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GEOLOGICAL AND GEOTECHNICAL CHARACTERISATION OF SHALE-DERIVED MATERIALS AND THEIR ENGINEERING IMPLICATIONS IN UGWUAJI AND ENVIRONS, SOUTHEASTERN NIGERIA

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Abstract

This study conducted in Ugwuaji and Environs, Enugu South L.G.A, scrutinized the geological and geotechnical features of the area. Two distinct units, A and B, were identified. Unit A consisted of fissile dark grey shale with pronounced weathering and cracking, while Unit B comprised fissile light grey shale displaying reddish-brown stains from overburden. A variety of sedimentary structures, such as cracks, lamination, joints, Orphiamorphar burrows, fractures, bedding planes, and mud cracks, characterized the Lithofacies of the region. Geo-technical assessments on six disturbed soil samples unveiled a stiff soil with the capacity to withstand load and pressure. Triaxial test outcomes revealed a cohesion range of 20-31 KNm-², an angle of internal friction range of 16-18, and an undrained compressive strength range of 111.05-144.2 KNm-². Atterberg's limit results indicated a low to medium swelling potential, with liquid limit ranging from 24-35.70%, plastic limit from 16.72-25.97%, and plasticity index from 5.71-12.35%. The particle size distribution test emphasized the prevalence of sands, clay, silt, and gravel in the soil composition. According to the Unified Soil Classification System (USCS), the area was classified as well-graded sands with gravel, poorly graded sand, and sands with fines. The AASHTO classification system categorized the soils predominantly as A-1-a, signifying granular, low-plasticity clay suitable for sub-grade material. In essence, this study provides a comprehensive understanding of the geological and geotechnical attributes of Ugwuaji and Environs within a 240-word framework.

Keywords: Shale, Geotechnical, Geological, Triaxial Test, Soil Classification.

INTRODUCTION

Shale, a fine-grained sedimentary rock formed from compacted and hardened clay, silt, or mud, exhibits distinct layers and easy splitting. Colors vary from black or gray to brown or red, and shale is characterized by thin lamina with an irregular curving fracture parallel to the bedding plane. The mineral content, particularly the clay fraction, significantly influences shale's geotechnical properties. Shale with high percentages of Illite and Montmorillonite tends to have lower strength, higher swelling potential, and undesirable properties compared to shale with predominant clay fractions of Kaolinite, Chlorite, or low percentages of Illite and Montmorillonite.

In a study on Enugu Shale, it was found that swelling soil behavior is primarily governed by mineralogical composition, environmental factors, and stress history. The area was classified as A-7 soils and low plasticity clay soils by AASHTO and USCS. The free swell ratio ranged from 1.02 to 1.45, indicating a mixture of swelling and non-swelling clay minerals. Van der Merwe's charts revealed low to medium swelling potential, suggesting the need for soil modification before use as sub-grade material.

On Awgu Shale, laboratory analysis showed high moisture content, moderate to high linear shrinkage, and plasticity, indicating unsuitability for engineering purposes without reinforcement. In contrast, a study on Makurdi Shale to determine geotechnical properties found that the proposed foundation was suitable for light buildings on expansive clays. The foundation performed well through five cycles of rainy and dry seasons, showing minimal cracks compared to similar sites.

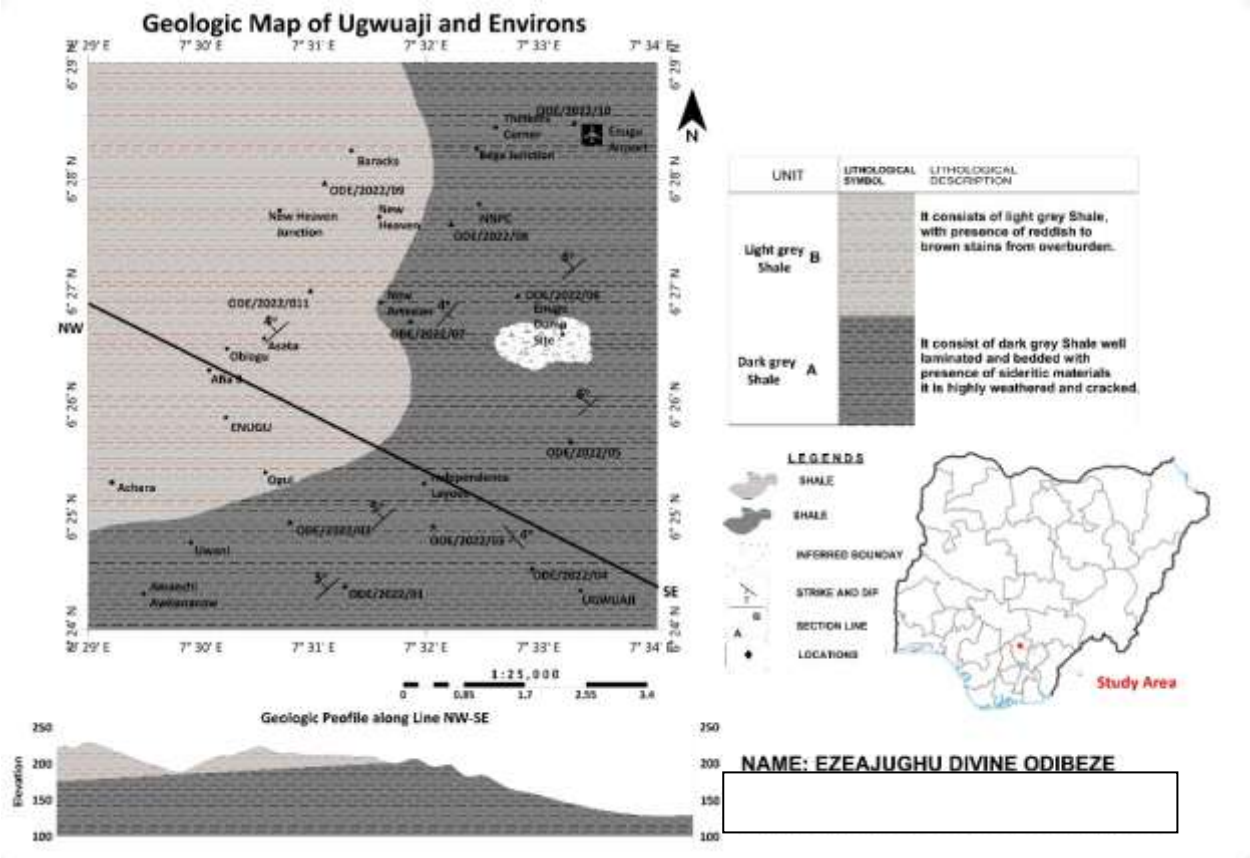
In summary, shale's geotechnical properties vary based on mineralogical composition. Enugu Shale exhibited low to medium swelling potential, Awgu Shale was deemed unsuitable without reinforcement, and Makurdi Shale demonstrated suitability for foundations on expansive clays. These findings underscore the importance of site-specific studies in assessing shale's engineering feasibility.

This Study aims to

1. To obtain the geotechnical properties of the soil using various laboratory study
2. To compare some of the measured properties with the constructions specifications in the area
3. To determine the problematic nature of Shale.

GELOGY OF STUDY AREA

The Study Area is Ugwuaji and Environs. Ugwuaji is a community in Enugu South L.G.A of Enugu State. The Study area covers areas around Enugu (Ugwuaji, Thinkers corner, New Artesian, New heaven, Enugu Dump Site, and Okpara Square) and is bounded by latitudes N6 ° 24′, N6 ° 29′, longitudes E07 ° 29′, and E07 ° 34′. The topography of the study area is characterized by hills (uplands) and lowland, with the hills attaining about 200m, which exposed the rock units of the area through road cuts, gullies and river channels. The area is underlain by Enugu Shale. Enugu Shale overlays the Agbani Sandstone/Awgu Shale. It is a lateral equivalent of Nkporo/Owelli formation and one of the oldest deposit of Anambra Basin (Nwajide, 1990). Enugu Shale consists of fissile, grey Shale with extra formational clast capped on top by Ironstone with presence of Pyrite, Siderite materials. The field data shows Enugu Shale as fissile, light grey with extra formational clast which graded into Mamu Formation which is made up of Shale, Coal and Sandy Shale. It passes upward into Ajali Sandstone which is characterized by cross beds, Herringbone structures and Ophiomorpha burrows. The youngest formation within the basin is Nsukka Formation.



GEOLOGIC MAP OF UGWUAJI AND ENVIRONS SHOWING LOCALITIES

UNIT	LITHOLOGICAL SYMBOL	LITHOLOGICAL DESCRIPTION
B		It consists of light grey Shale, with presence of reddish to brown stains from overburden.
A		It consist of dark grey Shale well laminated and bedded with presence of sideritic materials it is highly weathered and cracked.

MATERIALS AND LABORATORY METHODOLOGY

In the study of Ugwuaji and its environs, six soil samples were collected using stratified random sampling techniques, focusing on the Formation. The collection followed ASTM D4318-98 (2000) guidelines. Field analysis involved the use of a hoe and digger for sample extraction. Laboratory analysis included sedimentation, Atterberg limits (liquid limit and

plastic limit), triaxial shear strength, and sieve analysis. Triaxial tests measured mechanical properties, while Atterberg limits determined critical water contents of fine-grained soil. Sieve analysis assessed particle size distribution through progressively smaller mesh sizes, and sedimentation methods determined particle size in dispersed systems. The equipment employed included a soil auger, British electric shaker machine, Casagrande apparatus, and triaxial cylinder test apparatus. The comprehensive approach aimed to characterize the soil's physical and mechanical properties in Ugwuaji and its environs.

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. 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,

M1 = mass of cup

M2 = mass of cup and wet soil

M3 = mass of cup and dry soil

Consistency limits, also known as Atterberg limits, define the moisture contents at which a fine-grained soil transitions between different states. The Plastic Limit (WP) is determined by averaging three moisture content values obtained from portions of the soil. It represents the moisture content at which the soil changes from a plastic to a semi-solid state. The Liquid Limit (WL) is found by plotting the water content against the number of blows in a flow curve and determining the point corresponding to 25 blows. This identifies the moisture content at which the soil shifts from a plastic to a liquid state.

The Atterberg limit test provides additional parameters such as the Plasticity Index (Ip), calculated as the difference between the liquid limit and plastic limit, indicating the range of

moisture content where the soil remains plastic. The Liquidity Index (IL) signifies the proximity of a natural soil to its liquid limit. A positive IL between 0 and 1 indicates a plastic state, while values greater than 1 suggest a liquid or potential liquid state. Soft soils approach 100% IL, while stiff soils approach zero or even negative values.

The Flow Index (If) is determined by the slope of the log N vs. M line on the flow curve. If the flow index is negative, the line slopes down from left to right, indicating a soil in a plastic state. This comprehensive understanding of Atterberg limits aids in assessing the plasticity, liquidity, and flow characteristics of soils, essential for engineering applications and soil classification.

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 where the volume remains 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 *Where,*

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

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

LS = Linear Shrinkage (%)

Lavg = Average Length (mm)

Lo = Orginal length of mold (mm)

Swelling potential

Swelling soil classification based on the plasticity index according to (O' Neiland poormeayed 1980)

Table 3.3 Swelling soil classification based on the plasticity index according to (O' Neiland poormeayed 1980)

Liquid limit	plasticity index	potential swell(%)	potential/swell classification
<50	<25	<0.5	low
50-60	25-35	0.5-1.5	Marginal
>60	35	>1.5	high

Empirical correlation for predicting swelling potential for swelling soils by different authors

Chen (1988)	SP(%) =0.258$e^{0.0838}$PI
Muntohar (2000)	SP(%) = 7.518+ 0.3823©
Holtz et al (1956)	SP (%) =60K$(PI)^{2.44}$
Seed et al (1962)	SP (%) =2.16 X $10^{-6}(PI)^{2.44}$
Puppala et al (2014)	SP (%) = 0.05$(PI)^{1.415}$
Israr et al (2014)	SP (%) = 1.9A +0.68Wi – 7.55

AASHTO AND USCS Classification system

Soil classification systems, such as AASHTO and Unified Soil Classification System, categorize soils based on particle-size distribution and Atterberg limits. AASHTO, widely used by state and county highway departments, provides a common language for expressing soil characteristics, facilitating effective communication among engineers by succinctly summarizing the diverse properties of soils with similar behaviors.

RESULTS AND DISCUSSION

Table 4.1: Results of the index and geo-technical test

Locations	Ogulu ugwuaji	Thinkers corner	NAM(New artisan market)	Ugwuaji junction	ENDOS (Enugu old dump site)	NNPC
Cohesion C (KNm²)	22	20	27	28	31	29
θ° angle of internal friction	18	18	16	17	17	18
Undrained compressive strength (KNm-²)	124.65	127.28	111.05	126.07	134.7	144.2
Liquid limit LL%	27.50	35.70	30	27	24	34
Plastic limit PL %	19.82	25.97	21.05	21.29	16.72	21.65
Plasticity index	7.68	9.73	8.95	5.71	7.28	12.35
Shrinkage limit SL %	6.43	8.57	7.86	7.14	4.29	7.93
Swelling potential (according to puppala et al 2014) SP= 0.05(PI)^1.415	0.8945	1.2505	1.111	0.588	0.829	1.7525
Swelling potential (according to chen 1965) S= 0.2558e^0.0881PI (%)	0.486 (low)	0.578 (medium)	0.541 (medium)	0.412 (low)	0.470 (low)	0.720 (medium)

Swelling potential (according to Seed et al 1962) S= 2.16*10^-8(PI)^2.44	0.312 (moderate shrink) (low)	0.556 (moderate shrink) (low)	0.453 (moderate shrink) (low)	0.151 (moderate shrink) (low)	0.277 (moderate shrink) (low)	0.995 (moderate shrink) (low)
Activity of soil	-	0.46	0.617	-	-	-
AASHTO Classification	A-1-a(0)	A-2-4(0)	A-1-a(0)	A-1-a(0)	A-1-a(0)	A-1-a(0)

The results of the cohesion C (KNm-²) and undrained shear strength showed in table 4.1 ranges from 20-31 and 111.05-144.2 respectively, it reveals that the studied area is a stiff soil/stiff clay (according to Bell. F.G.2011 Engineering geology 2nd edition Elsevier, New Delhi India p 581). Which means it can carry light loads and withstand pressure.

Based on plasticity index from table 4.1 (according to puppala et al 2014) the swelling potential of the studied area is low to marginal.

Based on plasticity index from table 4.1 (according to O'Neiland Poormeayed, 1980) PI<25, the studied area can be classified under low swelling potential soils.

Based on plasticity index from table 4.1 (according to Seed et al, 1962) SP<16.0, the studied area can be classified under moderate to shrink swelling potential soils.

Based on liquid limit from table 4.1 (according to Chen, 1965) LL < 30, the soils in the studied area can be classified under low swelling potential soils.

Based on the activity of soil the result from table 4.1 shows Thinkers corner and New artisan market is dominated by kaolinite, which implies that the area won't swell in addition of water.

These areas are good for building and construction purposes.

The results from table 4.1 show that the area is dominated by A-1-a (0) and A-2-4(0) soils, which indicate they are granular materials and can be used as a sub-grade material, according to AASHTO system of classification.

Results for Sieve Analysis and Hydrometer Test on Soil Samples

Table 4.2 Results for Sieve Analysis and Hydrometer Test on Soil Samples

S/N	Locations	Gravel	Sand	Silt	Clay	Fines (Clay + Silt)	D_{10}	D_{30}	D_{60}	C_u	C_c	USCS Classification
1.	**Ugwuaji Junction 001**	32.9	65.1	-	-	2.0	0.4	2.0	4.0	10.0	2.5	Well graded Sand with

												gravel (SW)g
2.	**Thinker Corner 002**	-	90.2	7.5	2.0	9.5	-	-	-			Sand with fines
3.	**Ugulu Villa 003**	-	96.2	-	-	3.8	0.22	1.0	-	-	-	Poorly graded Sand (SP)
4.	**NAM (**new artisan market)	40.2	52.9	5.9	1.0	6.9	-	-	-	-	-	Sand with gravel and fines
5.	**ENODS (**Enugu old dump site)	57.9	41.6	-	-	0.5	0.6	2.2	4.9	8.2	1.6	Well graded gravel with sand (GW)s
6.	**NNPC-D- 006**	46.7	65.1	-	-	2.3	0.43	1.6	3.8	8.8	1.6	Well graded Sand with gravel (SW)g

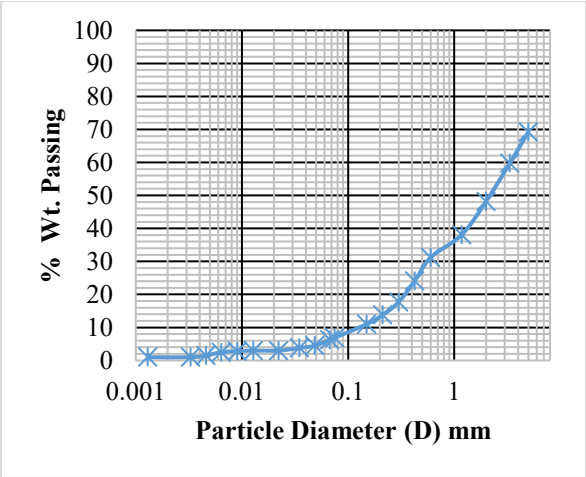


Figure 4.1 Graph showing results of particle distribution test done on sample gotten from New Artisan Market

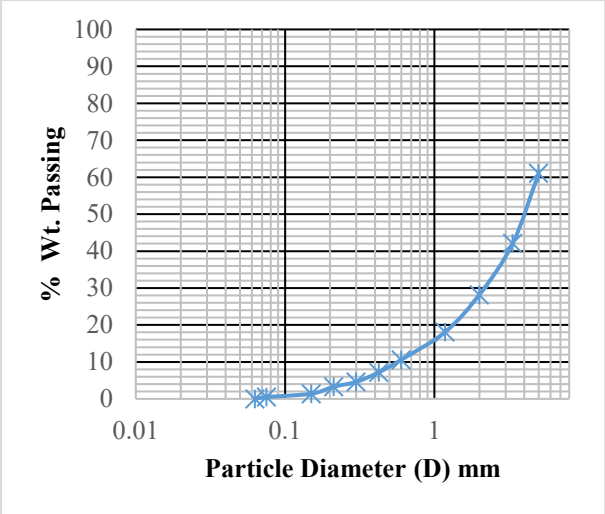


Figure 4.2 Graph showing results of particle distribution test done on sample gotten from Enugu

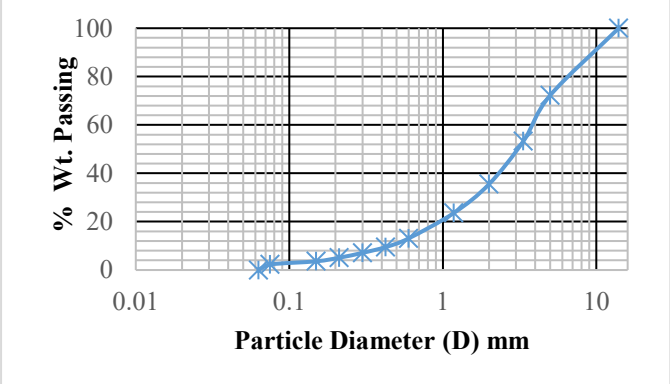


Figure 4.3 Graph showing results of particle distribution test done on sample gotten from NNPC

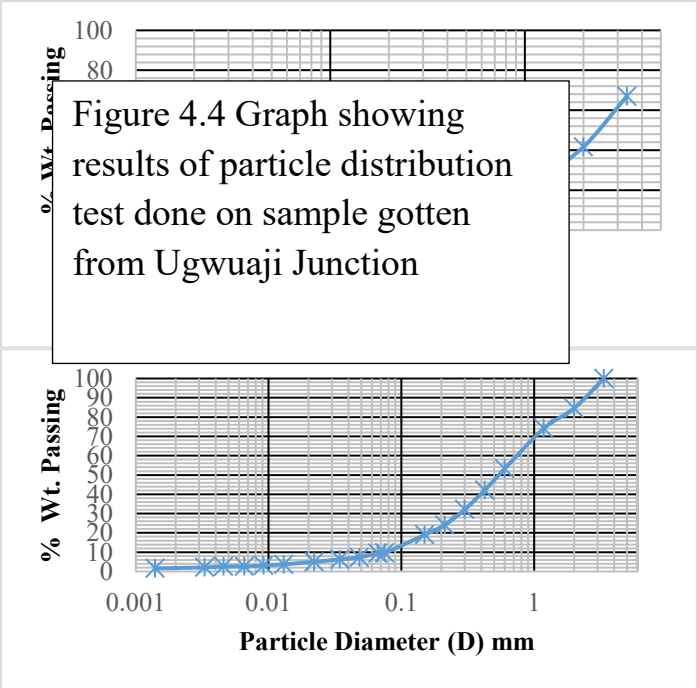


Figure 4.4 Graph showing results of particle distribution test done on sample gotten from Ugwuaji Junction

Figure 4.5 Graph showing results of particle distribution test done on sample gotten from

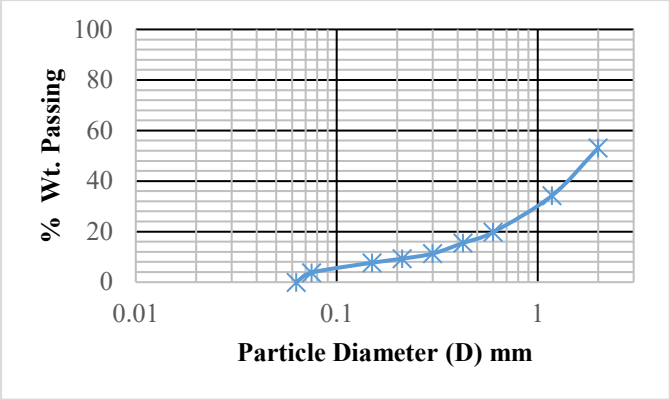


Figure 4.6 Graph showing results of particle distribution test done on sample gotten from Ogulu Ugwuaji Village

The results of the sieve analysis and hydrometer test from table 4.2 shows that the area is dominated by Gravel, sands, clay and silts. The fine gravel (%) ranges from 32.9 – 57.9, the coarse sand (%) ranges from 11.6 – 46.9, medium sand (%) ranges from 21.0 – 42.5, fine sand (%) ranges from 11.7 – 32.6, fines (%) ranges from 0.5 – 9.5. The area is mostly dominated by sands and gravel which can be used as a sub-grade material.

The results from table 4.2 show that Thinkers corner and New artisan market has a clay fraction of 2.0 and 1.0 respectively.

The results from table 4.2 according to USCS show that Ugwuaji junction has Well graded Sand with gravel (SW) g, Thinkers corner has Sand with fines, Ugwuaji village has Poorly graded Sand (SP), New artisan market has Sand with gravel and fines, Enugu Old dumpsite has Well graded gravel with sand (GW) s and, NNPC (Nigerian National Petroleum Corporation) has Well graded Sand with gravel (SW) g.

ENGINEERING IMPLICATIONS, CONSTRUCTION SIGNIFICANCE, LIMITATIONS AND FUTURE APPLICATIONS

The geotechnical results obtained from Ugwuaji and its environs have significant implications for engineering and construction, but their interpretation requires caution. The tested materials are predominantly granular to low-plasticity soils, with relatively low liquid limits and plasticity indices, moderate to high shear strength and generally low-to-moderate predicted swelling potential. These characteristics indicate that the sampled near-surface materials may be suitable for selected earthworks and subgrade applications where adequate compaction and drainage are provided. However, the results should not be interpreted as evidence that the underlying shale is inherently non-problematic. Recent research demonstrates that shale behaviour is strongly controlled by mineralogy, fabric, water interaction and geological heterogeneity, with significant differences potentially occurring between intact shale, weathered shale and shale-derived soils (Lalji et al., 2022; Wang et al., 2023).

The relatively low plasticity observed in the study is potentially advantageous for construction because it suggests limited volume change compared with highly expansive clay materials. Nevertheless, recent experimental studies demonstrate that water interaction can cause swelling, softening, cracking and mechanical degradation in shale and mudstone. Shale swelling may alter mechanical properties and contribute to damage, while water-induced softening can reduce material strength and modify failure behaviour (Wang et al., 2023; Zhang

et al., 2023). Therefore, the generally favourable strength and plasticity values obtained in this study should be regarded as representative of the tested moisture and sampling conditions rather than as permanent material characteristics. This is particularly important in Enugu, where seasonal rainfall and variations in moisture conditions may influence the long-term behaviour of weathered shale-derived materials.

For construction purposes, the findings suggest that some sampled locations may be appropriate for selected subgrade, embankment and earthwork applications. However, engineering suitability is spatially variable and should not be generalised across the entire study area. The presence of shale-bearing formations, contrasting lithologies and variable weathering states means that localised zones of weaker or more moisture-sensitive material may occur. Furthermore, the geological setting of the study area includes slopes, gullies and drainage features where erosion, slumping and slope instability may pose greater risks than those indicated by conventional laboratory strength parameters alone. Consequently, geological mapping, drainage assessment and slope stability considerations should complement routine geotechnical classification before construction.

A major limitation is that the investigation was based primarily on six disturbed soil samples. Thus, the results principally characterise near-surface and potentially weathered materials rather than the intact rock-mass properties of shale. This distinction is critical because shale is inherently heterogeneous and anisotropic, and its mechanical response may vary with bedding orientation, mineral composition and fracture development (Li et al., 2023). In addition, activity values alone cannot conclusively establish the dominance of a particular clay mineral; mineralogical confirmation using X-ray diffraction (XRD) is required. The study would therefore benefit from direct swelling-pressure tests, consolidation, permeability, slake-durability and intact-rock strength testing.

Future engineering research should adopt an integrated geological–geotechnical approach combining XRD, petrography, microscopy and hydro-mechanical testing. Such work would clarify whether the relatively favourable engineering behaviour observed in Ugwuaji reflects the intrinsic properties of the shale-bearing formation or the progressive weathering and transformation of shale into granular soil. This distinction has important implications for foundation design, road construction and long-term infrastructure durability. Ultimately, the findings provide a useful baseline for engineering assessment but support a site-specific approach rather than a blanket classification of shale as either suitable or problematic for construction.

LIMITATIONS OF THE STUDY AND RECOMMENDATIONS FOR FURTHER RESEARCH

Limitations of the Study

Although this study provides useful insights into the geology and geotechnical characteristics of shale-associated materials in Ugwuaji and its environs, several limitations constrain the extent to which the findings can be generalised. The most important limitation is the relatively small number of samples analysed. Only six disturbed soil samples were investigated, which may not adequately represent the considerable spatial and geological variability of the study area. Shale-bearing terrains are often heterogeneous, with engineering properties influenced by variations in mineralogy, bedding, weathering intensity, fracture development and

depositional facies. Consequently, the results obtained from the selected sampling locations may not fully represent conditions elsewhere within the study area (Li et al., 2023).

A further limitation is that the samples were disturbed during collection and preparation. While disturbed samples are appropriate for several index and classification tests, they cannot adequately preserve the natural fabric, fissility, bedding orientation and fracture characteristics that influence the behaviour of intact shale. Therefore, the reported geotechnical properties should be interpreted primarily as characteristics of the sampled near-surface or weathered materials rather than definitive properties of the intact shale formation. This distinction is important because shale can exhibit significant anisotropy and heterogeneous mechanical behaviour depending on its mineral composition and structural fabric (Li et al., 2023).

The study also did not undertake X-ray diffraction (XRD), scanning electron microscopy (SEM) or detailed petrographic analysis. Consequently, interpretations concerning clay-mineral composition and the possible role of kaolinite or other low-activity minerals remain indirect. Similarly, no direct swelling-pressure tests were performed. The swelling potential was instead estimated using empirical relationships, which may introduce uncertainty because swelling behaviour depends on mineralogy, moisture conditions, stress state and soil structure (Lalji et al., 2022). In addition, consolidation and permeability tests were not conducted, while groundwater conditions were not quantitatively characterised. These omissions limit the ability of the study to predict long-term settlement, drainage behaviour and moisture-induced changes under actual field conditions.

RECOMMENDATIONS FOR FURTHER RESEARCH

Future investigations should expand the sampling network to include a greater number of locations, sampling depths and geological horizons. This would allow spatial variability to be quantified more reliably and facilitate the development of engineering zoning maps for construction purposes. Both disturbed and undisturbed samples should be collected to distinguish between the behaviour of weathered shale-derived soils and that of materials retaining their natural geological structure.

Mineralogical investigations using XRD, complemented by SEM and petrographic analysis, are recommended to establish the actual clay-mineral assemblage and microstructural characteristics of the shale. These analyses would provide a stronger basis for explaining the observed plasticity and swelling behaviour than activity indices alone. For intact shale, point-load and uniaxial compressive strength tests should be undertaken, together with slake-durability testing, to evaluate resistance to weathering and mechanical degradation.

Further research should also include direct swelling-pressure and swell-strain measurements under controlled moisture and loading conditions, alongside consolidation and permeability testing. Such investigations would improve understanding of the coupled effects of water, stress and deformation, which are critical to long-term infrastructure performance. Recent research demonstrates that water–rock interaction can promote shale swelling, softening and mechanical degradation, highlighting the need to assess behaviour under realistic environmental conditions rather than relying solely on dry-state or empirical classifications (Wang et al., 2023; Zhang et al., 2023).

Finally, future studies should quantitatively assess groundwater levels, seasonal moisture fluctuations, drainage and slope stability. Integrating geological mapping, mineralogical characterisation and comprehensive geotechnical testing would provide a more robust framework for assessing the engineering suitability of shale-bearing formations. Such an approach would enable future research to move beyond simple material classification towards predictive models capable of identifying locations that may experience swelling, softening, erosion or instability during the service life of infrastructure.

CONCLUSION AND RECOMMENDATION

The studied area, underlain by units A and B, exhibits distinct lithofacies with features like cracks, lamination, joints, burrows, fractures, bedding planes, and mud cracks. According to AASHTO classification, the dominant soils are A-1-a, indicating granular and low plasticity clay suitable for use as sub-grade material. Triaxial shear strength results reveal a stiff soil, with cohesion (C) ranging from 20-31 KNm^{-2}, angle of internal friction from 16-18, and undrained compressive strength from 111.05-144.2 KNm^{-2}, indicating its ability to withstand load/pressure.

Particle size distribution analysis indicates a well-graded soil with dominant sands, clay, silt, and gravel. The Unified Soil Classification System (USCS) categorizes the area as well-graded sands with gravel, poorly graded sand, and sands with fines. Atterberg's limit results reveal low to medium swelling potential, as indicated by liquid limits (LL%) ranging from 24-35.70, plastic limits (PL%) from 16.72-25.97, and plasticity index (PI%) from 5.71-12.35. The swelling potential, according to various criteria, falls within the low to medium range.

Additionally, the activity of the soil, ranging from 0.46-0.617 the relatively low activity values are consistent with low-activity clay minerals, potentially including kaolinite, however, mineralogical confirmation through X-ray diffraction (XRD) would be required to establish the dominant clay mineral assemblage. Overall, the geotechnical properties suggest that the soil in the studied area is well-suited for sub-grade applications, with low to medium swelling potential and sufficient shear strength. These findings are crucial for informed engineering decisions in construction and foundation design in Ugwuaji and its environs.

REFERENCES

Agbedea, O. and Smart, P., 2007. Geotechnical Properties of Makurdi shale and effects on foundations by Nigerian Journal of Technology, Vol. 26, No. 2., p 63-73

Aghamelu, OP, Nnabo PN, Ezeh HN (2011). Geotechnical and environmental problems related to shales in the Abakiliki area, Southeastern Nigeria. African Journal of Environment Science and Technology Vol 5 No.2 p 80-88.

Bell FG., (2007). Engineering geology, 2nd edition. Elsevier: London, UK. p 207-248.

Bell, J. L., Driemeyer, P. E., &Kriven, W. M., (2009). Formation of ceramics from metakaolin-based geopolymers. Part II: K-based geopolymer. *Journal of the American Ceramic Society*, *Vol.* 3 P. 96.

Kogbe, C.A., (1981). Attempt to correlate the statigraphic sequence in the middle Benue basin with those of the Anambra and upper Benue basins. Earth Evolution Sciences, Vol 1 (2); p139-148.

Lalji, S. M., Ali, S. I., Awan, Z. U. H., et al. (2022). Comparative performance analysis of different swelling kinetic models for the evaluation of shale swelling. *Journal of Petroleum*

Exploration and Production Technology, 12, 1237–1249. https://doi.org/10.1007/s13202-021-01387-9

Li, et al. (2023). *Heterogeneity indexes of unconventional reservoir shales: Quantitatively characterizing mechanical properties and failure behaviors*. *International Journal of Rock Mechanics and Mining Sciences, 171*, 105577. https://doi.org/10.1016/j.ijrmms.2023.105577

Makki, L., Duc, M., Coppée, T., & Szymkiewicz, F. (2024). The swelling–shrinkage properties of intact and disturbed clayey and marly soils: The density effect. *Geotechnics, 4*(2), 512–529. https://doi.org/10.3390/geotechnics4020028

Nnamani, C., and Ogbonnaya, I., (2020). Estimation of swelling potential of Enugu Shale using cost effective methods Vol. 15(1), P. 10-21.

Nwachukwu, J.I. and Odjeba, E.T., (2001). Compaction in Reservoir Sandstones of the Niger Delta, Nigeria. Journal of mining and Geology, vol.32(2), P.113-120.

Nwajide CS., (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 CS, Reijers TJA., (1999). Geology of the southern Anambra Basin. In: Reijers TJA(Ed), Selected chapter on Geology SPDC Warri, p. 133-148.

Obi, G.C. and Okogbue, C.O., (2001). Sedimentary response to tectonism in the Campano–Maastrichian succession, Anambra basin, Southeastern Nigeria. Journal of African Earth Sciences Vol. 38 p 99-108.

Ola, S. A., (1983). Geotechnical properties of Sokoto clay shales of Northern Nigeria. In tropical soil of Nigeria in engineering practice.

Tombari Bodo., (2018). Engineering Properties of Awgu Shale in Enugu State, Nigeria. Asian Journal of Geological Research 1(3,) Pp.1-8.

Underwood, L.B., (1967) Classification and identification of shales. Proc. Am. Soc. Civ. Eng., J. Soil Mech. Foundn. Div. 93 SM6, P. 97-116.

Van der Merwe, D.H., (1975). Contribution to Specialty Session B, Current theory and practice for building on expansive clays. Proc. 6th Reg. Conf. for Africa on SMFE, Durban, Vol. 2.

Wang, et al. (2023). *Effects of shale swelling on shale mechanics during shale–liquid interaction*. *Energy, 279*, 128098. https://doi.org/10.1016/j.energy.2023.128098

Zhang, et al. (2023). *Investigating the influence of water on swelling deformation and mechanical behavior of mudstone considering water softening effect*. *Engineering Geology, 318*, 107102. https://doi.org/10.1016/j.enggeo.2023.107102