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Engineering Properties of Awgu Shale in Enugu State, Nigeria

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The samples of Awgu shale collected from Nnewi and Mgbowo in Awgu Local Government Area of Enugu state were analysed in the laboratory for such properties as linear shrinkage, moisture content and atterberg limits (plastic limit and liquid limit). The samples recorded moisture content ranging from 7.96%-54.16%, linear shrinkage ranging from 8.57-11.4%, plastic limit ranging from 26%-46%, liquid limit from 48%-88% and plasticity index ranging from 21%-54%. The results of the analysis showed that the samples had high moisture content (except for borehole 4 and 5 that showed low moisture content), moderate to high linear shrinkage and moderate to high plasticity. On the basis of the above results, it is inferred that Awgu shale cannot be used as engineering materials either for foundation support or road construction without reasonable reinforcement.

Keywords: Engineering properties; soil; shale; shear strength; plasticity.

1. INTRODUCTION

Shale is a sedimentary rock that is fined grained and it can spitted into different sheets (usually called fissility) along the surfaces of the thin layers (a process referred to as laminations) within the shale [1]. Plumer et al. [1], described shales as containing "both silt and clay averaging 2/3 clay-sized minerals, 1/3 silt-sized quartz which is so fine-grained, that the surface of the rock feels very smooth.

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Most times when you see a big opening on the road, shale visibility from the road cut is common [2,3]. Shale is commonly used in the construction of embankments, despite the number of failures that have been reported involving settlements and shear failure of compacted shale embankments [2,3]. Thus, shale has become a problem soil, because it is difficult to manage in construction [2,4].

In a study carried out on the Tertiary Shales in the Lower Benue Trough (which constitute Awgu Shale), the XRD results show the presence of clay and non clay materials and exhibited different weathering degrees ranging from moderately weathered to highly weathered [5].

This study aims to examine the engineering properties of Awgu Shale that could influence its geotechnical properties.

2. GEOLOGY OF THE STUDY AREA

The study areas are Mgbowo and Nenwe in Awgu Local Government Areas of Enugu State. They lie between latitude $7° 15^1$ and $7°45^1$ north of the equator and longitude $6° 0^1$ and $6° 14^1$ of the Greenwich meridian. Areas linked by roads and footpaths were accessible while areas covered by thick vegetation were inaccessible.

Awgu shale is one of the pre-santonia formations that occupy a narrow strip between the eastern flank of the cuesta between Enugu and Awgu[3] and gradually heading toward the surface area of Ndeaboth in the North [6,7]. Though, this could be higher or lower than it is recorded as some have reported that the oil well data revealed a thickness of between 600m and 750m[6]. This uncertainty of the actual thickness could be due to several sequences of erosions, following the late Satonian deformation and series of uplifts of the Benue depression [8,9,10-12].

Awgu is a subset of the Anambra Basin corresponding to the western syncline to the emergent Abakaliki anticlinoria in the lower Benue Trough of the south-eastern Nigeria [6,13,11,12].

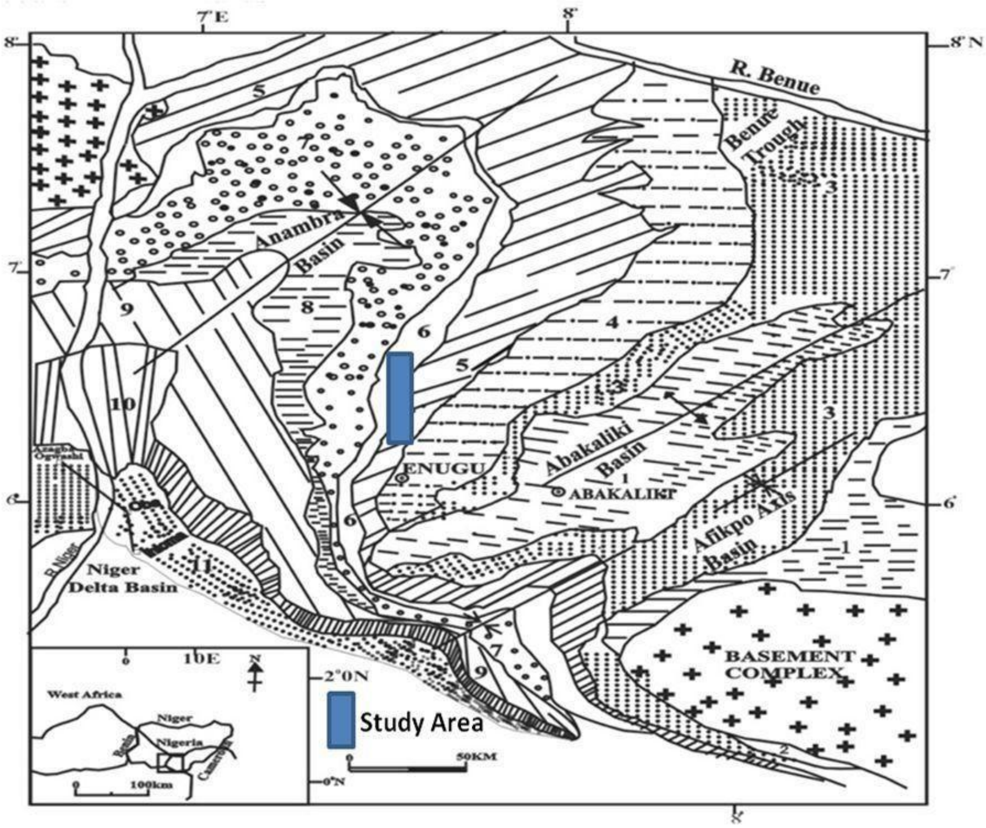

Fig. 1. Geologic Map of Anambra Basin and Afikpo Basin South-Eastern Nigeria showing the study area

1. Asu River Group; 2. Odukpani Formation; 3. Ezeaku Shale; 4. Awgu Shale; 5. Enugu/Nkporo Shale; 6. Mamu Formation; 7. Ajali Sandstone; 8. Nsukka Formation; 9. Imo Shale; 10. Ameki Formation; 11. Ogwashi Asaba Formation. Source: Chiagbanam et al [14].

3. METHODS AND MATERIALS

The method of study includes field and laboratory analysis.

3.1 Field Analysis

Samples were collected from the field using Auger boring.

3.2 Laboratory Analysis

Disturbed samples were analyzed in the laboratory for parameters such as Natural moisture content, Atterberg Limits (Liquid limit and Plastic limit) and Linear Shrinkage. These laboratory tests were carried out as stipulated by British standards BS 1377 [15] and American society for Testing and materials, (ASTM) standard [16].

3.2.1 Natural moisture content

The moisture content, *w*, is defined as the ratio of the weight of water to the weight of dry grains in a soil mass and is usually expressed as percentage [17].

It is mathematically expressed as follows:

$$M = \frac{\text{mass of water}}{\text{Mass of solid soil}} \times 100$$

$$= \frac{Mw}{Ms} \times 100\%$$

Or

$$\frac{m_2 - m_3}{m_3 - m_1} \times 100\%$$

Where,

M_1 = mass of cup
M_2 = mass of cup and wet soil
M_3 = mass of cup and dry soil

3.2.2 Atterberg or consistency limits

The moisture contents of a soil at the points where it passes from one stage to the next known as consistency limits. The limits are based on the concept that a fine grained soil can exist in any of four states depending on its water content. The two most important are [17]:

a. **Plastic Limit (*WP*):-** This is obtained by determining three moisture contents of portions of the soil and averages the values of the moisture contents, which is the plastic limit of the soil.

b. **Liquid Limit (*WL*):-** This is obtained by making a plot of water content, w% against the no. of blows. Such a plot is known as a flow curve, which is usually approximated linear through the points that give a straight line of best fit. Thus liquid limit (*LL*) = the water content which corresponds to 25 blows on the flow curve is the liquid limit of the given soil.

The following may be obtained from the Atterberg limit test:-

a. Plasticity Index *Ip* =Liquid limit – Plastic limit
It indicates the range of moisture content over which soil remain plastic.

b. Liquidity Index *IL*

$$IL = \frac{W_N - W_P}{IP}$$

It indicates the nearness of a natural soil to the liquid limit. If the liquidity index is > 0 but < 1, soil is in plastic range soils but if >1, it is a liquid state or potential liquid. Soft soils have values approaching 100% but stiff soils have value approaching zero even negative[4].

c. Flow index, I_f

$$I_f = \text{Slope of flow curve} = \frac{Aw}{\text{Log } N_2/N_1}$$

Flow index is negative, since the log *N* Vs *M* line slopes down from left to right.

3.2.3 Linear shrinkage

Linear shrinkage is the point at which the length of the soil remained constant even with prolonged drying. If the drying process continues after the plastic limit has been reached the soil will continue to decrease in length until a certain value of moisture content is reached were the volume remain constant. The soil was thoroughly mixed to a paste and filled into the shrinkage apparatus, then measurement of the length of the soil sample was taken with a measuring meter. The measured sample was oven-dried until no further decrease in length of the sample. The length was then measured. This process was taken for all the samples and the shrinkage calculated using this formula[4].

$$Shrinkage = \frac{\text{Length before Drying} - \text{length after drying}}{\text{Length before Drying}} \times 100$$

$$LS = \frac{L_{avg}}{L_o} \times 100\%$$

Where,

LS = Linear Shrinkage (%)
L_{avg} = *Average Length (mm)*
L_o = *Orginal length of mold (mm)*

4. RESULTS AND DISCUSSION

4.1 Natural Moisture Content

The moisture content of any given soil may be influenced by the season, depth, type of soil and distance to a stream or river or any water body. Although, the water content is one of the easiest properties of a soil to obtain, it is also one of the most useful. Moisture is a good indicator of the shear strength of a soil.

The Awgu shale showed a range of low to high moisture content (7.96% - 54.1%). The results show that natural moisture contents vary between the samples from the different locations.

However, since the sampling was done during the rainy season, the rain may have contributed to the recorded high moisture contents of the samples. The samples from Borehole 4 and 5 recorded the lowest moisture content. While sample from Boreholes 1, 2 and 3 recorded the highest moisture content. This may be a result of their higher percentage of finer grains compared to Borehole 4 and 5.

The result obtained from Boreholes 1,2 and 3 agree with previous works where Anambra basin was reported to contain moderate to high moisture content [5] but contrary to the moisture content result from borehole 4 and 5 that has very low moisture content (7.96% – 13.0%). Since moisture content is a good indication of the shear strength of saturated clay, Boreholes 4 and 5 are likely to show higher shear strength than borehole 1.2 and 3.

4.2 Linear Shrinkage

The linear shrinkage of samples from Awgu shale ranges from 8.6% – 11.4%. Borehole 5 showed the highest shrinkage values of 10% – 11.4% while Boreholes 3 recorded the lowest shrinkage values of 8.6% – 10%. Hence, the result indicate that sample from Borehole 5 have higher ability to reduce in Length on drying than the other five Boreholes.

4.3 Atterberg Limits

Atterberg limits are used to classify cohesive soil.

Table 1. Description of sample

Location	Sample No	Depth (M)	Colour
Borehole 1 Nenwe	A1	1	Brownish
	A2	2	
	A3	3	
Borehole 2 (Mgbowo)	B1	1	Brownish
	B2	2	
	B3	3	
Borehole 3 (Mgbowo)	C1	1	Brownish
	C2	2	
	C3	3	
Borehole 4 (Nenwe)	D1	1	Whitish Brown
	D2	2	
	D3	3	
Borehole 5 (Nenwe	E1	1	Whitish
	E2	2	
	E3	3	

Table 2. Natural moisture content result

Sample No	Location	Boring No	Moisture content, W%
A1			27.9
A2	NENWE	ONE	32.4
A3			28.8
B1			39.85
B2	MGBOWO	TWO	37.41
B3			39.35
C1			37.5
C2	MGBOWO	THREE	41.3
C3			54.16
D1			11.70
D2	NENWE	FOUR	11.73
D3			13.0
E1			9.0
E2	NENWE	FIVE	7.96
E3			8.64

Table 3. Linear shrinkage result

Sample No	Location	Boring No	Linear Shrinkage (%)
A1			10
A2	NENWE	ONE	8.6
A3			10.1
B1			8.6
B2	MGBOWO	TWO	8.6
B3			10.1
C1			8.6
C2	MGBOWO	THREE	8.6
C3			9.3
D1			8.6
D2	NENWE	FOUR	8.6
D3			10.0
E1			11.4
E2	NENWE	FIVE	10
E3			10

Table 4. Atterberg limits result

Sample No	Location	Boring No	Liquid limit	Plastic limit	Plasticity index
A1			88%	40%	48%
A2	NENWE	ONE	86%	33%	53%
A3			85%	46%	39%
B1			80%	30%	50%
B2	MGBOWO	TWO	86%	44%	42%
B3			85%	45%	40%
C1			85%	43%	42%
C2	MGBOWO	THREE	80%	40%	40%
C3			85%	44%	41%
D1			48%	27%	21%
D2	NENWE	FOUR	54%	32%	22%
D3			60%	35%	25%
E1			80%	38%	42%
E2	NENWE	FIVE	86%	33%	53%
E3			80%	26%	54%

4.3.1 Liquid Limit (L.L)

The minimum moisture content at which the soil will flow under its own weight. It is the moisture content above which the soil starts to flow in other words; it is a soil-water mixture with no measurable shear strength. The liquid limit as shown above ranges from moderate to very high (48-88%) for Awgu shale the liquidity index as shown above show a range of -0.41 to 0.49. the liquidity index show the stiffness of the sample, the lower the liquidity index values, the stiffer the soil.

4.3.2 Plastic Limit (P.L)

The soil content below which the soil no longer behaves as a plastic material. It may also be defined as the maximum moisture content at which the soil can be rolled into a thread 3mm diameter without breaking or it is the moisture content below which the material loses its plasticity and become crumbly.

The plastic limits ranged from 26% to 46%. The plasticity index of the samples ranged from 21% to 54%. From Table 5, plasticity index classification from borehole 1, 2, 3 and 5 show very high swelling potential, except for borehole 4 that range between medium to high.

4.4 Classification of the Soil Samples

The classification of the samples using the unified soil classification system is as shown in Fig. 1. The samples from Borehole 1,2,3 and 5, plot as high plasticity samples and borehole 4 having intermediate plasticity.

The above results agree with the works of Cratchley and Jones [18]; Offodile and Reyment [9] that the Anambra basin have high plasticity but Borehole 4 from Nenwi is in contrast with the above assertion, borehole 4 show inorganic clay silt with intermediate plasticity.

Thus, borehole 4 samples are likely to have greater shear strength than those from the other four boreholes, since the larger the plasticity, the greater will be the engineering problems associated with the soil.

Table 5. Potential expansiveness of soils After Ola [19]

Plasticity index %	Swelling potential
0 – 15	Low
15 – 25	Medium
25 – 35	High
> 35	very High

According to BS 5930 [15] code of practice for site investigation, if liquid limit is: (a) Less than 35%, soils is of low plasticity or low compressibility; (b) Between 35 – 50%, the soil of intermediate plasticity of compressibility; (c) Greater than 50%; then the soil is of high plasticity. The Federal Government of Nigeria standard design specification values for both sub-base and base course materials recommends that liquid limit, plasticity index and linear shrinkage should not be greater than 30%, 12%, and 8% respectively.

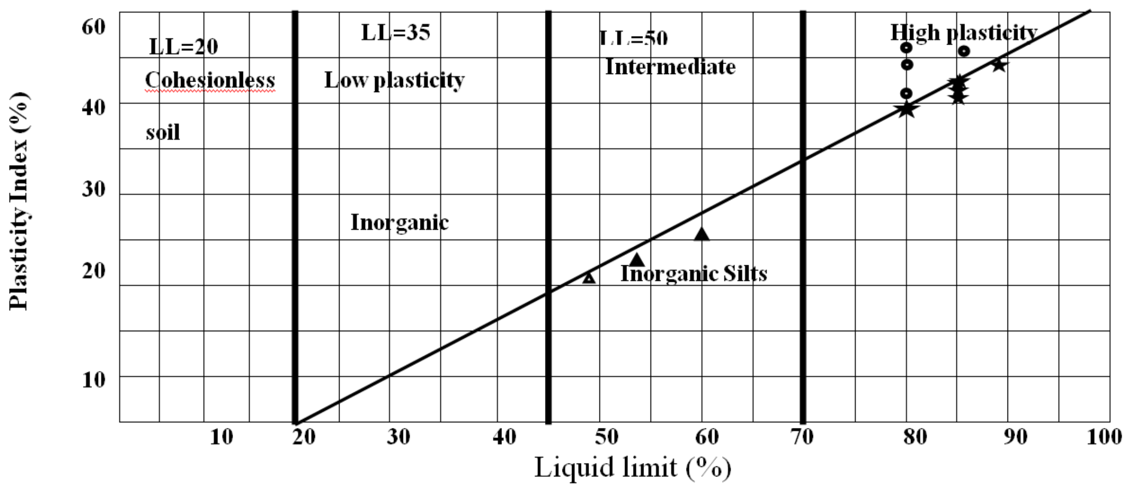

Fig. 2. Classification of the soil samples

Where ★ *is inorganic silts with high plasticity*

O *is inorganic clays with high plasticity*

△ *Is inorganic silts with intermediate plasticity*

Table 6. Unified classification system

Sample no	Location	Boring No	Liquid limit
A1			Inorganic silts with high plasticity
A2	NENWE	ONE	Inorganic clays with high plasticity
A3			Inorganic silts with high plasticity
B1			Inorganic clays with high plasticity
B2	MGBOWO	TWO	Inorganic silts with high plasticity
B3			Inorganic silts with high plasticity
C1			Inorganic silts with high plasticity
C2	MGBOWO	THREE	Inorganic silts with high plasticity
C3			Inorganic silts with high plasticity
D1			Inorganic silts with intermediate plasticity
D2	NENWE	FOUR	Inorganic silts with intermediate plasticity
D3			Inorganic silts with intermediate plasticity
E1			Inorganic clays with high plasticity
E2	NENWE	FIVE	Inorganic clays with high plasticity
E3			Inorganic clays with high plasticity

Thus, since the result from the Natural Moisture content, Atterberg Limits and Linear Shrinkage do not meet up the above specification, it can inferred that the soil samples from Awgu Shale cannot be use as Engineering materials either for foundation support or road construction without reasonable reinforcement.

5. CONCLUSION AND RECOMMENDATIONS

The study of the Engineering properties of the samples of Awgu shale collected from Nenwe and Mgbowo in Awgu Local Government Area of Enugu State revealed that the moisture content ranges from 7.96% to 56.16%. the Linear shrinkage limit ranges from 8.57% - 11.4%, the liquid limit ranges from 48% and plasticity index ranging from 21% to 54%.

In conclusion, Engineering properties of samples from Awgu shale reveal high moisture content except for borehole 5 with relatively low moisture content, moderate to high linear shrinkage, high liquid limit, moderate to high plastic limit and moderate to high plasticity index, hence the studied samples of Awgu shale are likely to have poor shear strength and is therefore not good for use as foundation support, road sub-grades, etc.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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