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INVESTIGATION OF THE SEDIMENTARY FORMATIONS IN OTUKPO BENUE STATE NIGERIA AND THEIR SUITABILITY AS CONSTRUCTION MATERIAL

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ABSTRACT

The geotechnical properties of the Otukpo sedimentary formations was investigated to identify suitability as construction materials. Eight (8) soil samples were collected from shale, sandstone and limestone formations making a total of twenty four (24) soil samples at varying depths ranging from 1.0m to 1.5m. The choice of sampling sites and locations were based on information obtained from the Nigeria Geological Surveying Agency in Makurdi. The topographical and geological maps of the sedimentary formation were used as base maps and for physiographical analysis. Reconnaissance field trip was undertaken to the study area to locate and identify the sampling sites via GIS. Moisture content, specific gravity, particle size, *permeability, porosity, Atterberg limits, dry bulk density, shear strength, compressibility and bearing capacity were evaluated. The moisture content in the sedimentary formation is in the range of 0.5% – 22.82%, however, there exist little variation in the mean values of the three major sedimentary formation with limestone having the highest moisture content 9.4% and Std Dev of ±7.24. The mean values of the coefficient of uniformity (Cu) were 62.38, 19.17 and 28.75 for shale, sandstone and limestone respectively and are all above 15 which defined the soils in the sedimentary formations to be well graded. The range of Gs for the three formations is 2.23, 2.25 and 2.27 for shale, sandstone and limestone respectively which is below 2.60 and classified the soils in the sedimentary formation as organic. The coefficient of permeability (K) for the three sedimentary formations clearly indicated that sandstone formation has the highest degree of permeability which agreed with fact that sandstone are more porous followed by limestone formation and shale respectively. Limestone recorded the highest compressive strengths both at 70, 140 and 210 cell pressure. The formations neither satisfies all the specifications as general filling and embankment, nor all the requirements as sub-base course and base course material, however Stabilization of the three formations for use as construction materials is possible*

KeyWords- Otukpo sedimentary formations. geotechnical properties. construction materials

I. INTRODUCTION

The successful practice of geotechnical engineering requires the knowledge of soil variability and uncertainty and its properties necessary for engineering design. Soil and rock are naturally occurring, highly complex materials with valuable constituents and variable properties (Das, 2017). Theoretical prediction of the behavior of these two materials has a number of simplifying and idealized assumptions. Much experience, imagination, and judgment are therefore needed in the practice of geotechnical engineering. Designing a structure in rock or soil is somewhat more difficult than designing one made of steel, concrete or other conventional construction materials. Most structures are supported by the soil; hence the importance of soil as a foundation-supporting material as well as a construction material is of outmost significance (Shah, 2003). Construction materials used in engineering projects are devoted to the realization of efficient and economical works. Geotechnical studies are imperative to determine the nature of soil and rock formation that can be used as construction materials for engineering works (Amadi *et al.*, 2012). This is because the impact of the imposed load is aggravated by the thickness and consistency of the compressible layer (Oke and Amadi, 2008). Thus, in addition to other intrinsic factors it contributes to haulage of simple construction materials from other locations (Youdeowei & Nwankwoala, 2013; Amadi *et al.*, 2012). It is imperative that site(s) be geo-technically characterized through sub-soil investigation for the purpose of generating relevant data inputs for the quality of soil and rock formation needed as construction materials for proposed structures. This study is to identify the non-performing sedimentary formations in Otukpo, and suggest curative treatments for the sediments.

II. THE STUDY AREA

Otukpo (Figures 1), is the headquarters of the Otukpo Local Government Area Council of Benue State, North Central Nigeria. It is the traditional headquarters of the Idoma nation, mainly populated by the Idoma speaking people, though numerous local dialects spoken in the diverse reaches of Idoma land aboud. In addition to metropolitan other prominent places in the local government area include Ogobia, Upu, Otukpoicho, Otobi, Adoka, Oyagede and Akpa-Igede. The LGA came into existence in 1923, with its headquarters at Otukpo.

Located within latitude 7^0 00’’N to 7^0 30’N and longitude 8^0 00’E to 8^0 30’E respectively. It is bounded to the North by Apa Local Government Area, the East by Obi Local Government Area, and the South by Ohimini Local Government Area, all of Benue State. The town is strategically located at the intersection of the eastern railway line and the only trunks “A” road linking the Northern parts of the country to the Eastern parts. According to Ngex (2008), Wikipedia (2012); it has an estimated landmass of about 390 sq. km, and with a population of 266,411 (NPC,2006).

The area under study is underlain by Cretaceous sediments of the lower Benue Trough located in the southern area of Benue valley. The Benue Trough has often been described as an intracontinental Cretaceous basin, occupied by up to 6,000m of marine and fluviodeltaic sediments that have been compressionally folded in a non-orogenic shield environment (Wright, 1976).

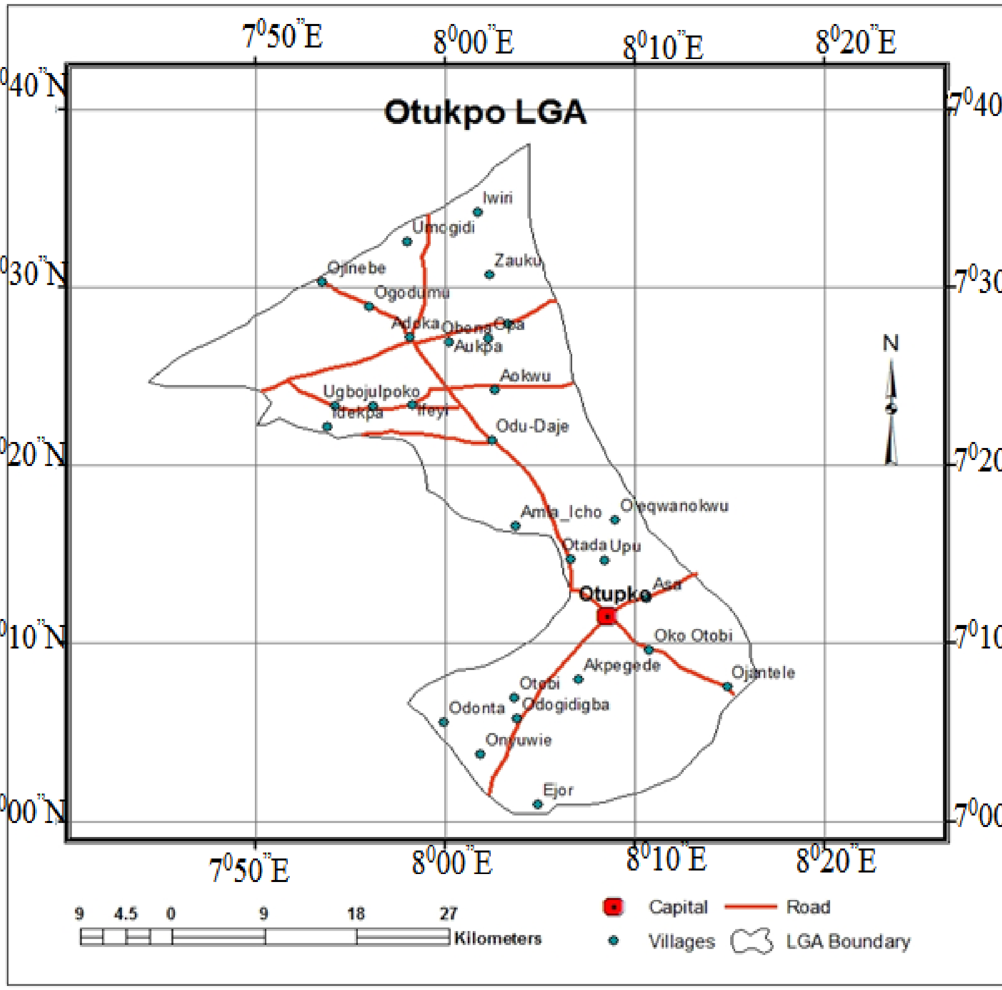


Figure 1: Map of Otukpo Local Government Area (BSTMLS, 2011)

The geological formations found in the area are namely; Asu River Formation, Eze-Aku Formation and the Awgu Formation. The oldest sediments present in the area belong to the Albian Marine transgression. Middle Albian transgression caused the deposition of very thick marine, dark, grey shales, siltstone and subordinate limestone of the Asu River group, which uncomformably overlie the crystalline basement rocks of pre-Cambrian age (Nwachukwu,1972). The second cycle resulted in the deposition of Eze-Aku Formation at the end of the Cenomanian transgression that ended with a regression in the early or beginning of Turonian. The Eze-Aku Formation consists of thick flaggy calcareous and non-calcareous shales, sandy or shaley limestones, and calcareous sandstones. It overlies the ASU River Group (Nwajide, 1986).The Eze-Aku Formation is overlain by Coniacian Awgu Shale Group. This group comprises bluish-grey, very soft; shallow marine bedded carbonaceous mudstones with occasional muddy limestone and siltstones as well as a narrow band of sandstone formation, which is generally fine to medium grained and moderately cemented (Agagu *et al*., 1985).

The variation in topography within the area is limited. It has been deeply dissected by erosion into tabular hills separated by river valleys. According to Federal Surveys, Nigeria, (1970), the section is especially rugged. The upland areas are generally undulating and strongly marked by inselbergs.

According to Abah (2014), soils in Otukpo LGA are deeply weathered red and yellowish brown, the soils developed essentially on sedimentary rock. The soils are easy to cultivate but prone to excessive internal drainage and intense leaching leaving plants in the area to obviate the adverse effects of the rapid internal drainage of the soil by drawing water from the subsoil.

III. METHODOLOGY

Reconnaissance field trip was undertaken on the study area to locate and identify the sampling sites; the local inhabitants provided the firsthand information of the area and was guided by the topographical and geological map (Figure 2&3) of the area based on different sedimentary formations; shale, sandstone and limestone respectively. Interpretation of maps, use of GPS for precise location of latitude, longitude, altitude and bearing were exercised.

Eight (8) soil samples were collected from each of the formations giving a total of twenty four (24) soil samples sites (Figure 4) to ensure proper coverage of the study area at varying depths ranging from 1.0m to 1.5m. The choice of sampling sites and locations was informed by their strategic location within their geological formation as obtained from the Nigeria Geological Surveying Agency (NGSA) in Makurdi.

Geotechnical properties of soils determined include; moisture content, specific gravity, particle size distribution, permeability, Atterberg limits, dry bulk density, consolidation, and shear strength.

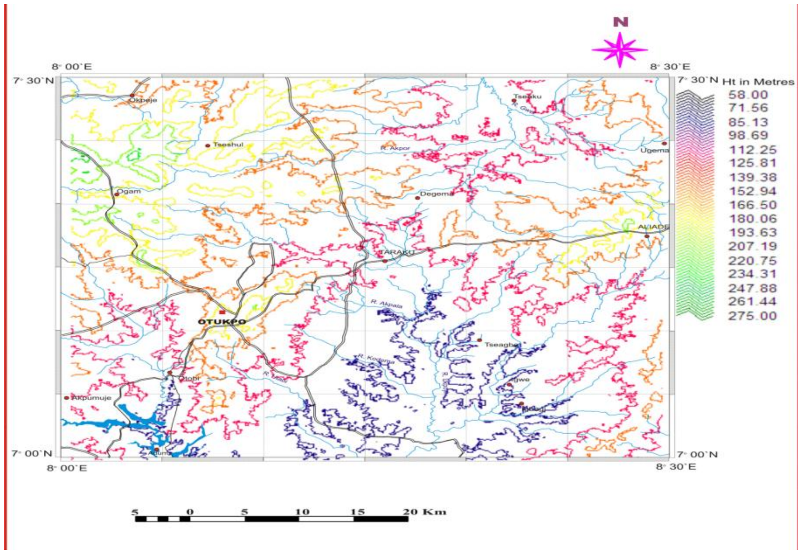


Figure 2: Topographical Map of the study Area

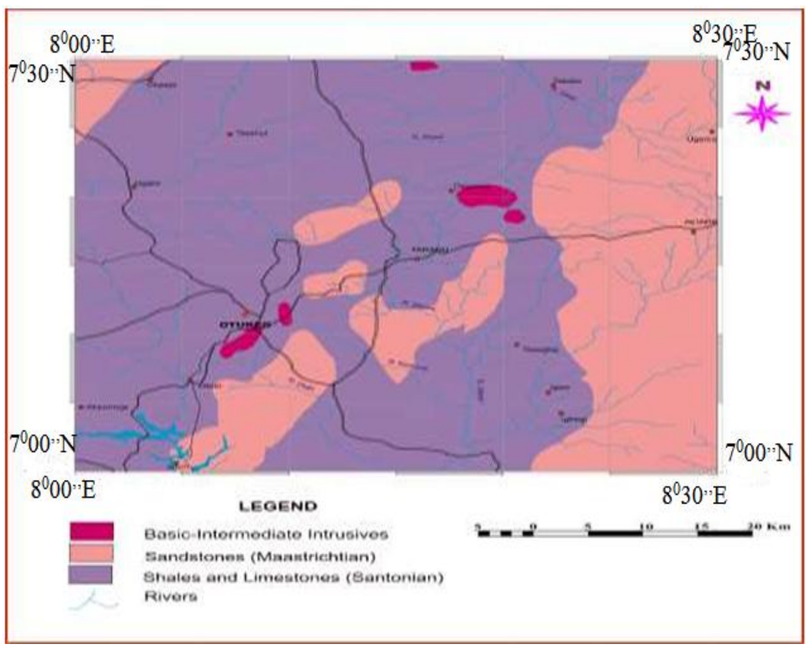


Figure 3: Geological Map of the Study Area

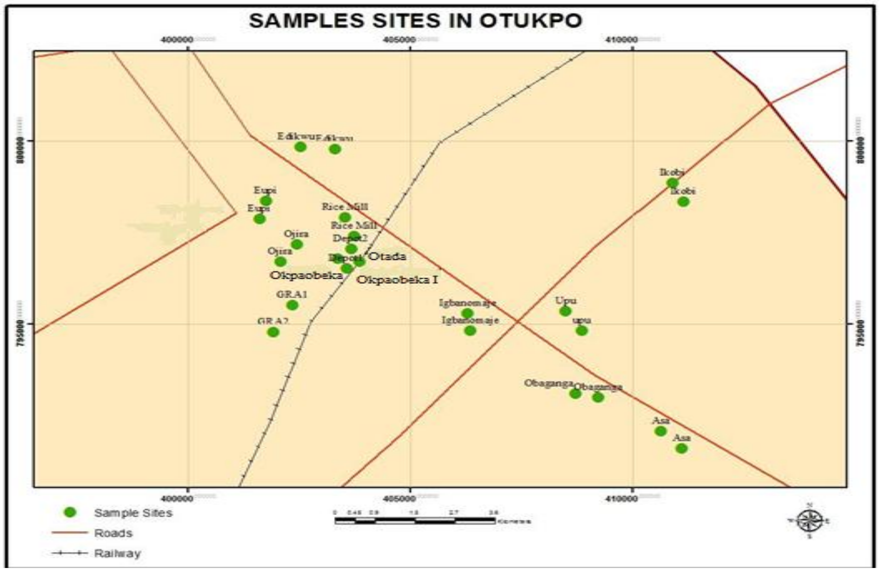


Figure 4: Map of Otukpo Showing the Sampling Sites

In-situ and Laboratory Tests

The permeability of the soil was determined insitu using the auger-hole method while the Laboratory analysis of soil samples was conducted in the Soil Science and Civil Engineering Laboratories of the Federal University of Agriculture, Makurdi. Benue State, Nigeria. Standard laboratory procedures were followed throughout as presented in Table 1 for data generation in this study

Table 1: Summary of Methods and Materials used to Determine Geotechnical Properties of Soil.

Geotechnical properties	Methodology	Materials	Formulae Standards
Atterberg Limits	Liquid limit by one point method	Casagrande apparatus	$W_L = \frac{w}{1.3215 - 0.23 \log N}$ AASHTO T-11
	Plastic Limit by one point method	Casagrande apparatus	$W_p = \frac{w}{1.3215 - 0.23 \log N}$ AASHTO T-11
	Plastic index by one point method	Casagrande apparatus,	$I_p = W_L - W_p$. AASHTO T-27
Specific gravity	Pycnometer method	Density Bottle	$GS = \frac{W_0}{W_{0+(W_4 - W_3)}}$ ASTM D854 (USCS)
Permeability	In-situ (Auger hole method)	Auger, Stop watches and graduated cylinder.	$K = \frac{Q.}{A..}$ ASTM D2434 (USCS)
Particle size Distribution	Mechanical analysis method	Sieves and Beaker	$C_U = \frac{D_{60}}{D_{10}}$, $C_C = \frac{D_{30}2}{(D_{60})(D_{!0})}$ ASTM D2487 (USCS)
Moisture Content	Oven – Drying method	Oven, Metal dishes, weighing balance	$Mc = \frac{M2 - M3}{M3 - M1} \times 100$. ASTM D2216 (USCS)
Dry Bulk Density	Core method	Cylindrical cutter, trowel, weighing balance, & crucible	$\rho_b = \frac{M_s}{V_b}$ ASTM D7263 (USCS)
Soil Consolidation	Fixed ring type and floating ring type consolidometer	Cylindrical mould, Spacer disc, Metal rammer, weighing balance	$Cv = \frac{k}{mv\, \gamma\, w}$ ASTM D2435 (USCS)

	method		
Shear strength	Direct shear method	Direct Shear Device, Load and deformation dial gauges	$S = C + \sigma \tan\varphi$ ASTM D3080 (USCS)

Where;

A = cross sectional area of the holes(cm). $\emptyset$ = soil's angle of internal friction; ρ_b = g/cm^3,

σ = normal stress

M_s = g

L = vertical load.

V_b = cm^3.

W_L = Liquid limit

S = shear strength;

w = water content (%) corresponding to N blows

C = cohesion;

N = Number of blows. See plate 3 below.

W_0=weight of oven-dry soil =W_2-W_1

W_1=Weight of the empty clean and dry density,

W_2=Weight of the density bottle containing the 10g of dry soil,

W3=Weight of density bottle filled with air free distilled water and soil,

W4=Weight of density bottle filled only air free distilled with water

M_1 = Mass of empty, clean can + lid (grams)

M_2 = Mass of can, lid, and moist soil (grams)

M_3 = Mass of can, lid, and dry soil (grams).

IV. RESULTS

Geotechnical Properties

Table 2 presents the summaries the field determination of the discharge (Q) and permeability constants (K) of the three sedimentary formations in Otukpo. The summary of Geotechnical Properties of the formations are in Table 3, These results are for moisture content, specific gravity, coefficient of uniformity, coefficient of curvature, coefficient of consolidation and shear strength. Summaries of the strength characteristics for shale, sandstone and limestone respectively in formation at different cell pressure of 70kN/m^2, 140kN/m^2 and 210kN/m^2, for dry bulk density (kg/m^2), moisture content (MC%) and compressive strength (kN/m^2) are presented in Tables 4.

Table 2: Permeability constants for Otukpo Sedimentary Formation

Factors	Shale Sites								Mean
	1	6	7	10	16	21	23	24	
Q(l/s)	29.23	31.39	32.89	35.01	32.95	34.91	33.12	30.41	32.48875
K(m/s)	0.29	0.31	0.33	0.35	0.33	0.35	0.33	0.30	0.32375
	Sandstone Sites								
	2	4	8	11	17	19	20	22	
Q(l/s)	49.34	50.63	51.89	55.24	52.85	54.59	53.12	52.08	52.4675
K(m/s)	0.49	0.51	0.52	0.55	0.53	0.55	0.53	0.53	0.52625
	Limestone Sites								
	3	5	9	12	13	14	15	18	
Q(l/s)	38.19	39.63	40.71	42,54	41.36	44.45	43.59	41.67	41.37143
K(m/s)	0.38	0.40	0.41	0.43	0.41	0.45	0.36	0.42	0.4075

Table 3: Geotechnical Properties of Otupko sedimentary Formation

Site	MC(%)	G_S	C_U	C_C	Cv (m^2/sec)	S (kg/m^2)
			Shale			
Mean	7.90	2.23	62.38	10.57	4.39	334.91
StdDev	±6.22412	±0.12829	±32.66276	±11.77008	±3.01011	±29.47928
			Sandstone			
Mean	4.34	2.55	19.17	3.58	4.95	218.54
StdDev	±3.65804	±0.86220	±1.97695	±2.78160	±0.02011	±54.35202
			Limestone			
Mean	9.40	2.27	28.75	4.70	4.78	485.48
StdDev	±7.244259	±0.471138	±18.45157	±4.70341	±0.03011	±112.4845

Where;

MC=Moisture content;

Gs=Specific gravity;

Cu=Coefficient of uniformity;

Cc=coefficient of curvature;

Cv=Coefficient of consolidation;

S=Shear strength

Mechanical Properties of Otukpo Sedimentary Formations

Summaries of the results of laboratory analysis for mechanical properties of shale, sandstone and limestone in Otukpo Sedimentary formations under AASHTO for liquid limits (LL%), plasticity limits (PL%), plasticity index (PI%), shrinkage limits (LS%), cohesion C (kPa) and angle of internal friction (Φ^0) are presented in Tables 5.

Table 4: Mechanical properties of Otupko Sedimentary Formation

Site	LL(%)	PL(%)	PI(%)	LS(%)	C (kPa)	$\Phi(^0)$
			Shale			
Mean	28.31	18.18	9.96	8.42	84.86	26.57
StdDev	4.16566	4.65518	4.01032	1.88775	0.70711	3.53553
			Sandstone			
Mean	27.50	19.81	7.69	9.075	109	17
StdDev	3.33809	2.63408	3.31811	1.47139	±60.5062	±4.61880
			Limestone			
Mean	26.75	19.73	13.46667	9.23	129.60	34.4
StdDev	5.20302	5.51595	5.86582	2.62556	73.14825	4.12311

Where;

LL=Liquid limits;

PL=Plastic limits;

PI=Plasticity index;

LS=shrinkage limits;

C=Cohesion

Φ=soil's angle of internal friction

V. DISCUSSION

Moisture Content Analysis

From the result presented in Tables 4, the moisture content in the Otukpo sedimentary formation is in the range of 0.5% – 22.82%, however, there were little variation ($\sigma^2 = \pm 2.6$) in the mean values of the three major sedimentary formations. Figure 1 shows that limestone is having the highest mean value of moisture content at 9.40% and Std Dev of ±7.24.

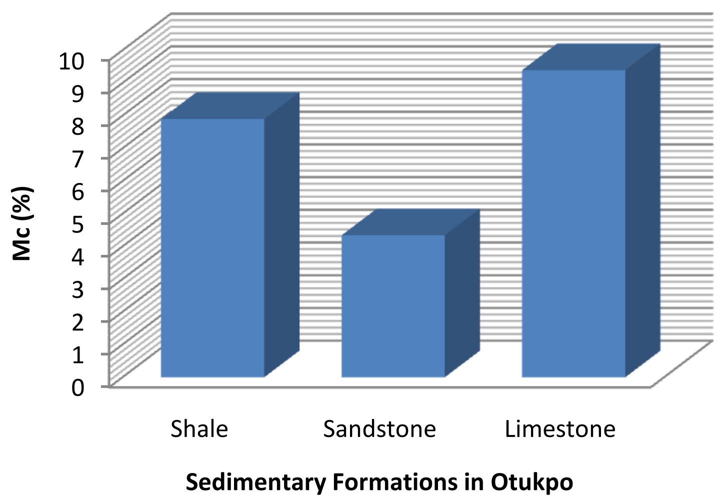


Figure 1: Plot of Mean Moisture Contents of the Sedimentary formations in Otukpo

Particle Size Analysis

The particle size analysis as presented in Tables 4, shows the mean value of the coefficient of uniformity Cu; 62.38, 19.17 and 28.75 for shale, sandstone and limestone respectively and are all above 15 which defined the soils in the sedimentary formations to be well graded. The coefficient of curvature Cc for the three formations are 10.57, 3.57 and 4.70 for shale, sandstone and limestone respectively does not show much degree of variation meaning that the entire formation are of similar soil type.

Bulk Density

The dry bulk density of the soil formations ranges from 2168kg/m3 to 2463kg/m^3 for shale, 2211kg/m^3 to 2380kg/m^3 for limestone and 2078kg/m^3 to 2393kg/m^3 for sandstone respectively and is favorable for the average range of values used as general filling and embankments.

Permeability

The results from the in-situ test of permeability obtained shows the discharge (Q) and permeability constants (K) of the three sedimentary formations in Otukpo. From the results, the permeability in the formations is within the range of 0.29m/s-0.35m/s for shale, 0.36m/s-0.45m/s for limestone and 0.49m/s-0.55m/s for sandstone respectively. The sandstone formation has the highest degree of permeability at mean value of 0.525m/s (Figure 2). However, from the average range of values (Underwood, 1967), it shows that the permeability K, results obtained is not suitable for construction materials because the permeability results obtained are unfavorable, (Table5). However, crusher dust could be used as curative treatments for the sedimentary formations.

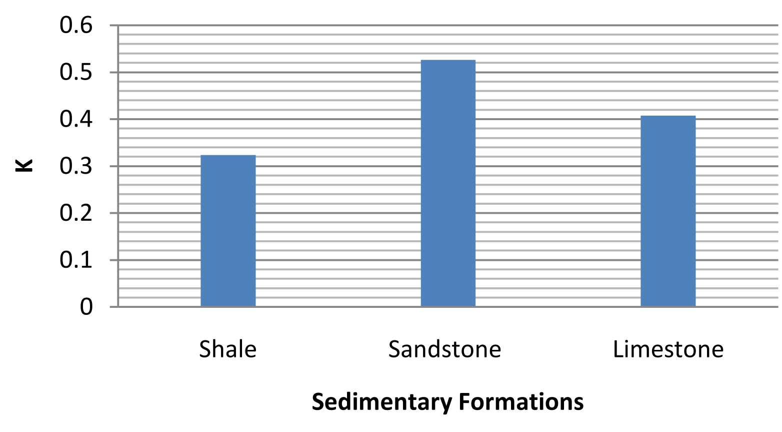
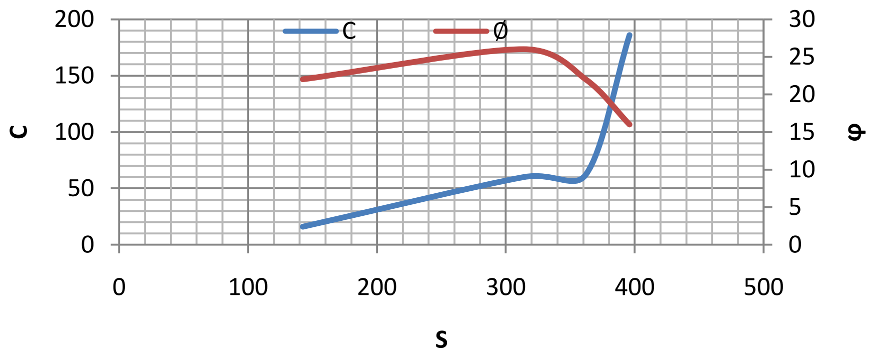
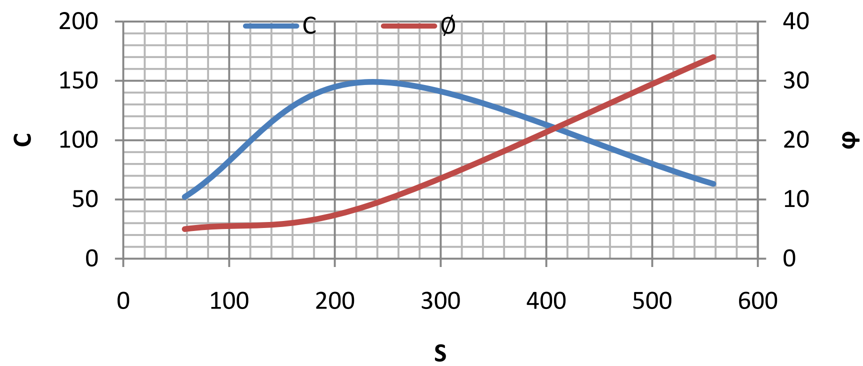


Figure 2: Plot of Mean coefficient of permeability for Sedimentary Formations in Otukpo

Cohesion reveals range from 7kPa-149kPa for shale, 16kPa-186kPa for limestone and 18kPa-155kPa for sandstone respectively, it could be said that the Otukpo sedimentary formations are partly cohesive. Angle of internal friction ranges from 5^o-34^o for shale, 16^o-26^o to limestone and 2^o-30^o for sandstone respectively(Figure 3). Comparing the result of angle of internal friction obtained with the range of values in Table 7, it is however not suitable as performing materials for construction.





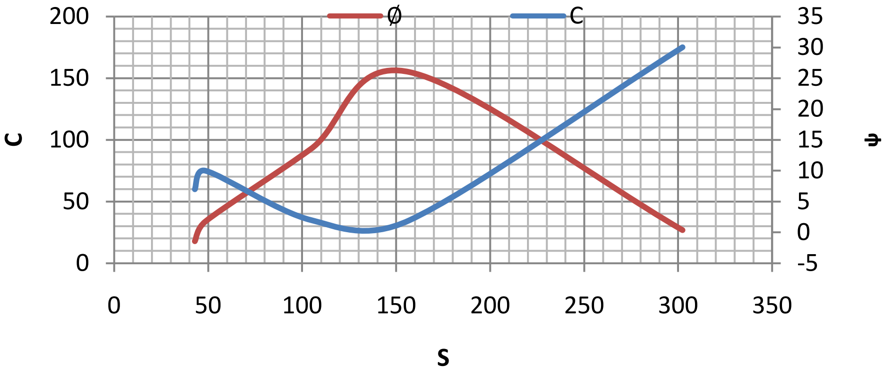


Figure 3: Plot of the Cohesion and angle of Internal Friction versus Shear strength for Shale, Sandstone and Limestone

VI. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Compressive strength and the liquid limits of the formation is suitable for general filling and embankments however it is not suitable for sub-base course and base course parameters for road construction (Table5). Declan and Paul (2003) stipulated that the liquid limit of soil liners should be less than 90 %. The determined liquid limits of the formation are all above 20 % and are less than 90 %. Thus the soils are expected to exhibit low hydraulic conductivity and are suitable base for supporting engineering projects which have been supported by findings of Kabir and Taha, (2004), they reported that soils with high liquid limit generally have low hydraulic conductivity. The Soil expansively prediction by liquid limit after (Sridharan and Prakash, 2000) is high because the average Value for LL are above 22 for the three formations. However, rice husk ash could be used as curative treatments for the sedimentary formations.

The formation is low-plastic to medium-plastic and is suitable for general filling and embankments however it is not suitable for sub-base course and base course parameters for road construction (Table5). It is suitable for general filling and embankments however not suitable for sub-base course and base course parameters for road construction. The Otukpo sedimentary formations are partly cohesive, the angle of internal friction obtained with the range of values in Table 6 is however not suitable as performing materials for construction.

The geotechnical properties of soils conducted on the samples show that the soils in the sedimentary formations are associated with fair to poor consolidation characteristics, low permeability, fair stability value for general filling and embankment materials, poor to very poor value as pavement sub-grade (when not subjected to treatment) and are not suitable as base course for pavement.

A comparison of the tests results of the Otukpo sedimentary formations with the Nigerian specification for roads and bridge construction materials points to the fact that the three formations neither satisfies all the specifications as general filling and embankment, nor all the requirements as sub-base course and base course material.

Stabilization of the three formations for use as construction materials is possible. This is because; the natural moisture content is generally low, dry bulk density values are very satisfactory for use as general fill and embankments, but most cohesion values are in the range of 20–146 kPa, and most internal friction angles are in the range of 0.2°–30° which requires stabilization.

Table 5; An Engineering evaluation of some Geotechnical Properties of Otukpo Sedimentary Formations

Laboratory Tests and In-situ Observations	**Average Range of values (Underwood, 1967)**		**Shale**	**Limestone**	**Sandstone**	**Remarks**
	Unfavorable	**Favorable**				
Moisture Content (%)	**20-35**	**5-15**	**1.37-8.08**	**2.81-18.0**	**0.59-9.82**	**Favorable**
Compressive Strength (kN/m^2)	35-700	700-10500	69-633	240-816	82-517	Unfavorable
Dry Bulk Density (Kg/m^3)	1130-1760	1760-2560	2168-2463	2211-2380	2078-2393	Favorable
Angle of Internal Friction (^{o})	10-20	35-65	5-34	16-26	2-30	Unfavorable
Permeability (cm/s)	10^{-9} to10^{-2}	10^{-2} to 10^{-}	2.9x10^{-}	3.6x10^{-}	4.9x10^{-}	Unfavorabl

		^{0}	^{3}to 3.5x10^{-3}	^{3}to 4.5x10^{-3}	^{3}to 5.5x10^{-3}	e
Coefficient of Consolidation (m^2/sec)	4.5-12.5	0.5-4.0	3.34-4.89	4.16- 4.99	4.49- 5.19	Unfavorabl e
Coefficient of uniformity (Cu)	3 - >15	<3	3.50- 104.0	2.13-55.0	5.50-40.0	Unfavorabl e
Specific gravity (Gs)	2.76-3.0	2.65-2.67	2.07-2.41	1.95-3.38	2.12- 24.65	Unfavorabl e
Plasticity Index (%)	3->17	<3	3.1-15.5	3.3-15.7	3.0-11.9	Unfavorabl e

Table: 6 Comparisons of Results with Nigerian Specification for Roads and Bridge Materials (Federal Ministry of Works 1970)

Properties of Materials	**Nigerian specification**	**Shale**	**Limestone**	**Sandstone**	**Remarks**
General filling and <u>embankments</u>					
MDD (Kg/m^2)	> 470	2316	2296	2236	
OMC (%)	< 18	3.34	9.40	7.90	Most likely to be
LL	< 40	27.50	26.75	28.31	Suitable
PI	< 20	7.69	13.47	9.96	
% Passing No. 200 (%)	≤ 35	14.39	59.00	25.14	
<u>Sub-base course</u>					
LL	< 35	27.50	26.75	28.31	Poor to marginally
PI	< 16	7.69	13.47	9.96	Suitable
AASHTO and OMC (%)	≥ 25	3.34	9.40	7.90	
<u>Base course</u>					
LL	≤ 30	27.50	26.75	28.31	
PI	≥ 13	7.69	13.47	9.96	Most likely to
AASHTO and OMC (%)	> 80	3.34	9.40	7.90	be unsuitable
% Passing No. 200 (%)	5-15	14.39	59.00	25.14	
Shear strength (kN/m^2)	>103	218.54	485.48	334.91	

Recommendations

(a) Soil expansivity characteristics of the soil types found in the sedimentary formations are adjudge to be very high from the analysis therefore it is recommended that the most suitable projects for each formation should be identified by further research.

(b) Further studies are recommended to be carried out by other researchers using soil samples from different depths (2m-5m) to check the performance evaluation of the soils as construction materials from the three major sedimentary formations of shale, sandstone and limestone respectively.

(c) The data generated and analyzed in this research is recommended to be made available by the Nigeria Geological Survey Agency for public use especially Otukpo populace.

Based on the observations and discussions, I hereby suggest the following curative treatments for the sedimentary formations:

(i) Quarry Dust can be used as stabilizing admixture for non performing soil.

(ii) Used fly ash and stone dust as curative treatments for the sedimentary formations.

(iii) Using lime for soil stabilization with optimum percentage of quarry dust.

(iv) The use of rice husk ash to stabilize non performing soil.

(v) The use of baryte powder as a soil stabilizer for expansive soil

(vi) Stabilization of Expansive soil using waste ceramic dust.

(vii) Stabilization of Expansive soil using Crusher Dust.

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