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A geotechnical investigation on the structural failures of building projects in parts of Awka, southeastern Nigeria

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Abstract

Twelve samples of shale from different locations within the Imo Shale Formation in the Awka area (southeastern Nigeria) have been assessed to evaluate the impact of the shale formation on some geotechnical problems experienced by constructed projects in the area. Results indicate that shale samples from the formation have Atterberg limits that might be considered moderate to high; while liquid limit (LL) ranged from 32 - 78, the plasticity index (PI) ranged from 11 - 32. These relatively high LL and PI suggest presence of expansive clays, some swelling of the shale on moisture influx and high compressibility. Natural moisture content (with mean value of 17%) was also significantly high. Despite indicating fair stability as fills (Maximum dry density and soaked California bearing ratio have mean values of 1.85 mg/m^3 and 42%, respectively), the formation is likely to have low shear strength, as suggested by its low values of strength parameters (mean value of angle of internal friction is 22°, while mean cohesion is 21 kN/m^3). Geotechnical behaviours of the Imo Shale also give indications that the shale failed some relevant material specifications for general engineering purposes and, thus, was significantly responsible for structural failures and foundation problems of buildings that are prevalent in some parts of Awka area.

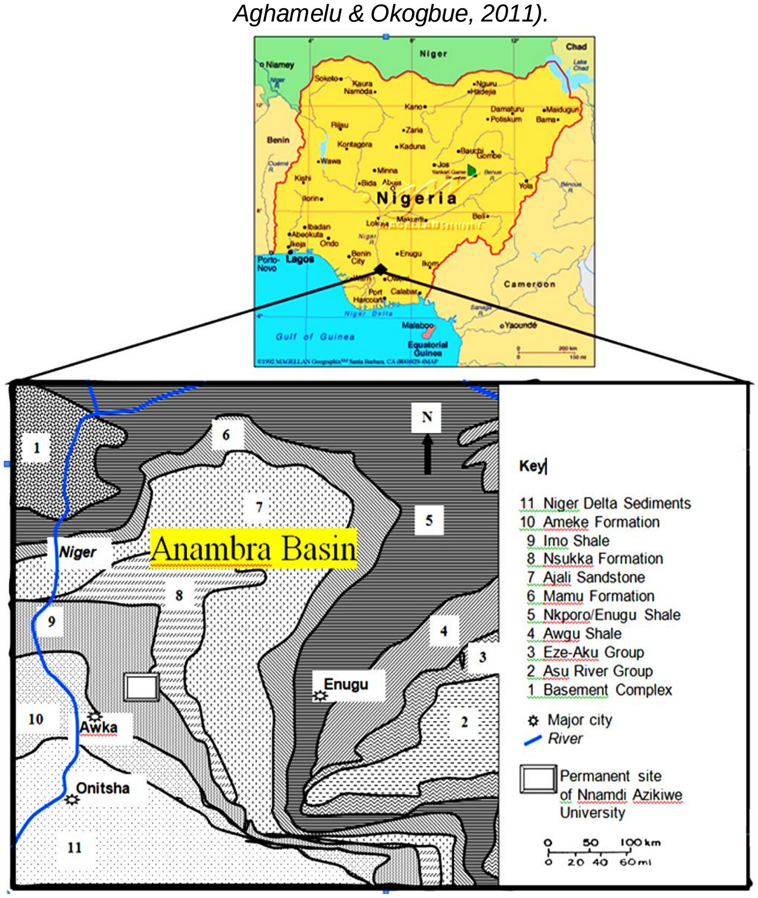
Keywords:Imo Shale; Nigeria; Building projects; Geotechnical analysis; Structural failures; Soil.

Introduction

Shale is most often regarded as problem materials in construction. These problems possessed by shales in shaley terrains of the world are, in most cases, being influenced by mineralogy, especially the sedimentary attributes, predominant clay mineral type (Sowers & Sowers 1970; Okagbue, 1989; Coduto, 1990) as well as the climate and physiography of the area under consideration (Ezeribe, 1994). An example of a shaley terrain in Southeastern Nigeria (Fig.1) is the Awka Metropolis where a shale formation widely referred to as 'the Imo Shale' underlies the major portion of the area. The Imo Shale is predominantly shales but has localized occurrences of sandstone and siltstone.

Owing to the abundance of the shale in that area, it serves both as subgrade (i.e., *in-situ*) in roads and as foundation material in most building construction projects, especially in the eastern part of Awka. A survey of roads in some parts of southeastern Nigeria (Aghamelu & Okogbue, 2011) has however revealed that these projects suffer incessant failures, soon or months after construction. Previous studies (Underwood, 1967; Sowers & Sowers, 1970) attribute high expansivity and compressibility, as well as low strength and bearing capacity to shales in general. These attributes have also been identified in some shales of southeastern Nigeria (Okogbue & Aghamelu, 2010; Aghamelu *et al.,* 2011).

Fig. 1.Generalized Geological map of southeastern showing the distribution of the Imo Shale and other lithologic units (Modified after Aghamelu & Okogbue, 2011).



In this work, an attempt has been made to

Table 1. Sedimentary succession of the Anambra Basin

Age*		Geological Unit
54	Eocene	Ameki/Nanka Formations
63	Paleocene	Imo Formation
	Danian	Nsukka Formation
	Maastrichtian	Ajali Formation
75		Mamu Formation
82	Campanian	Nkporo Shale/Enugu Shale

**in million years ago.*

employ relevant laboratory tests to assess some of the geotechnical problems associated with inappropriateness of Imo Shale in construction projects. The assessment mainly intends to highlight whether the shale formation (both as foundation material, subgrade and aggregate) contributes to the incessant structural failures of some engineering projects, especially buildings, that traverse some parts of Awka area, southeastern Nigeria.

Geology

Awka, the capital city of the present day Anambra State Nigeria, is underlain, especially in the eastern part, by the Imo Shale. The Paleocene Imo Shale forms part of the sediments of the Cretaceous to Recent Anambra Basin (Reyment, 1965). The formation consists of thick clayey shale, fine textured, dark grey to bluish grey with occasional admixture of clay ironstone and thick sandstone beds (Kogbe, 1989). Wilson (1925) observes that carbonized plants remains may be locally common and the formation becomes sandier towards the top, where it may consist of an alternation of bands of sandstone and shale.

The type locality is along the Imo River between and Okigwe in southeastern Nigeria, where it attains a thickness of about 500 m (Simpson, 1955; Wilson & Bain, 1928). The formation rest conformably on the Nsukka Formation (Fig.1), and continues laterally into western Nigeria and Dahomey Basin. It shows lateral variations into Akata Formation (Short & Stauble, 1967) and sandstones (the Igbabu Sandstone, Ebenebe Sandstone and Umuna Sandstone), in places (Reyment, 1965). Table 1 gives the sedimentary succession of Anambra Basin. Detailed discussions on the origin and geology of the Anambra Basin are presented by earlier workers (Reyment, 1965; Murat, 1972; Nwachukwu, 1972).

Physiography and climate

Anambra State falls into two main landform regions: a highland region of moderate elevation that covers much of the state south of the Anambra River, and low plains to the west, north, and east of the highlands. The highland region is a low asymmetrical ridge or cuesta in the northern portion of the Awka-Orlu Uplands, which trend roughly southeast to northwest, in line with the geological formations that underlie it. It is highest in the southeast, about 410 m above mean sea level, and gradually decreases in height to only 33 m in the northwest on the banks of the *Anambra River* and the *Niger River*.

The major river that drains the area is the *Anambra River* and its tributaries which are perennial and usually overflow their banks at the peak of the rains. Stunted trees and pockets of derelict wood land exist where the lithology has undergone high degree of laterization. Elsewhere, typical characteristics of the tropical rain forest are displayed; multitude of evergreen trees, climbing plants, parasitic plants that live on the other plants, and creepers.

Two main seasons exist in the Awka area, the dry season which lasts from November to March and the rainy season which begins in April and ends in October with a short period of reduced rains in August commonly referred to as “August break”. Temperature in the dry season ranges from 20°C to 38°C, and results in high evapotranspiration, while during the rainy season temperature ranges from 16°C to 28°C, with generally lower evapotranspiration. The average monthly rainfall ranges from 31mm in January to 270 mm in July, with the dry season experiences much reduced rainfall. Average annual rainfall varies from 1,500 mm to 1,650 mm. These climatic conditions might be responsible for the development of lateritic covers in some parts of the area.

Materials and methods

Sampling

A total of twelve shale samples were taken from Imo Shale Formation within the Awka area; all were from the permanent site of the Nnamdi Azikiwe University (NAU), Awka. Fig.1 shows the location of the permanent site of NAU. For all the shale samples, collected with the aid of 6 inches hand auger, sampling depths ranged from 0.5 m to 2.0 m. The shale sampling strictly followed standard procedure for soil sampling specified in British Standard Institution (BSI) 1377 (1990). All sampling was done in the dry season, between January and March, 2010.

Laboratory analyses

Geotechnical: The tests carried out on the shale samples included Atterberg limits (liquid and plastic limits), specific gravity, natural moisture content, compaction, California Bearing Ratio (CBR) and shear strength. The sample preparations and laboratory testing for these geotechnical parameters followed standard methods of testing soil for civil engineering purposes and were all carried out at the Soil and Material Laboratory of Marlun Construction Company, Enugu, Nigeria. The liquid limit and plastic limit tests were carried out on air-dried samples that passed 0.425 mm (BSI No. 36) sieve; both tests then followed standard procedures specified by BSI 1377 (1990).

Crushed shale samples that passed through 0.076 mm (BSI No. 200) sieve and oven-dried at 105°C for 24 hours were utilized for the specific gravity tests. The tests were also carried out with the aid of a 100.15 ml pycnometer bottle and distilled water with specific gravity of 0.99654 (distilled water temperature was 27°C), in accordance with testing method described by Lambe (1951). Laboratory procedure of this test attempted determination of the specific gravity of the shale excluding air and water contents.

Natural moisture contents determination following simple method outlined by Akroyd (1957). The laboratory compaction tests were limited to particles of shale that passed through 19.05 mm BSI sieve and followed procedure specified by BSI 1377 (1990). CBR tests were performed on compacted samples in both unsoaked and soaked conditions, following the procedure of Bailey (1976). However, soaking was done overnight (24 hours) in a water-filled bathtub. Samples for the shear strength tests were prepared and tested following the BSI 1377 (1990) standard. The test type was the triaxial compression strength test (consolidated undrained). However, the triaxial cell for the tests was the 76 mm diameter type, hence, the tested samples were proportionately scaled down to 152 mm by 76 mm, height by diameter, respectively. Pressured water was also used for confining the samples inside the cell.

Statistics: For both the geotechnical analyses, values of each of the parameters recorded were obtained after repeated tests on portions of the same sample for at least thrice. In other words, test for each parameter was repeated at least thrice and the average value of at least two consistent results then recorded as the value for the parameter. Statistical range, average value and standard deviation of data were carried out. Correlation analysis was also employed to establish relationships between geotechnical parameters tested.

Results and discussion

Geotechnical Properties

Atterberg limits, natural moisture content and specific gravity: The summary of the geotechnical properties of the Imo Shale is presented in Table 2. The Imo Shale recorded values of liquid limit (LL) ranged from 32 to 78, plastic limit (PL) 18 to 49. The difference between LL and PL, termed the plasticity index (PI), represents the range in the water contents through which the soil is in the plastic state (Seed & Woodward, 1964). The PI of samples from two spots was considerably high (greater than 31), while the rest were low (lower than 30). Sowers and Sowers (1970) note that PI>31 should be considered high and indicates high content of expansive clays, most probably montorillonite and/or illite.

Natural moisture content (W_n) of a material is a measure of the water-holding ability of the material, usually reflecting clay content and type of the material (Sowers & Sowers, 1970). W_n of the shale samples ranged from 14 to 19 %.

On the basis of LL and PI values, some crushed shale samples from the Imo Shale could be classified as high plasticity soil; a soil with PI >31 is described as highly plastic (Sowers &Sowers, 1970). Those samples with low PI might have had their expansive clays converted to less expansive types (Okeke, 2005). A highly plastic soil usually has the ability to retain appreciable amount of total moisture in the diffuse double layer, especially by means of absorption. This fact was buttressed by a significant mean value (17%) of natural moisture content recorded by the shale samples (Table 2). High plasticity materials are usually susceptible to high compressibility (Seed & Woodward, 1964; Sowers & Sowers, 1970; Coduto, 1999). An increase in plasticity of material also decreases its permeability and hydraulic conductivity (Sowers & Sowers, 1970).

In this study the specific gravity (G_s) of shale, a dimensionless parameter, is the weighted average of the soil minerals (excluding air and water). Results indicated that the Imo Shale has mean G_s value of 1.95 (Table 2); a value less than that of a potentially durable construction aggregate, which should have G_s value of 2.625 or above, according to Reidenouer (1970). A comparison of

Table 2. Summary of the geotechnical properties of the Imo Shale.

Sam. no.	Parameter									
	LL	PL	PI	G_s	W_n (%)	MDD mg/m^3)	OMC (%)	CBR*(%)	ø (°)	c (kN/m^2)
IMS1	75	48	27	2.05	18	1.86	14.2	35	15	19
IMS2	67	35	32	1.96	19	1.89	6.8	39	5	28
IMS3	78	49	29	1.95	18	1.89	6.8	40	15	27
IMS4	37	23	14	1.96	15	1.80	14.2	59	46	21
IMS5	57	28	29	2.15	16	1.66	12.6	31	35	21
IMS6	32	21	11	1.79	15	1.90	12.0	34	32	15
IMS7	36	23	13	1.90	14	1.94	13.6	51	10	18
IMS8	34	21	13	1.90	16	1.85	8.6	41	18	17
IMS9	71	40	31	1.92	18	1.91	7.6	44	18	23
IMS10	56	29	27	2.14	19	1.84	8.9	46	18	23
IMS11	37	18	19	1.73	16	1.86	11.8	36	36	18
IMS12	51	29	22	1.90	16	1.84	13.4	48	19	18
Range	32 - 78	18 - 49	11 - 32	1.73- 2.15	14 - 19	1.66- 1.94	6.8 - 14.2	31 - 59	5 - 46	15 - 28
Mean	53	30	22	1.95	17	1.85	10.9	42	22	21
*St.D**	19.41	10.52	7.89	0.12	1.67	0.07	2.92	8.03	12.17	3.98

**Tests performed on soaked samples, **Standard deviation*

Table 3. Average specific gravity of various rock types.

Rock type	SG[a]
Igneous Andesite	2.22
Basalt	2.77
Gabbro	3.0
Granite	2.67
Rhyolite	2.4
Sedimentary	
Limestone	2.69
Sandstone	2.58
Shale[b]	1.73 - 2.15
Metamorphic	
Gneiss	3.12
Marble	2.73
Slate	2.77

[a]apparent specific gravity data adapted from Krynine & Judd (1957). [b]bulk specific gravity data from this study

Compaction and California Bearing Ratio (CBR)

Compaction test seeks to simulate the right combination of moisture (optimum moisture content) and load (compactive effort) on a soil that would result in increased density (maximum dry density) of such soil; thus improving its appropriateness in construction projects. Results indicated that the compacted Imo Shale achieved mean maximum dry density (MDD) value of 1.85 Mg/m^3 at mean optimum moisture content (OMC) of 10.9 (Table 2). The MDD was considerably high; MDD of other shales from southeastern Nigeria ranges from 1.50 to 1.68 Mg/m^3 (Okogbue & Aghamelu, 2010). In addition to compactive effort, Okogbue and Aghamelu (2010) point out that cementation, nature of the compacted sample and moisture condition of the sample may have also contributed to the relatively high MDD recorded by some shale formations of southeastern Nigeria.

CBR is the ratio (expressed as percentage) of the actual load required to produced a 2.5 mm deflection to that required to produce the same deflection in a certain standard crushed stone (Yoder, 1959; Sowers & Sowers, 1970; Mannering & Kilareski, 1998; Wignall *et al.,* 1999). Results of the laboratory CBR (soaked condition) tests showed that the mean value for the tested samples is 42%. Aghamelu *et al*. (2011) observe that reduction in CBR of shale samples is continuous as long as there is moisture influx. Therefore, moisture influx would be detrimental to subgrades of pavements and foundations of other engineering structures constructed on the Imo Shale.

*Table 4. Correlation of the various properties**

	LL	*PL*	*PI*	*Gs*	*Wn %)*	*MDD* (mg/m^3)	*OMC (%)*	*CBR (%)*	*ø (°)*	*c* (kN/m^2)
LL	1.000									
PL	0.952	1.000								
PI	0.912	0.742	1.000							
Gs	0.502	0.407	0.553	1.000						
Wn (%)	0.808	0.690	0.842	0.450	1.000					
MDD mg/m^3)	0.012	0.154	-0.179	-0.563	0.079	1.000				
OMC (%)	-0.440	-0.348	-0.496	-0.035	-0.672	-0.295	1.000			
CBR (%)	-0.260	-0.189	-0.316	-0.015	-0.258	0.212	0.184	1.000		
ø (°)	-0.490	-0.504	-0.398	-0.144	-0.497	-0.556	0.488	0.064	1.000	
c (kN/m^2)	0.731	0.612	0.778	0.423	0.733	0.014	-0.673	0.051	-0.381	1.000

**Statistical Note: Correlation Rating: > 0.91 = very Strong; 0.90 - 0.81 = Strong; 0.80 - 0.31 = moderate; < 0.30 = weak.*

specific gravity values of rock aggregates that serve well in construction project with the Imo Shale (Table 3) points out the fact that the shale is unlikely to be durable in most construction projects.

Table 5. An engineering evaluation of some physical properties of the Imo Shale.

Physical properties			Imo Shale	*Remarks*
Laboratory test and *in-situ observations*	Average range of values (Underwood, 1967)			
	Unfavourable	*favourable*		
Cohesive strength (kN/m^2)	35 - 700	700 - 10,500	15 - 28	Unfavourable*
Angle of internal friction (°)	10 - 20	20 - 65	5 - 46	Favourable**
Dry density (Mg/m^3)	1.13 - 1.76	1.76 - 2.56	1.66 - 1.94	Favourable**
Natural Moisture content (%)	20 - 35	5 - 15	14 - 19	Unfavourable
Predominant clay minerals	Montmorillonite, illite	Kaolinite, hlorite	-	Unfavourable

**significantly below unfavourable limits. **marginally favourable, although the lower range is within the unfavourable limits.- not available.*

Triaxial shear strength

Shear strength of a material denotes the ability of such material to resist shearing deformational stresses (Sowers, 1963). It is expressed in terms of two parameters, angle of shearing resistance (ϕ) and cohesion (c). Laboratory analysis showed that ϕ for Imo Shale ranged from 5° to 46°, while c ranged from 15 kN/m^2 to 28 kN/m^2. Coduto (1999) and Punmia *et al.* (2005) remark that shales that are predominated only by clays and are as well non-cemented, most often, record very low values of ϕ (close to 10°). Reasonable values of c recorded denoted a cohesive material, similar to consolidated clay and other materials with high clay content.

The fact that values of c were significantly greater than 10° and c reasonably high would suggest that the Imo Shale as subgrade and construction material would have considerable strength, and is likely to withstand shear stresses. Moisture influx, however, would deteriorate its constituent minerals, especial clays, resulting in strength reduction and perhaps, bearing capacity loss, during the engineering life of such project. Low G_s has already clued-up such suspicion.

Correlation analysis

From the correlation table (Table 4), it can be seen that there is a strong positive correlation between Wn and LL (0.808), while G_s shows a moderate positive correlation with LL (0.502). There is a weak correlation between MDD and LL (0.012). Plots of MDD against PI (Fig.2) gave weak correlation coefficient (*r*) (-0.189), suggesting that the plasticity of the sample have but less effect on their dry densities. Also plots of c against G_s gave moderate *r* (0.423), indicating predominance of probably lightweight minerals with weak cohesion (Fig.3), while low *r* of CBR versus Wn (-0.258) implies that moisture, although weakly, influenced the CBR results of the samples (Fig.4).

Conclusions

This work has provided insights into the probable causes of widespread and persistent occurrence of foundation and structural failures, as experienced in some part of Awka metropolis (especially projects within the permanent site of the Nnamdi Azikiwe University), situated partly on top of Imo Shale.

Geotechnical assessment showed that the Imo Shale is of moderate to high plasticity (although altered samples have PI<31), most probably due to its content of expansive clay minerals. Attributes of material with high plasticity, like the Imo Shale, include swelling on moisture influx, high compressibility, low bearing capacity and low permeability (i.e., low drainage). These properties, most probably, would negate few favourable properties, like high MDD and relatively high shear strength parameters (Table 5), recorded by the shale and ultimately render it unsuitable for use for most construction purposes, especial where moisture influx cannot be effectively controlled.

Affinity of the Imo Shale for water, its low permeability, topography of the area and high volume of rainwater and runoffs, result to waterlogging and flooding in the middle of the rainy season in the study area. This accumulated water, thus, alters the volume of the subgrade and foundation material, resulting in differential settlement and structural damages of engineering projects founded within the shale formation.

Fig.2. Plot of Maximum dry density (MDD) versus plasticity index (PI).

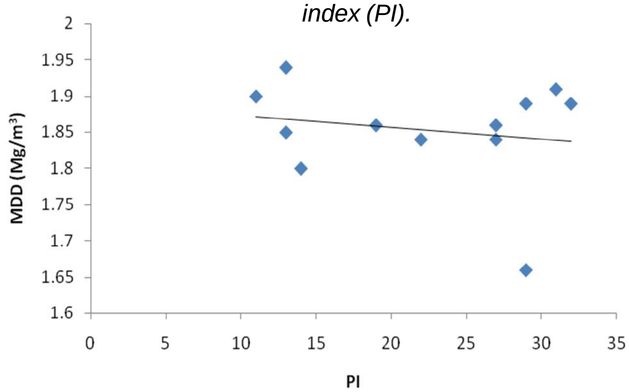


Fig. 3. Plot of cohesion (c) versus specific gravity (Gs).

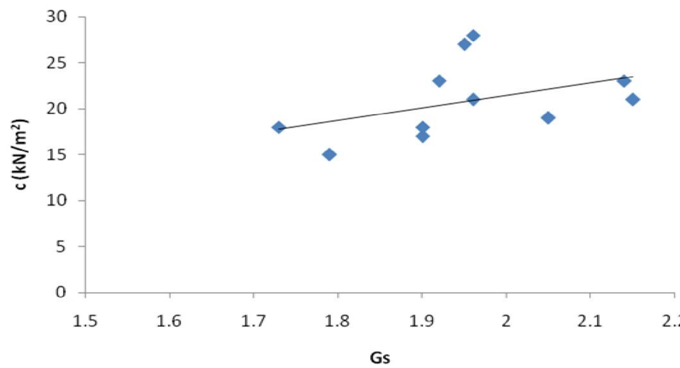
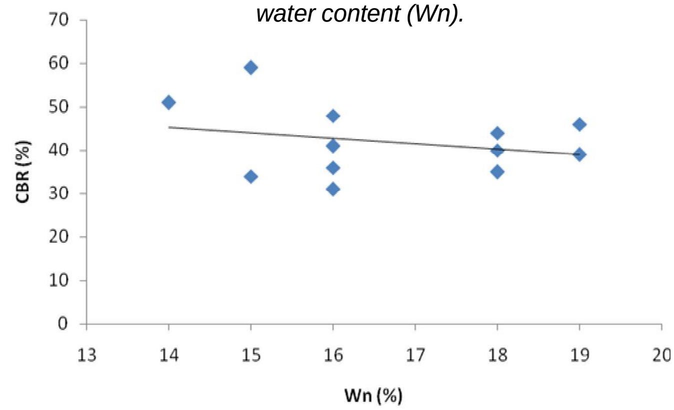


Fig.4. Plot of California bearing ratio (CBR) versus natural water content (Wn).



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