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Investigation of the Geotechnical Properties and Chemical Oxide Composition of Sub-Soils at Delta State University of Science and Technology, Ozoro, for Infrastructural Development

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Abstract

Infrastructural failures remain a major concern in developing regions due to poor soil conditions, substandard materials, and inadequate construction practices. This study investigates the geotechnical and chemical properties of subsoils at Delta State University of Science and Technology, Ozoro, Nigeria, to provide insights that can help mitigate structural failures. Soil samples from three depths (9, 12, and 15 m) at three strategic locations were analyzed using ASTM-approved methods. The findings indicate that sampling depth significantly affects soil behavior, with particle size grading classifying the soils as A-2-6 and A-2-4 (AASHTO). The chemical composition confirmed non-lateritic soil characteristics, while Atterberg limits revealed zero plasticity (PL = 0%). The subsoil's Maximum Dry Density (1.95–2.51 g/cm³), Optimum Moisture Content (10.03–13.00%), and California Bearing Ratio (11.92–19.19%) suggest moderate load-bearing capacity. The angle of internal friction (16.33°–25.33°) and cohesive strength (0.76–0.93 kN/m²) further highlight variations in the soil's stability strength. These findings are critical for foundation design and construction planning, ensuring long-term structural integrity in the region. Additionally, this study's outcomes mitigate infrastructural failures problems, and provide a framework for safe and sustainable high-rise buildings and pavement construction.

1. Introduction

The engineering properties of the soil are fundamental to the design, construction, and installation of engineering-based Infrastructures. These properties influence the patterns that the soil will interact with foundations, retaining walls, pavements, and other structural components; thus, influencing their stability, durability, and safety [1]. Some of the vital soil engineering properties that influence the suitability of soils as foundation and road pavement material, are its California Bearing Ratio (CBR), shear strength, compressibility, permeability, and consolidation. They assist in evaluating the soil's load-bearing capacity and moisture retention behaviors, both of which are crucial for guaranteeing the durability and integrity of engineering projects [2, 3]. As stated by Drusa [4], a thorough comprehension of soil geotechnical properties enables engineers to make accurate decisions on foundation design, earthwork operations, and materials selection. Geotechnical properties and chemical oxides composition of sub-soils are essential criteria, which directly influence the utilization of these soils for construction purposes. According to Verma [5] failure to account for soil properties can lead to structural failures, resulting from excessive soil settlement, slope failures, and binding failures, leading to dangerous and costly consequences. Higher CBR levels typically indicate that soil is more resistant to deformation when subjected to load, which is crucial for preserving the integrity of roads, runways, and building foundations. In contrast, soils with poor CBR values may need stabilization or reinforcement to fulfill the required strength standards for engineering projects, thereby ensuring long-term performance and durability [6]. Shear strength is a key geotechnical property that plays a fundamental part in preventing foundation failures, landslides, and building collapses [7, 8]. Understanding shear strength is vital for designing structures that reduce the risk of slope instability, excessive settlement, and structural failure [2, 9]. Soil permeability plays an important part in maintaining the stability of foundations and the longevity of pavements. Soils that have a high permeability rate necessitate extra drainage monitoring solutions, whereas soils with lower permeability often face issues related to water accumulation [5, 10]. Soil geotechnical properties are substantially dependent by some key factors, including soil type, moisture content, stress conditions, chemical composition, vegetation type, soil depth, and climatic conditions [7, 11]. The behavior of soil under load has a strong correlation with its stress conditions, which vary depending on the pressure exerted on the soil [12]. Stress distribution varies with soil depth, with deeper strata experiencing higher stresses, resulting from the mass of the overlying soil strata. These stress conditions are critical in predicting the soil's load-bearing capacity, shear strength, and consolidation behavior [13, 14]. Soil types—such as clay, sand, and gravel—greatly influence geotechnical properties. Fine-grained soils, such as clay and silt, have a tendency to exhibit lower CBR, shear strength, and compaction values compared to coarser soils like sand or gravel; however, fine-grained soils typically exhibit a higher permeability rate. Fine-grained soils often have weaker load-bearing capacity and can be more susceptible to deformation under load [15, 16].

Delta State University of Science and Technology (DSUST) is situated in Ozoro in Delta state, in the Niger delta area of Nigeria. Geologically, the soil located in this region is basically the alluvial type, characterized by high organic matter content and low poor load carrying capacity [17-18]. These conditions along with the various soil characterizations presented, presents various degrees of structural and settlement implications for buildings, civil engineering infrastructure and other related infrastructural facilities. Ozoro terrain, like most Niger Delta communities is generally flat, low-lying, gently sloping, and prone to seasonal flooding. The campus area however consists of slightly depressed expanses occupying about a third of the campuses current habitation, which constitutes some of the lowest portions of the Ozoro environ, into which vast amounts of the region’s runoff collects [36]. Resulting for inadequate knowledge of the region’s soils geotechnical properties and building designs, cases of structural failures are prevalent in the Niger Delta region, especially within the Ozoro community. Generalization of local soil conditions from the regional characteristics often restricted to major cities, may generally suffice for some areas on the campus, they however proved inadequate with respect to certain medium rise building (with foundations at depths in excess of 3m), situated within the vast localized depression within the institution, as settlement cracks developed, consequent from local soil instabilities relating to depth and soil properties within the recently built up superficial deposits contained therein [39]. Several researchers have determined the geotechnical properties of the subsoils, with the basic aim of foundation design for the specific regions [7, 13, 14, 16, 17]. While previous studies have investigated the geotechnical properties of sub-soil samples, there is a notable absence of documented literatures on the spatial variability of geotechnical properties and chemical oxides composition of the sub-soils located with the University community of Delta State University of science and Technology (DSUST) Ozoro, Nigeria. Consequently, this research focuses on evaluating the geotechnical properties and chemical oxides composition of sub soils found within the DSUST premises. Essentially, the findings of this study will offer essential information for designing suitable foundations for buildings within the school community and for evaluating the potential utilization of the soil in rigid and flexible pavement construction. Additionally, the information obtained will also provide effective chemical characterization of the underlying soils (oxide compositions), thereby supporting the design, construction, and maintenance of structural works.

2.0 Materials and Method

2.1 Study Area Description

The research was conducted at DSUST, with total landmass of about 4 km^2 (400 hectares), and situated within the tropical rain forest community of Nigeria (Figure 1). The university community geographical coordinates are 5.549°N to 5.570°N latitude and 6.241°E to 6.249°E longitude. The university's landmass, which includes both developed and undeveloped areas, faces seasonal flooding in about 20% of its total area. This vulnerability to flooding can affect infrastructure development, land use planning, and environmental management strategies within the campus. The undeveloped portion of the university has both thick and light vegetation, reflecting the diversity of plant life in the area, and the soil is predominantly alluvial [18]. Due to the upgrading of the school from polytechnic to university in 2021, there is upsurge in infrastructural development, mostly in the undeveloped region of the school.

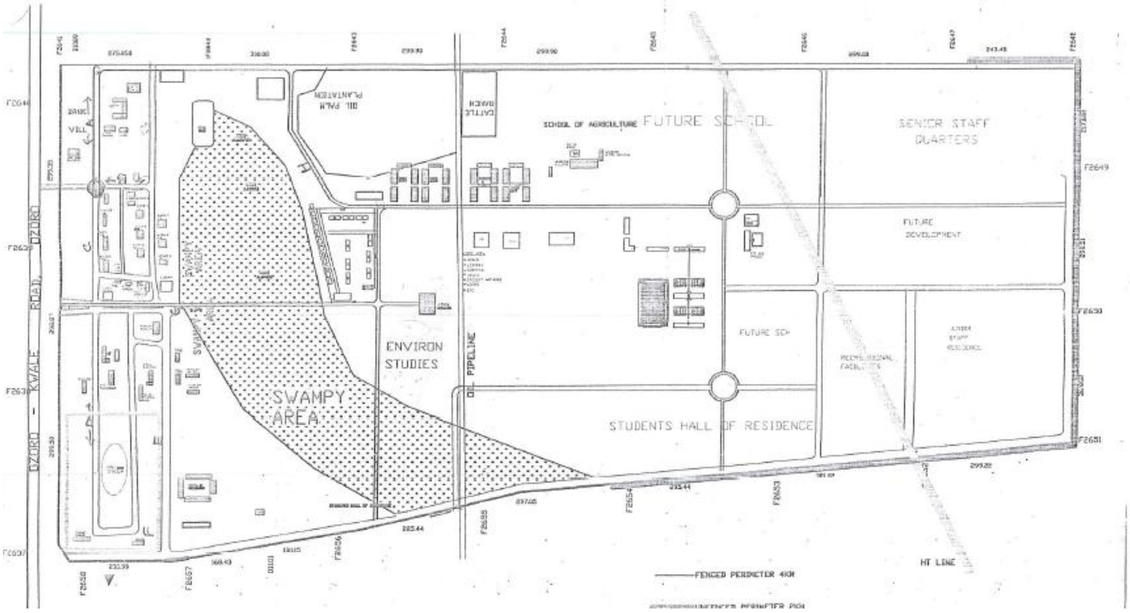


Figure I: The university layout map [18]

DSUST is situated in Ozoro in Delta state, in the Niger delta area of Nigeria. Geologically, it is located within the Niger Delta (Miocene-Recent) geological and startological formation of the southern part of Nigeria, which borders the Atlantic Ocean. The Niger Delta geological formation consists of sedimentary rocks overlain by superficial soils deposits of highly differing engineering properties. These properties characterized into four broad groups basically based on their geomorphology, geology, geotechnical properties, and drainage conditions, viz: sandy loamy soils with reddish brown hue and of low of medium plasticity; sandy clays, with a brown hue, with medium to high plasticity [1, 36].

2.2 Soil Sampling

For this research, three strategic points within the undeveloped region of the school were selected. These areas have been identified as having potential for future high rising building development, and other construction activities, due to the rapid infrastructural development of the school. These points were chosen to assess the soil's suitability for supporting structural foundations, and for pavement and embankment construction. At each sampling point, subsoil samples were collected at three depths—6 m, 12 m, and 15 m—using a soil auger, typically employed for manual water borehole drilling (Figure 2). This approach (sampling depths) of this current study was adopted based on references in existing literature [18,37-38], which showed information dearth on the geotechnical properties of DSUST sub soil. Therefore, these sampling depths were chosen to ensure that the geotechnical properties of the soil profile are well represented, which is critical for construction planning. The sub-soil specimens sampled were carefully transferred into black sacks, each coded according to the sampling location, and then transported to the laboratory for further geotechnical, chemical and microstructural analyses.

Figure 2: sub-soil sampling operation

2.3 Laboratory analysis

2.3.1 SEM Analysis

The SEM analysis of each soil sample was conducted by employing the service of a scanning electron microscope (model JEOL JSM-7600F). The analysis was performed at a voltage of 20 kV and a magnification of 10,000, allowing for detailed observation of the soil's microstructure and surface characteristics [19].

2.3.2 Chemical Oxides Composition

The chemical oxides content of the samples were chemically evaluated in harmony with ASTM procedures. The Thermo Scientific X-ray Fluorescence (XRF) Epsilon Spectrometer was used for the operation [20]. Evaluating the chemical composition of sub-soil, particularly the presence of various oxides, provides insight into its geotechnical behavior and stability. The silica/sesquioxides (S/R) ratio presented in Equation 1 was used to categorize the soil into various soil grade [21].

$$S/R = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \tag{1}$$

Interpretation of the S/R ratios:
The soil is considered laterite if $S/R \leq 1.33$
The soil is considered lateritic if $1.33 \leq S/R \leq 2$
The soil is considered non-lateritic if $S/R > 2$ [21].

2.3.3 Geotechnical Properties Analyses

All the geotechnical evaluations were conducted in consistence with approved ASTM International standards, ensuring all geotechnical evaluations were consistent with international standards. The samples particle size grading (sieve analysis) test was conducted in accordance with ASTM D6913 procedures [22], while the soil moisture content was determined gravimetrically per ASTM D2216 [24] recommended procedures.

Additionally, the samples consistency limits test was done in agreement with ASTM D4318 procedures [25], and the California Bearing Ratio (CBR) test was conducted following ASTM D1883 guidelines [26]. The compaction characteristics (MDD and OMC) of the soil were measured by using the Proctor compaction test technique, in accordance with the ASTM D698-12 approved standard [27]. Also, the consolidation and direct shear box tests were also performed in compliance with approved ASTM [28, 29] guidelines

2.4 Data Analysis

The laboratory test results were statistically analyzed, by employing the SPSS statistical software (version 20.0). An analysis of variance (ANOVA) was conducted to assess the impact of sampling location and depth on the geotechnical properties. Subsequently, "means" were differentiated by using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

3.0 Results and Discussion

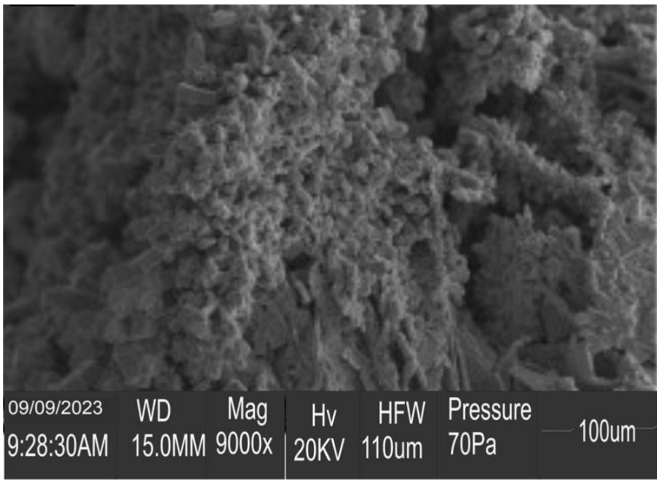
3.1 Chemical Oxide Composition and Microstructural Pattern

The results SEM and chemical oxide composition of the sub-soil samples are shown in Table 1 and Figure 3. SEM results have the ability of providing detailed soil particles microstructural images; thereby, enabling better understanding of the soil's grains morphology, and textural pattern. The SEM results revealed that the soil specimens obtained at a depth of 15 m were notably more granular and porous compared to those sampled at 9 m depths. This indicates that soil depth will influence the soil's load-bearing capacity and permeability. Scanning electron microscopy result contributes immensely to better understanding of soil geotechnical properties, as there is a perfect correlation between soil microstructure pattern, and the macroscopic behavior [40, 41]. This pictorial view of the soils will enable structural engineers to forecast soil stability under stress; hence, facilitating the design stable foundations, and minimizing the occurrence of structural failures. According to Kafle [16], granular soils tend to exhibit a higher capacity to withstand vertical loads, resulting in higher CBR and shear strength values compared to fine-grained soils. This makes them more suitable for use in foundations and road pavements. Based on the S/R ratio classification, the soil can be categorized as non-lateritic soil (S/R values were greater than 2), regardless of the sampling location [21]. This classification highlights the predominantly sandy nature of the subsoil samples.

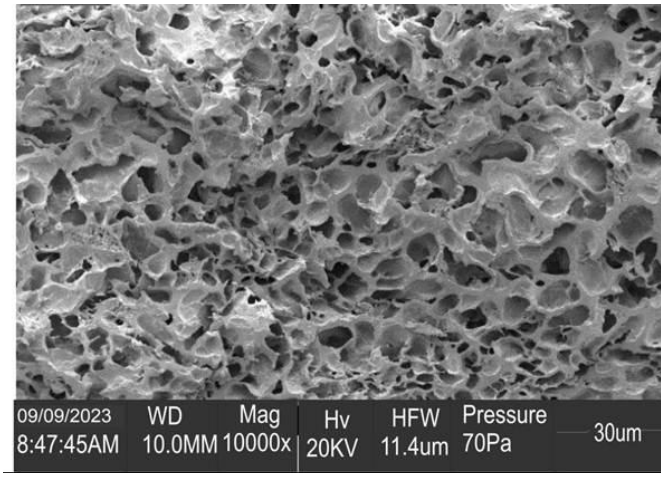
Furthermore, the analysis of the soil's chemical oxide composition revealed that SiO_2 (silicon dioxide), Al_2O_3 (aluminum oxide), P_2O_5 (phosphorus pentoxide), and Fe_2O_3 (iron oxide) were the most predominant oxides, regardless of the sampling location or depth (Table 1). The chemical oxide content of the soil significantly influences its geotechnical properties and overall structural integrity [30]. The higher SiO_2 percentage and lower Al_2O_3 percentage indicates that the soil is rich in quartz and other silicate minerals but deficient in clay minerals, further confirming its low cohesion and plasticity index [17]. Quartz, silicate, and clay minerals significantly influence the soil's cohesion and plasticity potential. Quartz and other silicate minerals have minimal impact on cohesion and plasticity, whereas clay minerals are the major contributors to these properties [31]. The presence of quartz, mainly consisting of silicon dioxide (SiO_2), contributes largely to reduced plasticity, shrinkage and refractoriness of clay minerals; hence, higher SiO_2 quantities in soil samples, results in reduced cohesion of soils [32]. Some predominant soil oxides such as silica, alumina, iron oxides and lime can substantially affect soil's geotechnical parameters. They contribute immensely to soil shear strength and compaction through binding ability of the soil particles. $CaCO_3$ and other pozzolanic oxides have the potential of enhancing soil strength and workability. Chemical oxides properties determine soil's appropriateness for constructional purposes, under different environmental conditions [43].

Table 1: Chemical oxide composition of the soil samples **(ppm)**

Oxide	**Location A**			**Location B**			**Location C**		
	9 m	**12 m**	**15 m**	**9 m**	**12 m**	**15 m**	**9 m**	**12 m**	**15m**
Na_2O	0.027	0.321	0.081	0.077	0.061	0.164	0.045	1.001	0.093
MgO	0.782	4.313	0.890	0.638	0.415	0.182	5.015	0.698	0.339
Al_2O_3	11.009	12.271	10.941	13.412	17.136	15.023	13.193	15.372	14.714
SiO_2	58.821	56.214	63.831	50.127	55.642	58.611	54.965	59.142	60.182
P_2O_5	6.742	8.012	9.192	9.113	5.275	10.093	4.442	10.213	10.239
SO_3	0.442	0.178	1.211	0.391	1.045	1.814	0.195	0.739	1.006
Cl	0.002	0.092	0.002	0.001	0.042	0.009	0.043	0.104	0.026
K_2O	0.019	0	0.057	0.132	0.044	0.088	0	0	0.066
CaO	0.072	0.012	0	0.101	0	0.017	0.01	0	0.023
TiO_2	1.412	0.604	0.078	2.143	0.109	0.101	0.196	0.047	0.048
Cr_2O_3	0.055	0	0	0.101	0.015	0	0	0.015	0.069
Mn_2O_3	0.011	0.014	0.056	0.018	0.029	0.072	0.003	0.003	0.072
Fe_2O_3	8.101	8.987	9.094	10.629	9.805	11.012	8.123	7.341	7.082
ZnO	0.017	0.012	0.003	0.071	0	0.067	0	0.006	0.002
SrO	0.102	0	0.008	0.064	0	0.019	0.002	0	0.013
S/R	**3.07**	**2.64**	**3.19**	**2.08**	**2.06**	**2.25**	**2.58**	**2.52**	**2.76**



At 9 m depth



At 15 m depth

Figure 3: The SEM pictures of the soil specimens

3.2 Particle Size Grading

Table 2 presents the results of the particle size grading of the soil samples. Table 2 (the results) shows that the fine content of the soil varied between the sampling points and depths, with soil samples collected at 9 m depths containing a higher fines content compared to those collected at a depth of 15 m. Also, the results highlight that the various sub-soil samples had zero percent gravel content across all sampling locations. Adopting the guidelines of the American Association of State Highway and Transportation Officials (AASHTO) classification system, the soil sampled between 9 and 12 m primarily falls under the A-2-6 category, indicating a mixture of silty or clayey sands. In contrast, apart from Sampling Point B, the soil sampled at 15 m mainly belongs to the A-2-4 category, which is characterized by more granular materials (as confirmed by Figure 3). Additionally, the unified soil classification system (USCS) confirms that the soil samples were well-graded sand, with a consistent distribution of particle sizes. USCS states that sand can be considered Well Graded (SW) when $Cu \geq 6$) and fines < 5%. The findings indicate that the sub-soils, regardless of spatial location and depth, are suitable as borrowed materials for solid and malleable road pavement construction. Notably, the Federal Ministry of Works and Housing (FMWH) recommended that soils intended for subgrade, subbase, and base course materials should have fines content of lower than 35% [33], a criterion met by all the samples analyzed in this research.

Table 2: Particle size grading system based on USCS and AASHTO

Point	Depth (m)	Grain Size Range (%)			Cc	C_u	Grading	
		Gravel	Sand	Fines			AASHTO	USCS
A	9	0	96.8	3.2	0.80	7.00	A-2-6	SW
	12	0	97.2	2.8	0.94	7.08	A-2-6	SW
	15	0	97.8	2.2	0.85	6.69	A-2-4	SW
B	9	0	96.4	3.6	1.04	6.02	A-2-6	SW
	12	0	97.0	3.0	0.68	6.23	A-2-6	SW
	15	0	98.2	1.8	0.81	6.15	A-2-6	SW
C	9	0	97.0	3.0	0.67	7.17	A-2-6	SW
	12	0	98.0	2.0	0.07	6.23	A-2-6	SW
	15	0	98.4	1.6	1.04	6.36	A-2-4	SW

Cc = Coefficient of curvature; Cu = Coefficient of Uniformity (ASTM D2487); SW = well graded sand

3.3. Geotechnical Properties

The geotechnical properties of the sub-soils are presented in Tables 3 and 4. These results, discussed in the various sub-sections, highlight factors such as soil strength, bearing capacity, and consolidation characteristics, which are essential in assessing the stability and load-bearing potential of the soil within the university premises.

Table 3: The Atterberg limit, compaction and soaked CBR results of the soil samples

Location	Depth (m)	LL (%)	PL (%)	PI (%)	MDD (g/cm^3)	OMC (%)	Soaked CBR (%)
A	9	$16.5^c \pm 1.13$	0	$16.5^c \pm 1.13$	$2.25^a \pm 0.02$	$11.30^b \pm 0.26$	$14.29^a \pm 0.59$
	12	$14.5^b \pm 0.94$	0	$14.5^b \pm 0.94$	$2.40^b \pm 0.02$	$10.50^a \pm 0.10$	$16.87^b \pm 0.97$
	15	$10.0^a \pm 1.02$	0	$10.0^a \pm 1.02$	$2.51^c \pm 0.03$	$10.03^a \pm 0.15$	$19.19^c \pm 0.44$
B	9	20.0c±2.12	0	20.0c±2.12	$1.95^d \pm 0.03$	$13.00^b \pm 0.10$	$11.92^a \pm 0.63$
	12	$17.0^b \pm 0.62$	0	$17.0^b \pm 0.62$	$1.97^e \pm 0.02$	$11.20^a \pm 0.11$	$14.37^b \pm 0.86$
	15	$13.5^a \pm 0.44$	0	$13.5^a \pm 0.44$	$2.21^f \pm 0.04$	$10.87^a \pm 0.06$	$17.49^c \pm 1.02$
C	9	$15.0^c \pm 0.61$	0	$15.0^c \pm 0.61$	$2.15^g \pm 0.02$	$12.03^b \pm 0.04$	$13.78^a \pm 0.63$
	12	$13.5^b \pm 1.17$	0	$13.5^b \pm 1.17$	$2.23^h \pm 0.02$	$11.73^b \pm 0.06$	$15.97^b \pm 0.44$
	15	$9.5^a \pm 0.02$	0	$9.5^a \pm 0.02$	$2.31^i \pm 0.04$	$10.53^a \pm 0.07$	$18.95^c \pm 0.85$

LL = liquid limit, PL = plastic limit, PI = plasticity index, Replication = 3, Mean ± standard deviation, columns with the same common letter for each particular soil depth indicates that means are not significantly differ at p ≤0.05 using DMRT.

Table 4: Consolidation and shear box tests results

Location	Depth (m)	Consolidation			Shear strength	
		Cv (m^2/yr)	Mv (kN/m^2)	TS (mm)	C (kN/m^2)	Ø°
A	9	184.33±7.57	0.0028±0.001	$1.19^a \pm 0.06$	$0.82^b \pm 0.02$	$18.67^b \pm 1.53$
	12	256.67±6.66	0.0014±0.001	$0.97^b \pm 0.04$	$0.78^a \pm 0.01$	$22.67^d \pm 1.53$
	15	306.00±6.00	0.0008±0.001	$0.85^c \pm 0.04$	$0.76^a \pm 0.02$	$25.33^e \pm 1.53$
B	9	139.67±15.70	0.0052±0.001	$1.50^d \pm 0.13$	$0.93^e \pm 0.02$	$16.33^a \pm 1.15$
	12	218.33±5.86	0.0032±0.001	$1.17^e \pm 0.07$	$0.87^d \pm 0.02$	$20.33^c \pm 0.58$
	15	261.67±16.44	0.0019±0.001	$0.97^b \pm 0.04$	$0.82^b \pm 0.01$	$22.00^d \pm 1.00$
C	9	169.00±16.70	0.0049±0.001	$1.24^a \pm 0.03$	$0.86^d \pm 0.02$	$18.33^b \pm 0.58$
	12	244.33±3.51	0.0024±0.001	$1.03^b \pm 0.02$	$0.84^c \pm 0.01$	$20.33^c \pm 0.58$
	15	279.67±16.56	0.0013±0.000	$0.91^c \pm 0.02$	$0.81^b \pm 0.02$	$23.00^d \pm 2.00$

Replication = 3, Mean ± standard deviation, Cv = Coefficient of consolidation, Mv = Volume compressibility, TS = Total settlement, C = Cohesive strength, Ø° = Angle of internal friction, columns with the same common letter for each particular soil depth indicates that means are not significantly differ at p ≤0.05 using DMRT.

3.3.1 Atterberg limit

The consistency limits results shown that spatial point and depth had significant impact on the sub-soil liquid limit (LL) values (p ≤0.05). At a 9 m depth, the liquid limit (LL) values for the soil samples sampled from Locations A, B, and C were 16.5, 20.0, and 15.0%, respectively; while at a 12 m depth, the LL values recorded for Points A, B, and C were 14.5, 17.0, and 13.5%, respectively. Also, at a 15 m depth, the LL values for Points A, B, and C were 10.0, 13.5, and 9.5%, respectively. Notably, all soil samples exhibited zero plastic limit (PL) values, indicating zero plasticity, portraying that the soils are non-cohesive, and have high resistance to deformation under load.

The non-cohesive nature of the soil, as indicated by its zero plasticity, suggests that any structures built on it will have a reduced risk of excessive deformation, such as settlement or tilting. Consistency limits provide valuable insights into a soil's strength, stability, and state of consolidation; hence, they are vital for several civil engineering tasks such as: foundation, pavement and building designs [3]. According to references and recommendations by International regulatory bodies' recommendations, the subsoil in the area regardless of the sampling point and depth are suitable material for pavement construction. FMWH has established specific Plasticity Index (PI) criteria for soils used in pavement design; sub-grade, Sub-base and Base course soils must have PI values not exceeding 20, 16 and 13%, respectively [33]. These PI standards help to ensure that the soils possess adequate stability and strength to support traffic loads without undergoing excessive failure.

3.3.2 Soaked California Bearing Ratio (CBR)

Table 3 further depicted that the school community subsoil soaked CBR values ranged from 11.92 to 19.19%, and that these values tend to increase with depth in the soil profile. This increase in CBR values could be attributed to improved compaction and soil stabilization occurring at greater depths. Soils with a higher CBR value tend to have a better load-bearing capacity, making them more suitable for supporting foundations and road pavements (subgrades). The CBR is an essential metric for assessing soil strength and stability, reflecting its ability to resist pressure and support structural loads. Consequently, soils with higher CBR values can be constructed with thinner pavement layers while still ensuring optimal performance, ultimately reducing material costs in road construction [6]. Based on FMWH guidelines, the CBR values of the subsoil depicted that the soils can be effectually used as a sub-grade material for road construction purposes. FMWH establishes specific criteria for different layers of road infrastructure, with a soaked California Bearing Ratio (CBR) requirement of at least 5% for sub-grade materials [33].

3.3.3 Compaction Characteristics

Remarkably, the MDD and OMC results showed considerable variation throughout the region, with the MDD values for soils collected at a depth of 9 m being significantly lower than those taken from a depth of 15 m (Table 3). Notably, the subsoil MDD varied from 1.95 to 2.51 g/cm^3, and the OMC varied from 10.03 to 13.00%. The lower OMC values and higher MDD values, recorded in this research, indicate that the subsoil samples contain a lower proportion of silty-clay. This composition is favorable for road and foundation construction because soils with high compaction exhibit increased shear strength and reduced permeability [2, 34]. Generally, Location B soil samples had the lowest MDD values among the three sampling points. This result indicates that the soil at location B requires additional compaction to bring it to par before it can be deemed of suitable equivalent for construction of similar infrastructure projects. Adequate compaction is critical in pavement construction and backfilling to ensure the structural integrity of the construction over time [35].

3.3.4 Consolidation

The consolidation results reveal significant variations in the coefficient of consolidation (Cv), volume compressibility (Mv), and total settlement values across the area under investigation in this research. It was noted that the Cv, Mv and total settlement ranged from 139.67 to 306.00 m^2/yr, 0.0008 to 0.0052 kN/m^2, and 0.85 to 1.50 mm, respectively. Generally, the soils sampled from the 15 m depth exhibited the higher Cv, but the lower Mv and total settlement. This can be linked to the higher proportion of coarse-grained particles present at the 15 m depth mark, as compared to the soils sampled at 9 m and 12 m depths. Coarse-grained soils tend to have a greater Cv, because they dissipate water more quickly when subjected to loading, a result of their higher permeability [23]. According to Vincen [3], having adequate knowledge of a soil's consolidation behavior is essential for accurately forecasting settlement rates. This understanding plays a critical role in enhancing the stability and durability of structures developed on such soils.

3.3.5 Shear Strength

Table 4 shows that at spatial points A, B and C, the Ø ranged from 18.67 to 25.33^o, 16.33 to 22.00^o, and 18.33 to 23.00^o, respectively; while the cohesive strength ranged from 0.76 to 0.82 kN/m^2, 0.82 to 0.93 kN/m^2, and 0.81 to 0.86 kN/m^2, respectively. The results further revealed that the Ø values increased significantly with soil depth; conversely, the cohesive strength declined as soil depth increased. This indicates that the deeper soils exhibit better frictional resistance, which is likely due to a reduction in finer particles that typically contribute to soil cohesion [16]. This study's findings highlighted that the soils at 12 and 15 m depth are less cohesive, and are more suitable for foundations and other infrastructures that required greater frictional support. This is due to the high load-bearing capacity of the soils at greater depths. The lower angle of internal friction of the soils sampled at 9 m, compared to those collected at 12 m and 15 m, could be linked to the relatively higher proportion of fine particles present in the soils at that depth. Ironically, the soils obtained from the study area at the depth of 9 to 15 m are not suitable for construction of homogeneous earth dams, impervious embankments and related drainage control solutions, due to their poor (low) cohesive strength values and their coarse-grained structure which result in high permeability rates. Shear strength, a combined effect of cohesive strength and strength induced by internal friction between coarse-grained materials, is critical for determining the soil's ability to support loads without experiencing shear failure or excessive deformation. It directly affects the design of foundations and the stability of slopes [9].

3.4 Comparison of this study's results with previous author's findings

Table 5 presents the university community subsoils geotechnical properties, alongside results from other researchers for comparison. It was also noted that the mean LL and PL values of the campus subsoils were less than that the values recorded these authors [2, 7, 8, 13, 14, 21, 43-44]. Additionally, the MDD values of the analyzed soil samples were higher than those found in Refs [2, 8, 13, 21, 43, 44], but the mean OMC value of the studied subsoils was found to be higher than the value documented by Onana [21]. Furthermore, it was observed from the findings that the mean soaked CBR value of the subsoils was considerably lower than the findings of Refs [8, 21, 43-44], but greater than the results documented by Muhammad [13]. Regarding the cohesion and angle of internal friction, the campus subsoils had mean cohesion value that was noticeably lower than the outcomes documented by these authors [7, 8, 13, 14, 43]; while the mean Ø value of the evaluated soil specimens was larger than those reported by [13, 43], but smaller than the values documented by [7, 8, 14]. The variations in the geotechnical properties of the university premises subsoils, compared to other studies can be attributed to variations in the sampling depth, soil age, laboratory inaccuracies, the number of samples collected, the numbers of replication, prevailing climatic conditions and other anthropogenic factors. Anthropogenic factors and climatic conditions greatly affect soils geotechnical properties [2, 38].

Table 5: Comparison of the campus subsoil geotechnical properties with other authors

Location	LL (%)	PL (%)	MDD (kg/m^3)	OMC (%)	CBR** (%)	C (kN/m^2)	Ø°	Reference
Ozoro	14.38*	0*	2.22*	11.24*	15.87*	0.83	20.78	My study
Ebonyi - Nigeria	34.00	23.00	1.85	13.30	47.89	13.70	16	[43]
Bayelsa - Nigeria	80.40	37.30	NA	NA	NA	20	32	[7]
Abuja- Nigeria	50.00	30.00	NA	NA	NA	21.95	35.6	[14]
Cameroon	75.10	28.40	2.07	11.19	42.00	NA	NA	[21]
Kaduna - Nigeria	22.50	11.70	1.83	12.92	22.65	NA	NA	[44]
Ethiopia	41.6	16.45	1.49	19.66	76.33	18.81	33.19	[8]
Borno - Nigeria,	38.00	16.00	1.37	NA	10	20	13	[13]
Ekiti – Nigeria	49	22	1.61	24.60	6	NA	NA	[2]

* = mean value from the three depths and three locations; ** = soaked CBR; C = Cohesion, strength, Ø = internal friction, NA = Not available

3.5 Engineering Implications of the Findings

The appreciable geotechnical properties of the sub soils - high shear strength, CBR, compaction characteristics and non-cohesive nature of the soil, are critical factors, which directly influenced foundations design and integrity, pavements performance, and other engineering structures. The shear strength and CBR tests outcome depicted that the sub soils, especially those found between 12 and 15 m, have appreciable load bearing capacity. Therefore, these soils are suitable for pavement and foundation design and construction without the need for stabilization. Additionally, the non-cohesive nature of the soils revealed that the soils are not expansive; hence, minimizing the risks associated with pavement and foundation failures. These findings highlighted that the sub soils within the campus community can support high-rise buildings and roads pavement, provided that such structures are properly designed, using the data obtained from this current research.

4.0 Conclusion

This research concentrated on the geotechnical and chemical characteristics of sub-soils at Delta State University of Science and Technology in Ozoro, Nigeria, aiming to offer insights that could help prevent structural failures. The chemical oxide composition, microstructural pattern and geotechnical parameters of sub-soil samples, collected at various depths and locations within the university community were assessed following ASTM International-approved procedures. The findings indicated that both the depth and location of sampling significantly influenced the chemical and geotechnical properties of the soil. The analysis of the chemical composition indicated that the sub-soil is classified as part of the non-lateritic soil group. Additionally, the geotechnical properties' results revealed that sub-soils at depths between 9 and 15m exhibit an appreciable load-bearing capacity. This is supported by the favorable values of shear strength, California Bearing Ratio (CBR), Maximum Dry Density (MDD) and consolidation recorded from the laboratory tests. It was also observed that with increasing depths, sub-soils demonstrated improved (higher) load-bearing capacity and faster consolidation rates, attributed to a progressively higher presence of coarse-grained particles. This study's outcomes will significantly influence the development of high-rise structures within the university community. Additionally, the subsoils, especially those found at 15 m depth, can be effectively utilized for road construction, helping to reduce both construction costs and carbon emissions, associated with transporting load-bearing soils to the campus, and soil compaction machinery used during road construction. Conclusively, by analyzing key geotechnical and chemical properties, this study provides crucial insights into the potential behavior of the subsoil that will support the infrastructural design and development within the area, resulting in the long-term stability and durability of infrastructures in the region.

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