a high water adsorption capability of the clay material. It is used as an indicator for the shear strength of soils, as increase in the moisture content results in a decrease in the shear strength of the material. The difference in moisture content can be attributed to the seasonal changes, time of collection and their storage conditions. The liquid limit range from 33-65% with an average of 54.3%. The plasticity index range from 17-31% with an average of 26%. The plasticity index of 26% falls within the range of high swelling potential (Ola, 1981) Table 2.



Key:

1. and 2. Inorganic clays, low compressibility
3. and 5. Inorganic/organic silts, medium compressibility
4. Inorganic clays, medium compressibility
6. Inorganic clays, high compressibility
7. Organic clays, high compressibility

Fig 3. Casagrande Plasticity Chart of the studied clay.

The consistency limit properties of the evaluated clay samples show that the samples fall into inorganic clay of medium to high plasticity and compressibility in the Casagrande Plasticity Chart fig 3. All the sample cluster above the A-Line indicative of materials with similar clay mineralogy. The high plastic nature of samples from Amuro Okigwe and Ozu-Abam Ohafia 4agrees with the relationship established by Ola (1982) between plasticity index and swelling potential of clays as it is expected to exhibit very high swelling potential. The plasticity indexes of the samples from Amuro Okigwe and Ozu Abam Ohafia is higher than that of the Asaga ohafia, thus are expected to exhibit higher swelling potential because the more plastic the material the higher the swell potential and as they are likely to have higher percentage of expansive clays (Mitchell, 1993). FMWH (1997), specified that a good sub-base material must have liquid limit and plasticity index of <35 % and <16 % respectively.

Consolidation Characteristics

The consolidation characteristics of expansive soil from Amuro-Okigwe, Asaga-Ohafia and Ozu-Abam Anambra basin, Southeastern Nigeria are represented with plots of void ratio versus log-pressure. As shown in Fig 4, Fig 5 and Fig 6 respectively. For consolidation to take place, the soil should be subjected to a pressure greater than the swelling pressure (ASTM, 1996). The consolidation swell test on samples of expansive soil from parts of Southeastern Nigeria has shown that the e-logP curve for pressure greater than the swelling pressure is a steeper e-logP plot (Fig 4, Fig 5, & Fig 6).

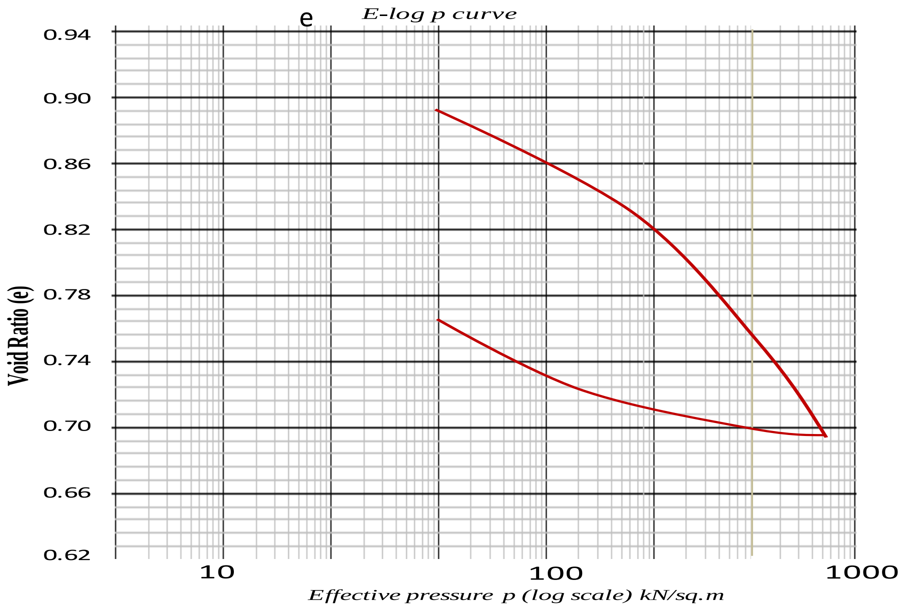


Fig 4. Plot of Void ratio versus log Pressure of sample of expansive soil from Amauro Okigwe.

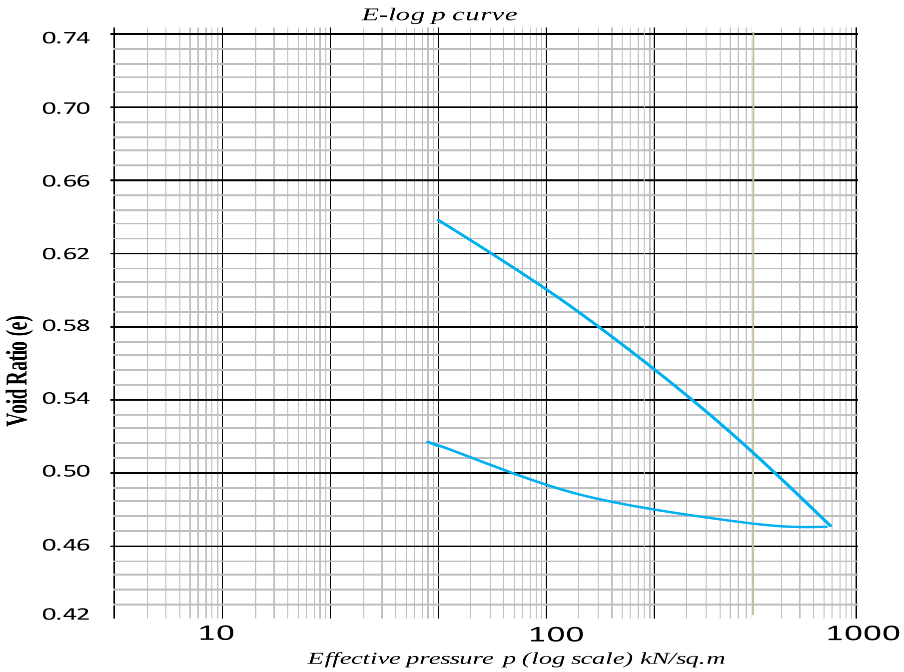


Fig 5. Plot of Void ratio versus log Pressure of sample of expansive soil from Asaga

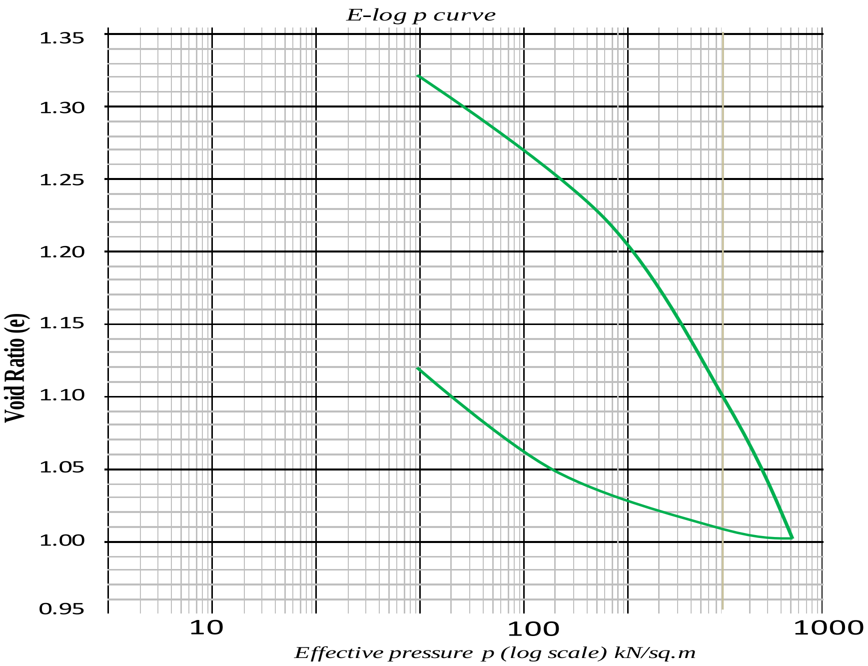


Fig 6. Plot of Void ratio versus log Pressure of sample of expansive soil from Ozu-Abam

In expansive soils, larger moisture change implies higher degree of disturbance in the soil structure. The laboratory result of the samples showed that samples with higher swelling potential has higher compression index (Table 2). Consolidation-swell test on samples of expansive soil with different initial moisture content and dry density has shown different consolidation characteristics, i.e. different compression index (Table 2, Fig 4, Fig 5, & Fig 6).

For instance samples from Amuro-Okigwe and Asaga have dry density of $1.58Mg/m^3$ and $1.37Mg/m^3$ respectively with corresponding compression index of 0.73 and 0.68, respectively. All the expansive soils used in the study (derived from Imo Shale and Mamu Formation) plot above A –Line in the Casagrande Plasticity Chart with high compressibility (Fig. 3). Soils the derived from Imo Shale have higher liquid limit and plasticity values compared with soils derived from Mamu Formation (Table 2). They also have higher compression index compared with soils derived from Mamu Formation. It was also observed that liquid limit of the soils influence the values of the compression index. The higher the Compression index, the higher the compressibility of the soil.

Skempton (1953) gave the following relationship:

For remoulded clay: $C_c = 0.007 (w_L-10)$. . . . . . . (6)

For undisturbed clay: $C_c = 0.009 (w_L-10)$. . . . . . . (7)

Where w_L = liquid limit of soil

The settlement of a compressible clayey soil due to consolidation whose compression index is low can therefore be computed with the equation (Craig, 1987):

$$S = \frac{C_c}{1+e} H_o \log \frac{e_o + \Delta e}{\acute{\alpha}_o} \quad (8)$$

$$= \frac{C_c}{1+e} H_o \log \frac{\acute{\alpha}}{\acute{\alpha}_o} \quad (9)$$

Where:

S = Settlement

Cc = Compression Index

H_o = Original thickness of compressible layer

ά = Change in effective stress due to consolidation

$\acute{\alpha}_o$ = Initial effective stress

Equation (8) and (9) apply to both normally consolidated and over-consolidated soils.

V. CONCLUSION

The aim of this work was to determine the compression index as a parameter for consolidation characteristics of expansive soil from parts of Anambra Basin, Southeastern Nigeria and compare there values with atterberg limit values. Results from the study indicate that the samples fall within inorganic clay of medium to high plasticity and compressibility based on their plots in the casagrande plasticity chart and that the consolidation characteristics of expansive soils are influenced by swelling potential of the soils. However, the study has also shown that the compression index of expansive soil from parts of Anambra Basin as determined from the consolidation-swell test ranges from 0.73 -0.68 which is related to the parent rock from which the soils where derived. For example, soils from Amuro-Okigwe and Ozu-Abam where derived from Imo Shale and they have high swelling potential, while soils from Asaga were derived from Mamu Formation and they have medium swelling potential. Liquid limit of the expansive soils may therefore be used to estimate compression index of the soils.

ACKNOWLEDGMENTS

The authors hereby acknowledge the assistance of laboratory staff of Institute of Erosion Studies, Federal University of Technology Owerri, in the performance and interpretation of consolidation/oedometer tests on clay samples.

REFERENCES

[1]. Arora, K.R. 2004. ‘Soil mechanics and foundation engineering’, Standard Publishers Distributors, New Delhi.
[2]. ASTM, 1996, ‘Special procedure for testing soil and rock for engineering purpose’. ASTM International, Washington DC, USA
[3]. Burke, K., 1972. Longshore Drift, Submarine Canyons and Submarine Fans in the Development of NigerDelta: American Assoc. Petrol. Geologists, 56: 1975-1983.
[4]. British Standard Institute, 1981. British standard code of practice for site investigation; BS 5930-1981
[5]. Chen, F.H, 1988, ‘Foundation on expansive soils’, Elsevier, Amsterdam.
[6]. Craig, R. F. 1987, Soil mechanics. Fourth Edition, Van Nostrand U.K. Limited, London.
[7]. Emery, K., O.E. Uchupi, J. Philips, C. Brown and J. Masle, 1975. Continental Margin off West Africa, Angola to Sierra Leone, *AAPG Bull*., 59: 2209-2265.
[8]. Federal Ministry of Works and Housing, 1997. Nigerian General Specification for Roads and Bridges (Revised Edition), 137-275.
[9]. Genik, G.J., 1993. Petroleum Geology of Cretaceous–Tertiary Basins in Niger, Chad and Central African Republic. *AAPG Bull*., 77: 1405-1434.
[10]. Jones H. A. and Hockey R.D 1964. The geology of parts of Southwestern Nigeria. Geological Surv. Niger. Bull., 31: 22-24.
[11]. Kartikey T, Sahil K. and Aman J, 2012. Performance, Problems and Remedial Measures for the Structures Constructed on Expansive Soil in Malwa Region, India, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 12, December 2012.
[12]. Kogbe, C. A. 1985. Paleogeographic history of Nigeria from Albiam time. In Geology of Nigeri (ed C.A Kogbe), P. 237. Lagos (Nigeria): Elizabethan Pub. Co.
[13]. Madurwar, K. V. Dahale P.P. and Burile A.N. 2013,‘ Comparative Study of Black Cotton Soil Stabilization with RBI Grade 81 and Sodium Silicate‘, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 2, February 2013.
[14]. Mode, A.W. (2004). Shallow marine transgressive sedimentation in the Nsukka Formation,Southeastern Anambra Basin, Nigeria. NAPE Bull., 17(1), 28-41.paleogeography of West Africa. J. Geol., 8, 311-322
[15]. Murat, R.C., 1972. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Dessauvagie, T.T.J., and white man, A.J. (Eds), African Geology, University of Ibadan Press, Nigeria, pp: 251-266.
[16]. Mitchell J.K 1993, Fundamental Soil Behavior, Wiley, New York.
[17]. Nelson, D., and Miller, D. J. 1992. Expansive Soils: Problems and Practices in Foundation and Pavement Engineering. New York: John Wiley, 259.
[18]. Nwajide, C.S. and T.J.A. Reijers, 1997. Sequence Architecture of the Campanian Nkporo and the Eocene Nanka Formations of the Anambra Basin, Nigeria. NAPE Bull., 12(01): 75-87.
[19]. Offodile, M.E. 1975. A review of the Cretaceous of the Benue valley. In: Geology of Nigeria (C.A. Kogbe, ed.). Elizabethau Publishing Company, Nigeria, 319 – 330.
[20]. Ojoh, K.A., 1990. Cretaceous Geodynamic Evolution of the southern part of the Benue Trough (Nigeria) in the equatorial Domain of the south Atlantic Stratigraphy Basin Analysis and Paleogeography. Bull. Centres Rech. Explor-Prod, Elf-Aquaintine, 14: 419-442.
[21]. Ola, S.A. 1981. Mineralogical properties of some Nigerian residual soils in relation with building problems. Engineering Geology, 15: 1-13
[22]. Olade, M.A., 1975. Evolution of the Nigerian Benue Trough (Aulocogen): A Tectonic Model. *Geol. Mag*., 12: 575-583.
[23]. Peters, S.W. (1978). Stratigraphic evolution of the Benue Trough and its implications for the Upper Cretaceous paleogeography of West Africa. J. Geol., 8, 311-322.
[24]. Peters, S. W. and Ekweozor, C. M. 1981. Origin of Cretaceous black shales in the Benue trough, Nigeria. Palaeogeography Palaeoclimatology Palaeoecology, 40, pp. 311-319
[25]. Prasad, D, Prasada, G, and Ramana, M. V. 2008. Use of Waste Plastic and Tyre in Pavement System, The Institution of Engineers India Journal, Vol 89, 2008, 31-34.
[26]. Radhey, S. S, 1998, Mechanical Bahaviour of Unsaturated Highly Expansive Clays, Ph. D.Thesis.
[27]. Reyment, R.A, 1965. Aspects of the Geology of Nigeria. Ibadan Univ. Press. 133p, 19pl.
[28]. Skempton, A.W. 1953: Soil mechanics in relation to geology. Proc. Yorksshire Geol. Soc., 29, Part 1(3), 33-62.
[29]. Underwood, L. B. 1967. “Classification and Identification of Shales.” *J. Soil Mech. Found.Div., ASCE*, 93 (11): 97-116.
[30]. Whiteman, A.J., 1982. Nigeria. Its Petroleum Geology, Resources and Potentil. Graham and Trotman, London, 39p.

OKEKE O.C,etal. "Consolidation Characteristics of Expansive Soils from Parts of Anambra Basin, Southeastern Nigeria." *The International Journal of Engineering and Science (IJES)*, 9(4) (2020): 50-57.