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SPATIAL VARIABILITY OF THE GEOTECHNICAL PROPERTIES OF SOILS: A CASE STUDY OF ELIZADE UNIVERSITY

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ABSTRACT

Soil variability can alter the mechanical behaviour of foundations. It is therefore, necessary to conduct site investigations specific geotechnical analysis before any construction. This study evaluated selected engineering index and properties of soils at three different locations (sites) and depths withing Elizade University (EU), Ilara-Mokin. Five soil samples were collected from each of these locations and their engineering index and properties were determined. Statistical analysis namely Analysis of Variance (ANOVA) was utilised to determine the effects of location within the campus on the selected engineering properties. The mean and standard deviation (SD) of the engineering properties of soils collected within each site were also determined. The study revealed that plastic index (P_i), liquid limit (L_L), moisture content (M_c), and plastic limit (P_l) were in the range of 4 to 32, 38 to 58.5, 11.6 to 29.04 %, 20 to 42 and respectively. The engineering index of the soil and engineering properties of the soil were significantly affected by the location with $F_{14,42}$ equal to 2.592212, p was 0.008673 and $F_{14,\ 42}$ equal to 3.210318 and p was 0.001719, respectively (which are less than 0.05). The high SD also showed that the soil properties have a wide range of values within same site, this was particularly so, in the case of the Atterberg's limits, shear strength parameters and bearing capacities. The concluded that there is variability in the soil properties within the location.

Keywords: Bearing Capacity, Soil, Foundation Footings, Geotechnical Engineering Properties

INTRODUCTION

Soil is essential to both man and plant in various ways, especially for food, clothing, shelter, medicine and ecosystem services. The composition of soil is in terms of mineral particles, organic matter, water and air determines its properties. The properties of soil can be in the form of its texture, structure, porosity, chemistry, colour (Oyetola and Philip, 2014), behaviour of soil in the presence of water (consistency limits), behaviour of soil under load (compressibility) and load-carrying capacity (bearing capacity) among others are essential. Engineering properties of these soils are of utmost importance to structural and geotechnical engineers whose focus is to prevent failures of any structure coming on the soil. Soil engineering properties comprise physical and index properties, while strength parameters include shear strength and bearing capacities, modulus parameters, consolidation properties, dynamic behaviour and permeability characteristics (Tbatou et al., 2014; Oyetola and Philip, 2014). Literature such as Ngah and Nwankwoala (2013); Nwankwoala and Amadi (2013); Nwankwoala and Warmate (2014); Ofem et al. (2017); Oghenero et al.(2014); Ojetade et al. (2016); Ojetade et al. (2022); Olusola et al. (2023); Oyediran and Durojaiye (2011); Roy (2016); Roy and Bhalla (2017), and Yardım and Mustafaraj (2015) stated the importance engineering properties and index in stability of civil structures and other infrastructures against settlement and cracks. Engineering properties of any soil affect the stability of soil, which also affects the stability and performance of any civil engineering structure erected upon it (Tbatou et al., 2014). Engineering properties of any soil determine its suitability for a particular construction purpose and should not be assumed by visual inspection or assumption that the soil is in the same vicinity (Oyetola and Philip, 2014).

The engineering properties of soil differ from one point to another showing soil heterogeneous nature. Adequate engineering data or properties of an area prior to design and construction can serve as a preventive measure against construction failure as well as a remedial measure to impending ones (Oyetola and Philip, 2014). Past and recent records show that building and construction failures or collapsed are rampant and the causes could be traced to sub-standard construction materials, construction technology, design error and geotechnical problems with insufficient accuracy for practical purposes (Yoshida and Hamada, 1990; Hamma-Adama and Kouider 2017). Failure of civil structures and other infrastructures arising from materials and geotechnical properties problems of the soil are well documented in literature. It has been reported that engineering properties and index are significant in the lifespan of structures, therefore there is a need to attend to these problems of structural failures and collapse of buildings at various levels (Akinyemi et al., 2016; Odeyemi et al., 2019; Awoyera et al., 2020). Figure 1 shows a typical collapsed building. In addition, rampant construction failure in the society coupled with dynamic variation reports of soil properties necessitate the need to conduct some selected geotechnical tests on soil to ascertain its engineering properties and index. Previous studies on variability of engineering properties, engineering index and nutrients of soil such as Afu et al. (2017), Agbede et al. (2015); Ajayi and Okonokhua (2024); Akanwa et al. (2024); Akayuli et al.(2013); Akinola et al. (2024); Ademilua et al. (2015); Adenika et al. (2018); Ofomola et al. (2009); Ayanninuola et al. (2023); Awe et al. (2018); Awe et al. (2021); Atilade et al. (2024); Atere et al. (2020); Amuyou et al. (2013); Alaminiokuma and Chaanda (2020); Alabi et al. (2022); Akpa et al. (2014); Ayofe et al. (2023); Bakoji et al. (2020); Chen and Jensen, (2013); Chen et al. (2022); da Silva Chagas et al. (2016); Danjuma et al. (2020); Daramola et al. (2024); Dickson et al. (2020; 2024); Eluwole et al. (2023); Ezeokpube et al. (2022); Falae and Ogundana (2022); Falowo (2023a and b); Fasina et al. (2007); Laekemariamet al. (2018); Ganiyu et al. (2024); Gogoi and Laskar (2015); Gökmen et al. (2023); Ibrahim (2023); Ibrahim et al. (2022); Ibrahim et al. (2020); Ishaku et al. (2021); Jain et al. (2015); Jordan et al. (2024); Khaledian and Miller (2020); Koçak and Köksal (2010); Laskar and Pal (2012); Law-Ogbomo and Nwachok.or (2010); Mahmood et al. (2017); Mallo and Umbugadu (2012); Mashalaba et al.. (2020); Ngah and Nwankwoala (2013); Nwankwoala and Amadi (2013); Nwankwoala and Warmate (2014); Nwogu et al. (2023); Ojetade et al. (2022); Obi and Ogunkunle (2009); Ofem et al. (2017); Ogbozige and Sani (2022); Ogbu et al. (2023); Oghenero et al. (2014); Ojeh et al. (2023); Ojetade et al. (2016); Oke and Amadi (2008); Oku et al. (2010); Olomo (2023); Olorunlana (2015); Olugbenga et al. (2021); Olusola. (2021); Olusola et al. (2023) Orimoloye et al. (2024); Oyebiyi et al. (2024); Oyediran and Durojaiye (2011); Oyediran and Falae (2018); Peter-Jerome et al. (2022); Poggio et al. (2021); Roy (2016); Roy and Bhalla (2017); Sayom et al. (2023); Sadiq et al. (2021); Sadiq et al. (2021); Saleh et al. (2022); Sayed and Khalafalla (2024); Zhao et al. (2022); Yusuf et al. (2019); Senjobi et al. (2013); Soliman et al. (2024); Wadoux et al. (2020); Wegbebu (2023); Yahqub et al. (2024); Yardım and Mustafaraj (2015); Youdeowei and Nwankwoala (2013) and Yusuf and Jauro (2024), provide information and data on engineering properties, engineering index and nutrients of soil in other regions and areas, but information and data on engineering properties and index at Elizade University's vicinity for safe construction purposes at the institution is not available. Elizade University (EU) is a private University established in Ilara-Mokin, Nigeria between Longitude, latitude and elevation of 7^0 22' 5.61" N, 5^0 06' 09.77"E, elevation 341 and 7^0 21' 47.76" N, 5^0 06' 17.03"E, elevation 338, and7^0 22' 6.45" N, 5^0 06' 37.37"E, elevation 350 and 7^0 21' 48.80" N, 5^0 06' 46.09"E, elevation 367 (Figure 1e). The University needs infrastructural development which the management is undertaken. Figure 1e presents the aerial view and location of EU. The focal objectives of this study are to ascertain the suitability of the soil in the location and establish variability or not in the geotechnical engineering index and properties of soils at various locations within the University in readiness for construction works.

MATERIALS AND METHODS

Accuracy of the materials and calibration of equipment used

All chemicals and reagents used in this research study had a chemical purity of 95% or above. Distilled water was used in the preparations of primary and secondary standard solutions or as the case may be. All equipment used in the experiments were calibrated using standard procedures, techniques and methods and the coefficient of determinations of these calibrations (relationship between expected and obtained values) were 96 % or above.

Collection of Soil Samples

Specific soil samples were collected from proposed three major construction project sites namely, Faculty of Engineering Building (FE), Faculty of Law Building (FL) and New Hostel Building (NH) in Elizade University, Ilara – Mokin. Figures 2 and 3 present the location of the sampling points in the University. These sites were selected based on management decision as proposed construction sites for new buildings, the pictures of the cleared sites are presented in Figure 4. Five (5) soil samples were composed from five points within each of the sites, making a total of fifteen soil samples (disturbed and undisturbed) suitable for identification of engineering and index properties of the soil. These samples were collected at 1.5 m depths across all locations. Cylindrical core cutters were driven into the soil using wooden hammer to collect undisturbed samples while diggers and shovel were used to collected disturbed samples into sacks. The core cutters with undisturbed sample were placed in air tight containers to preserve the soil's natural state. The samples collected from FE were termed S1 to S5, while samples from FL were termed S6 to S10 and samples from NH were termed S11 to S15. Samples were transported to the laboratory for testing. Soil samples collected were subjected to selected tests as stated in BS 1377 (1990). Selected tests conducted on the soil samples were moisture content, sieve analysis, specific gravity, consolidation and triaxial tests. Computations of these parameters were conducted as follows:

Moisture Contents (M_c)

The natural moisture contents of the collected samples were monitored in accordance with the American Society for Testing and Materials (ASTM) D- 2216 (2019); Afu et al. (2017), Agbede et al. (2015); Ajayi and Okonokhua (2024); Ayanninuola et al. (2023); Awe et al. (2018); Awe et al. (2021); Atilade et al. (2024). The M_c was computed as follows:

$$M_c = 100\left(\frac{w_1 - w_2}{w_1}\right) \quad (1)$$

Where: Mc represent the moisture content (%), W_1 stands for the mass of wet soil sample, W_2 represent the mass of dry soil sample

Figure 1a: Typical collapsed building (Source: Vanguard News 2024)

Figure 1b: Aerial view of a collapsed building (Source: Akinyemi et al., 2016)

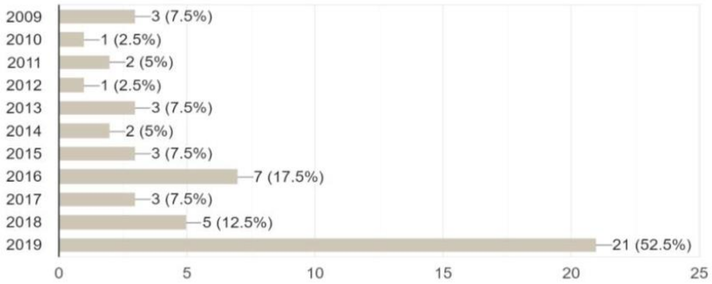

Figure 1c: Number of collpased buildings between 2009 and 2019 (Source: Awoyera et al., 2020)

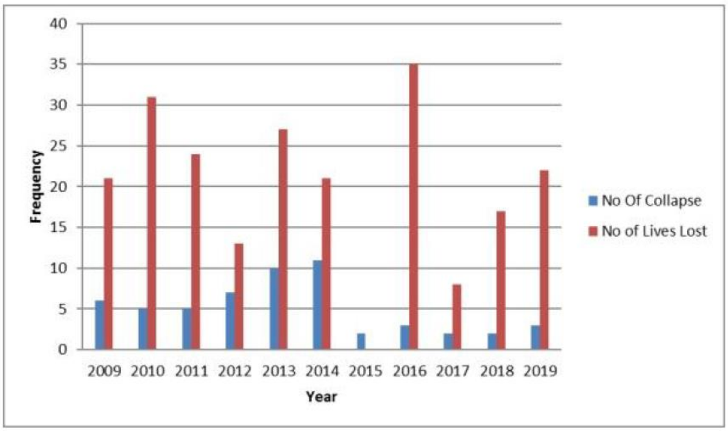

Figure 1d: Number of collapsed buildings and lives lost (Source: Odeyemi et al., 2019)

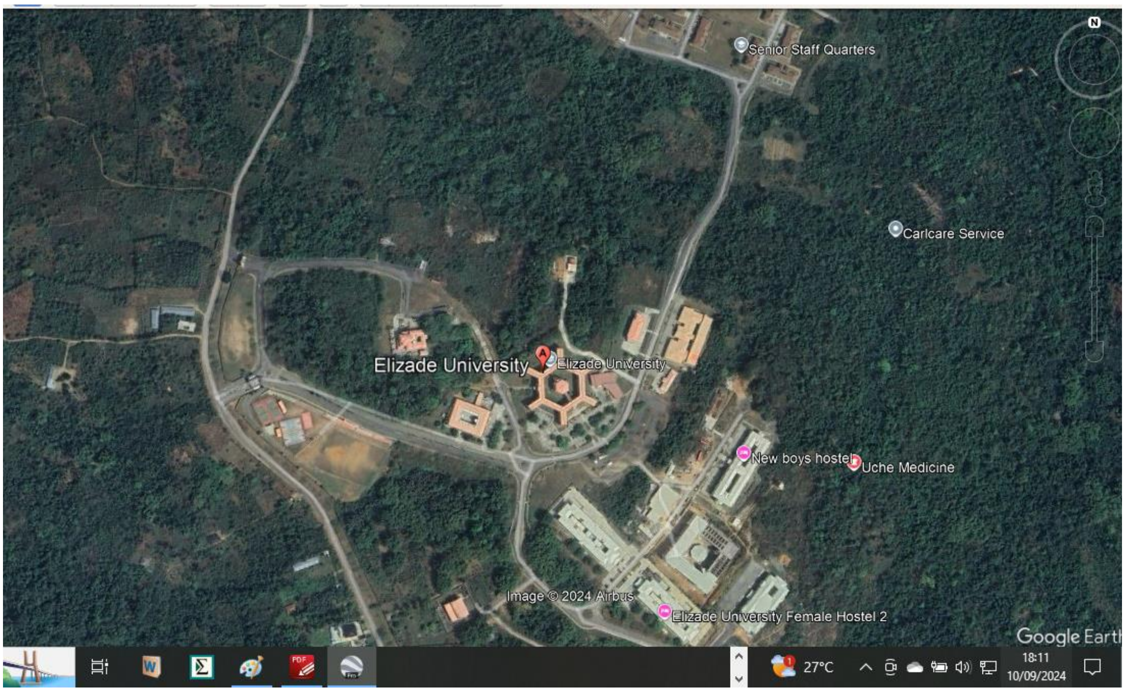

Figure 1e: The aerial view and location of EU (Source : Google Earth Pro Map 2024)

Figure 2: Elizade University, Ilara-Mokin and its environment (Source: Google Earth Pro, 2024)

Figure 3: Location of the three sampling points at Elizade University (Source: Google Earth Pro, 2024)

Figure 4a: Front view of proposed FE site

Figure 4b: Front view of proposed NH site

Figure 4c: Front view of proposed FL site

Sieve Analysis (Particle Size Distribution, Particle Size Analysis)

The sieving method was conducted in accordance with BS 1377 (1990). Soil characterisation systems categorised soils into sub-groups and groups based on similar engineering properties and index such as particle-size distribution, L_l, and P_I. The classification system utilised in this study is the Unified Soil Classification System (USCS) as stated in ASTM-D 2487-93 (2017). Results of sieve analysis were used to determine D_{60} (diameter corresponding to 60% finer in the grain size distribution), D_{30} (diameter equivalent to 30 % finer in the particle size distribution) and D_{10} (diameter equivalent to 10% finer in the particle size distribution, also known as effective Size). The values of standard parameters were used to compute or determine other specific essential values as follows (ASTM-D 2487-93, 2017):

C_u (Coefficient of Uniformity) = $\frac{D_{60}}{D_{10}}$ (2)

C_z (Coefficient of Curvature), = $\left(\frac{(D_{30})^2}{D_{10}D_{60}}\right)$ (3)

Determination of Atterberg limits (Liquid and Plastic limits)

Atterberg limits (Liquid and Plastic limits) of the soil were determined in accordance with ASTM D-4318 (2017). Liquid and plastic limit tests were conducted on particles passing sieve No. 40 (i.e. 0.425 mm opening) of the obtained samples and the plasticity, liquidity and consistency indices were determined using Equations 4, 5 and 6, respectively.

Determination of Plasticity index (P_I)

Plasticity index is the range of water content over which the soil remains in the plastic state and is mathematically defined as follows (ASTM-D 2487-93, 2017):

$$P_I = (L_L - P_L) \quad (4)$$

Determination of Liquidity index (L_I)

Liquidity index indicates the nearness of its water content to its liquid limit. When the soil is at its liquid limit, its liquidity index is 100% and it behaves like a liquid. When the soil is at the plastic limit, its liquidity index is zero. Negative values of the liquidity index indicate water content smaller than the plastic limit. The liquidity index is also known as the Water-Plasticity ratio and is defined as follows (ASTM D-4318, 2017):

$$L_I = 100\left(\frac{w-P_L}{P_I}\right) \quad (5)$$

Where, w is the natural moisture content

Determination of Consistency Index (CI)

the consistency index indicates the consistency of soil. It shows the nearness of the water content of the soil to its plastic limit. A soil with a consistency index of zero is at the liquid limit. It is extremely soft and has negligible shear strength. On the other hand, soil with a water content equal to the plastic limit has a consistency index of 100 %, indicating that the soil is relatively firm. A consistency index of greater than 100 % shows that the soil is relatively strong. Mathematically expressed as follows(ASTM D-4318, 2017)::

$$CI = 100\left(\frac{L_L - w}{P_I}\right) \quad (6)$$

Determination of Specific gravity (G)

A specific gravity test on the soil was determined in accordance with ASTM C-127 (2015).

Determination of Consolidation Properties

Consolidation tests were conducted. Monitoring the compression of the sample due to an applied load increment was achieved by plotting logarithms of time against the vertical settlement curve. Literature (Nishida, 1956) revealed that soil compression can be divided into three parts as follows:

i. Initial compression attributed to load seating, elastic expansion of the oedometer ring, compression of the porous stones, or the presence of air;
ii. Primary compression due to consolidation resulting from the dissipation of excess pore pressures; and
iii. Secondary compression is thought to be caused by a gradual readjustment of the soil particles.

The compression index (C_c) of these soil samples was determined using the standard methods described in the literature (ASTM D2435 – 04, 2017). In order to ascertain the maximum compression index and computed direct formulae using standard equations as follows (Terzaghi and Peck, 1967; Slamet and Abdelazim, 2012; Oke and Ayodele, 2014):

$$C_{c9} = 9.0 \times 10^{-3}(L_L - 10) \text{ (undisturbed Clay soil)} \quad (7)$$

$$C_{c10} = 7.0 \times 10^{-3}(L_L - 10) \text{ (disturbed Clay soil)} \quad (8)$$

$$C_{c11} = 1.0 \times 10^{-2}(L_L - 13) \text{ (Clay soil)} \quad (9)$$

$$C_{c12} = 1.2 \times 10^{-2}(W_n) \text{ (Clay soil)} \quad (10)$$

Where; LL is the Liquid Limit (in %) and W_n is the natural water content (moisture content, %)

The coefficient of Compressibility was calculated as follows (Phanikumar and Amrutha, 2014):

$$a_v = \frac{\Delta e}{\Delta \delta} \quad (11)$$

Where; Δe is the change in the void and Δδ is the change in the vertical stress

Triaxial Tests

Triaxial test on the soil was determined in accordance with BS 1377 (1990), where three similar or identical samples or specimens were sheared under three vertical load situation and the extreme or peak shear stress in each case was measured. The strength parameters, which are cohesion (C) and angle of internal friction (φ_f) were determined from the maximum shear against normal stress plot. Triaxial examinations were conducted. The bearing capacities were calculated utilising the shear test parameters of cohesion, angle of internal friction and the soil density of the samples or specimens removed from the boreholes. A well-known Terzaghi equation with correction terms suggested by Schultze can be utilised to compute the bearing capacity of the rectangular foundation of any side's ratio breadth to length. The bearing capacities were computed utilising Terzaghi method (analytical method) as follows (Chuantao et al., 2020; ASTM D5321 / D5321M-20, 2020; Afu et al., 2017, Agbede et al., 2015; Ajayi and Okonokhua, 2024; Ayanninuola et al., 2023; Awe et al., 2018; Awe et al., 2021; Atilade et al., 2024):

$$q_u = nN_c s_c + \gamma_0 D N_q s_q + 0.5\gamma_1 B N_y s_y \quad (12)$$

where: γ_o is for the Unit mass of soil above the foundation level (KN/m³), γ_1 is for the Unit mass of soil under the foundation level (kN/m³), c, and φ_f are the shear strength parameters of the soil under the foundation level in kN/m² and degrees, respectively. B is for the width of the foundation (m). L is for the length of the foundation (m). N_c, N_q, N_y are the bearing capacity coefficients that depend on the angle of internal friction of the soil below the foundation level. D is for the Depth of foundation (m). s_c, s_q and s_y are for the shape factors for the footing. Bearing loads were computed for pad and continuous footings to ascertain the strength of the soil at these selected locations.

Statistical Computation of Parameters

The mean and standard deviation (SD) of each data set within a location were calculated to determine the variability of the soil properties. All these statistical parameters were determined utilising standard procedure and methods. The choice of this statistical measure as the quality characteristic is analysed based on the need to control both the mean level of the process, and the variation around this mean. Mean and standard deviation, skewness and skewness were calculated using equations (13 - 15) respectively.

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \quad (13)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \overline{X})}{N}} \quad (14)$$

$$\mu = \frac{\sum_{i=1}^{N}(X_i - \overline{X})^3}{(N-1)\sigma^3} \quad (15)$$

Determination of Effects of the Factors and Computations of Statistical Values

Effects of operational factors that can influence location of the engineering index and properties of the soil were evaluated using analysis of variance (ANOVA). The total sum of squared deviations (SST) is calculated from the total average as per the following equations (18- 22):

$$SST = \frac{1}{N}\left(\sum_{i=1}^{N}\left(X_i - \overline{X_T}\right)^2\right) \quad (16)$$

Where, X_i is the engineering index and properties of the soil i; SST is the total sum of squared deviations of engineering index and properties of the soil; N is the number of the soil samples and X_T is the overall average of the engineering index and properties of the soil. This total sum of squared deviation, SST, occurs due to the sum of squared deviations due to each control factor (SS_A, SS_B, SS_C, SS_D and SS_E) and the sum of squared deviations due to error, (SS_e) The sum of squared deviation due to the factor is calculated as by

$$SSF_i = \frac{1}{N_j}\sum_{j=1}^{N_j}\left(\overline{X}_j - \overline{X_T}\right)^2 \quad (17)$$

Where: F_i is the factor i (A, B, C, D------------N) X_j is the average of the response of the factor F_i at level j and j is the level of the factor F_i (1, 2, ------------N_j) . The sum of squared deviation due to the error (SS_e) and degree of freedoms are calculated as by

$$SS_e = SST - SSA - SSB - SSC - - - SSN \quad (18)$$

$$d_{Tfe} = N - 1 \quad (19)$$

$$d_{Ffe} = N_j - 1 \quad (20)$$

RESULTS AND DISCUSSION

Index Properties and Classification of the Soil Samples

Figure 5 shows the results of sieve analysis of the soil samples. Table 1a presents the values for specific gravity, D_{10}, D_{30}, D_{60}, C_u, and C_c, percentage soil passing sieve numbers 10, 40 and 200 (P_{10}, P_{40} and P_{100}, respectively) as obtained from Figure 5. The results revealed that the specific gravity of the soil was in the range of 2.60 to 2.65 g/cm^3, with an overall average of 2.62, standard deviation of 0.03 and coefficient of variation of 1.18 %, which indicated that mass per unit volume of the soil samples were similar. D_{10} were in the range of 0.1 and 0.2 mm, with an overall mean of 0.15 mm, standard deviation of 0.02 and coefficient of variation of 14.81 %. D_{30} was between 0.2 and 0.6 mm, with an overall mean of 0.37 mm, standard deviation of 0.18 and coefficient of variation of 47.93 % as obtained from Figure 4. D_{60} was in the range of 0.5 and 1.1 mm, with an overall mean of 0.81 mm, standard deviation of 0.24 and coefficient of variation of 29. 11 %. The values of D_{10}, D_{30} and D_{60} indicate that the particle sizes of the soil samples were not similar but varied within the location. Computation revealed that C_u was between 2.9 and 8.6, with an overall mean of 5.49, a standard deviation of 2.11 and coefficient of variation of 38.44 %. C_{cv} were between 0.2 and 3.0, with an overall mean of 1.29, standard deviation (SD) of 1.01 and coefficient of variation of 78.04 %. The values of C_u and C_{cv} indicated particle sizes of the soil samples were not similar and varied with the location. P_{10} was in the range of 83.0 and 96.7 %, with an overall mean of 91.36 %, standard deviation of 4.17 and coefficient of variation of 4.57 %. P_{40} was in the range of 16.4 and 81.8 %, with an overall mean of 47.80 %, standard deviation of 24.05 and coefficient of variation of 50.32 %. P_{200} was in the range of 1.8 and 66.6 %, with an overall mean of 22.50 %, standard deviation of 27.84 and coefficient of variation of 123.76 %. Low SD indicates that the data points are close to the mean, whereas, high SD indicates that the data are spread out over a wide range of values. These results revealed that the data were spread out over a wide range. These observations agreed with literature such as Falae and Ogundana (2022); Falowo (2023a and b); Fasina et al. (2007); Laekemariamet al. (2018); Ganiyu et al. (2024); Gogoi and Laskar (2015); Gökmen et al. (2023); Ibrahim (2023); Ibrahim et al. (2022); Ibrahim et al. (2020); Ishaku et al. (2021); Jain et al. (2015); Jordan et al. (2024); Khaledian and Miller (2020); Koçak and Köksal (2010); Laskar and Pal (2012); Law-Ogbomo and Nwachok.or (2010); Mahmood et al. (2017); Mallo and Umbugadu (2012); Mashalaba et al.. (2020); Ngah and Nwankwoala (2013); Nwankwoala and Amadi (2013); Nwankwoala and Warmate (2014) on engineering index and properties of selected soils

The values of percentage passing sieve number numbers 10, 40 and 200 indicated particle sizes of the soil samples were not similar and varied with location. The soil needs to be classified based on the location. Based on these findings the soil in NH, FE and FL can be classified as GW (well-graded gravel, gravel sand mixtures), SW (well-graded sand, gravel sand – gravel mixtures) and GC (clayed gravel, gravel sand-clay mixtures) using USCS (ASTM D- 2487, 2017). The moisture content, liquid limit, plastic limit, plastic index, liquid index and consistency index of the soil samples are also presented in Table 1.

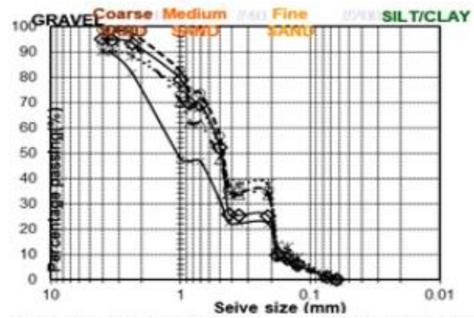

Figure 5a: Particle size distribution of soil sample from NH site

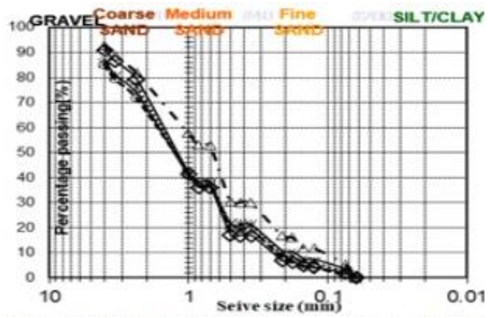

Figure 5b: Particle size distribution of soil sample FE site

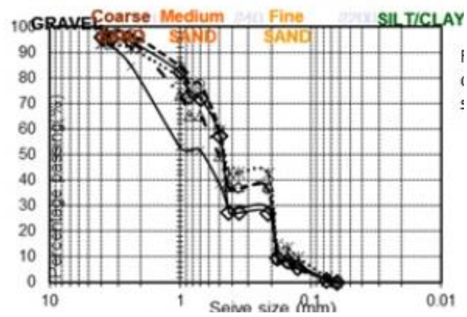

Figure 5c: Particle size distribution of soil sample FL site

Table 1: Index Properties of the Soil Samples

	G	D_{10}	D_{30}	D_{60}	C_u	Cz	P_{10}	P_{40}	P_{200}	MC (%)	LL (%)	PL (%)	PI (%)	LI (%)	CI (%)
S1	2.6	0.2	0.5	1.1	5.8	1.3	95.0	45.5	3.0	18.62	38	22	16.0	-21.1	121.1
S2	2.6	0.2	0.4	0.8	4.2	1.1	90.0	40.3	4.4	13.49	45	27	18.0	-75.1	175.1
S3	2.6	0.2	0.2	0.7	4.4	0.5	90.1	45.7	3.4	17.67	41	22	19.0	-22.8	122.8
S4	2.6	0.2	0.2	0.6	3.5	0.5	91.2	44.9	6.8	12.38	39	22	17.0	-56.6	156.6
S5	2.6	0.2	0.2	0.7	4.3	0.5	94.5	47.2	4.2	12.38	40	22	18.0	-53.4	153.4
Mean	2.6	0.2	0.3	0.8	4.5	0.8	92.2	44.7	4.4	14.9	40.6	23.0	17.6	-45.8	145.8
SD	0.0	0.0	0.1	0.2	0.8	0.4	2.4	2.6	1.5	3.0	2.7	2.2	1.1	23.3	23.3
CoV	0.0	9.3	42.0	23.4	18.9	53.9	2.6	5.8	33.9	20.2	6.7	9.7	6.5	-50.8	16.0
S6	2.65	0.15	0.60	1.05	7.00	2.29	91.0	16.4	1.8	18.9	58.5	34.0	24.5	-61.6	161.6
S7	2.6	0.12	0.60	1.05	8.61	2.81	83.0	19.4	2.0	11.6	42.0	24.8	17.2	-76.7	176.7
S8	2.66	0.12	0.61	1.05	8.54	2.88	92.8	30.2	5.4	18.0	52.5	32.5	20.0	-72.5	172.5
S9	2.56	0.12	0.62	1.05	8.47	2.95	86.8	21.1	3.4	12.1	38.5	24.0	14.5	-82.1	182.1
S10	2.60	0.13	0.50	1.00	8.01	2.00	85.6	21.5	2.2	12.7	39.0	25.0	14.0	-87.9	187.9
Mean	2.61	0.13	0.59	1.04	8.12	2.59	87.8	21.7	3.0	14.7	46.1	28.1	18.0	-76.2	176.2
SD	0.04	0.01	0.05	0.02	0.67	0.42	4.0	5.1	1.5	3.5	8.9	4.8	4.3	10.0	10.0
CoV	1.57	9.24	8.33	2.11	8.25	16.27	4.56	23.7	50.7	23.8	19.4	17.0	24.0	-13.1	5.7
S11	2.65	0.2	0.2	1.0	5.7	0.2	96.7	81.8	63.6	19.05	45	29	16.0	-62.2	162.2
S12	2.65	0.2	0.2	0.5	2.9	0.5	95.4	80.6	60.1	21.28	48	42	6.0	-345.3	445.3
S13	2.65	0.2	0.2	0.5	3.1	0.6	93.7	79.1	66.6	13.64	52	20	32.0	-19.9	119.9
S14	2.65	0.2	0.2	0.6	3.7	0.6	87.8	62.5	48.8	20.5	38	34	4.0	-337.5	437.5
S15	2.65	0.1	0.2	0.6	4.0	0.7	96.8	80.8	61.8	29.04	57	35	22.0	-27.1	127.1
Mean	2.65	0.16	0.22	0.63	3.89	0.53	94.1	77.0	60.2	20.7	48.0	32.0	16.0	-158.4	258.4
SD	0.00	0.02	0.02	0.23	1.11	0.20	3.7	8.1	6.8	5.5	7.2	8.2	11.6	167.9	167.9
CoV	0.00	9.88	8.21	36.06	28.46	37.74	3.9	10.6	11.3	26.7	15.0	25.5	72.3	-106.0	65.0
Mean	2.63	0.16	0.35	0.79	5.28	1.17	91.68	49.71	23.86	16.76	44.90	27.69	17.21	-93.45	193.45
SD	0.03	0.02	0.17	0.23	2.02	0.93	4.13	23.75	28.37	4.81	7.08	6.44	6.70	103.24	103.24
CoV	1.02	14.19	48.20	29.60	38.20	79.36	4.50	47.79	118.89	28.73	15.78	23.27	38.90	-110.5	53.37

The moisture of the soil samples was within 11.6 % and 29.04% with an overall average of 16.76 %, a standard deviation of 4.81 and a coefficient of variation of 28.73 %. The results revealed there was higher variation within the natural moisture of the soil within the campus. This result indicated that these soil samples were neither too dry nor too wet, but better moisture of good engineering index was needed as required in the selection of types of drains in a given catchment. The plasticity consistency and liquidity indexes are the basic geotechnical parameters of cohesive soils. The liquidity index determines the consistency and physical state of the soil. The plasticity index refers to the type of soil and its degree of cohesion. Both show clear and important correlations with the strength parameters of the substrate and are used in the process of designing the construction foundations. The plasticity index indicates the amount of water, in relation to the mass of the soil skeleton, that is absorbed when a given soil changes from a semi-solid to a liquid state. As the water content of a cohesive soil approaches the lower limit of the plastic range, the stiffness and degree of compaction of the soil increase (Krawczyk and Flieger-Szymańska, 2018). If the water content of a natural soil stratum is greater than the liquid limit (liquidity index greater than 1.0 or 100 %), remolding transforms the soil into a thick viscous slurry. If the natural water content is less than the plastic limit (liquidity index negative), the soil cannot be remolded. The unconfined compressive strength of undisturbed clays with a liquidity index near unity commonly ranges between 30 and 100 kPa. If the liquidity index is near zero, the compressive strength generally lies between 100 and 500 kPa (Krawczyk and Flieger-Szymańska, 2018). These results established that moisture content and other engineering index and properties of soil varies with locations as stated in literature such as Peter-Jerome et al. (2022); Poggio et al. (2021); Roy (2016); Roy and Bhalla (2017); Sayom et al. (2023); Sadiq et al. (2021); Sadiq et al. (2021); Saleh et al. (2022); Sayed and Khalafalla (2024); Zhao et al. (2022); Yusuf et al. (2019); Senjobi et al. (2013); Soliman et al. (2024); Wadoux et al. (2020); Wegbebu (2023); Yahqub et al. (2024); Yardım and Mustafaraj (2015); Youdeowei and Nwankwoala (2013) and Yusuf and Jauro (2024).

The table presents the liquid limit of the soil samples to be between 38 % and 58.5 %, with an overall average of 44.90 %, standard deviation of 7.08 and coefficient of variation of 15.78 %. Liquid limit of between 38 % and 58.5 % indicated that the soil can flow easily. Plastic limit and plastic index were in the range of 22 and 42 %, and 04 and 24.6 % respectively. The overall averages, standard deviation and coefficient of variation were 27.71 % and 17.13 %, 6.43 and 6.71, and 23.19 % and 39.20 % respectively. Liquid and consistency indexes were between -21.1 % and – 345.3 %, and 121.1 % and 445.3 % with overall averages of -93.45 and 193.45 %, standard deviation of 103.24 with a coefficient of variation of 110.47 and 53.37 % respectively. These results revealed that the characters of these samples were partially uniform within the campus. The results revealed that the soils had fair to good cohesion properties. Classification of the soil at various locations revealed that the soil at NH, FE and FL can be classified as CL (inorganic clay), CL and ML (inorganic silt) respectively based on liquid limit and plastic index (Table 2). This shows that classifications varied with locations as highlighted in literature such as Afu et al. (2017), Agbede et al. (2015); Ajayi and Okonokhua (2024); Ayanninuola et al. (2023); Awe et al. (2018); Awe et al. (2021); Atilade et al. (2024).

Shear Strength Parameters of the Soil Samples

Table 2 presents the cohesion, angle of internal friction, bearing capacities, compression indexes and coefficient of compressibility of the soil samples. Cohesion (C) and angle of internal friction (φ) were between 23.2 and 55.0 KN/m^2, an overall mean of 40.95 KN/m^2, and 17.47, standard deviation of 12.78 and 4.05 with a coefficient of variation of 31.21 and 23.15 % respectively. Figures 6 and 7 present a plot of PI and LL as well as a typical Mohr's circle from the sites, respectively. The bearing capacities (B_{cf}, continuous and B_{sf}, square footings) of the soil samples were from 109.0 to 553.0 and 125 to 668.2 kN/m^2, with overall averages of 203.23 and 240.87, standard deviation of 136.13 and 165.71 and coefficient of variation of 66.98 and 68.84 % for continuous and square footings respectively. Comparing the bearing capacities with presumed bearing values specified by BS 8004 (2015) for preliminary analysis, the soil samples can be said to be cohesive, very hard clays and very stiff boulder clays.

Table 2: Engineering Properties of Soil Samples

	C (kN/m^2)	φ	B_{cf}	B_{sf}	C_{c9}	C_{c10}	C_{c11}	C_{c12}	C_c	a_v
S1	55.0	10.2	147.0	158.0	0.252	0.196	0.250	0.223	0.076	0.0159
S2	30.0	19.3	138.0	155.0	0.315	0.245	0.320	0.162	0.116	0.0006
S3	40.0	19.3	125.0	135.0	0.279	0.217	0.280	0.212	0.070	0.0003
S4	45.0	21.8	120.0	150.0	0.261	0.203	0.260	0.149	0.190	0.0002
S5	56.0	22.8	127.0	143.0	0.270	0.210	0.270	0.149	0.092	0.0002
Mean	45.2	18.7	131.4	148.2	0.275	0.214	0.276	0.179	0.109	0.0034
SD	10.8	5.0	10.9	9.3	0.02	0.02	0.03	0.04	0.049	0.0070
CoV	24.0	26.7	8.3	6.3	8.8	8.8	9.8	20.2	44.8	201.8
S6	41.1	23.0	216.5	269.4	0.437	0.340	0.455	0.227	0.050	0.0006
S7	29.1	22.5	270.8	318.7	0.288	0.224	0.290	0.139	0.055	0.0008
S8	56.0	16.0	329.5	394.2	0.383	0.298	0.395	0.216	0.041	0.0003
S9	43.2	17.5	433.7	519.6	0.257	0.200	0.255	0.145	0.075	0.0006
S10	67.0	15.0	553.0	668.2	0.261	0.203	0.260	0.152	0.071	0.0005
Mean	47.3	18.8	360.7	434.0	0.325	0.253	0.331	0.176	0.058	0.0006
SD	14.6	3.7	134.3	161.4	0.08	0.06	0.09	0.04	0.015	0.0002
CoV	30.8	19.8	37.2	37.2	24.8	24.8	27.0	23.8	25.1	31.4

S11	37.8	11.1	127.0	143.0	0.315	0.245	0.320	0.229	0.116	0.0131
S12	23.2	14.5	112.0	135.0	0.342	0.266	0.350	0.255	0.161	0.0139
S13	28.7	16.1	130.0	145.0	0.378	0.294	0.390	0.164	0.302	0.0091
S14	32.4	14.9	109.0	125.0	0.252	0.196	0.250	0.246	0.098	0.0008
S15	29.7	18.1	125.0	154.0	0.423	0.329	0.440	0.348	0.139	0.0634
Mean	30.4	14.9	120.6	140.4	0.342	0.266	0.350	0.248	0.163	0.0201
SD	5.3	2.6	9.4	10.9	0.06	0.05	0.07	0.07	0.081	0.0248
CoV	17.6	17.2	7.8	7.8	18.9	18.9	20.5	26.7	49.6	123.5
Mean	40.95	17.47	204.23	240.87	0.314	0.244	0.319	0.201	0.110	0.0080
SD	12.78	4.05	135.46	165.81	0.064	0.050	0.071	0.058	0.068	0.016
CoV	31.21	23.15	66.33	68.84	20.30	20.30	22.21	28.73	61.53	204.114

These results revealed that the bearing capacity of these soil samples was not uniform and some (FL) were lower than the recommended value of not less than 150 kN/m^2 for a safe structure. Contrasting the admissible bearing limit and assumed bearing qualities determined by BS 8004 (2015) for fundamental investigation, the soil samples can be said to be strong, exceptionally hard clays as well as extremely firm. From the table (Table 2), the compression indexes (using empirical equations) of the soil samples were between 0.149 and 0.437. the overall averages for empirical equations (9), (10), (11) and (12) were 0.314, 0.244, 0.319 and 0.201, with standard deviations of 0.064, 0.050, 0.071 and 0.058, and coefficient of variations of 20.30, 20.30, 22.21 and 28.73 % respectively. Figure 8 presents the typical relationship between the deformation of the soil from the sites and the root of time (minutes). From the figure compression index from the campus was found to be between 0.041 and 0.302, with an overall average of 0.110, standard deviation of 0.058 and coefficient of variation of 61.53 %.

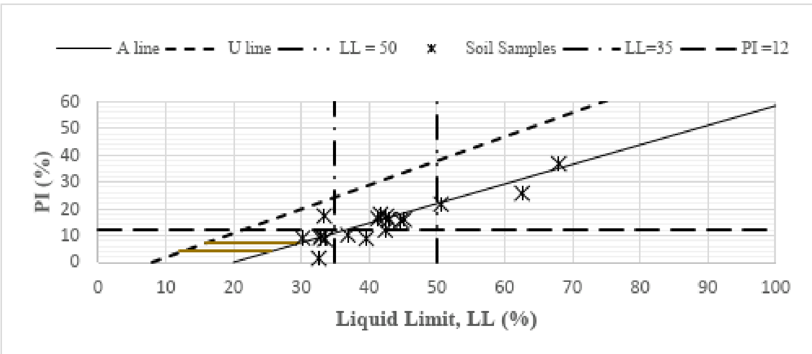

Figure 6: Classification of soil sample using PI and LL

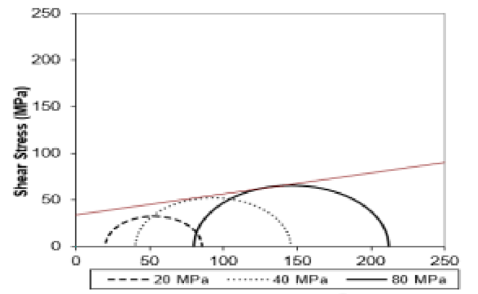

Figure 7a: Typical Mohr's circle from the site (NH)

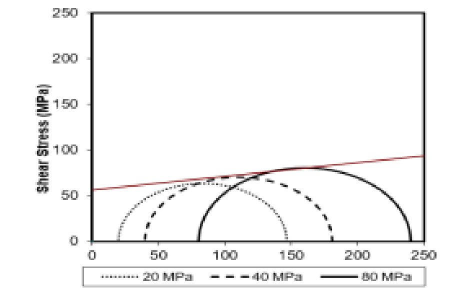

Figure 7b: Typical Mohr's circle from the site (FL)

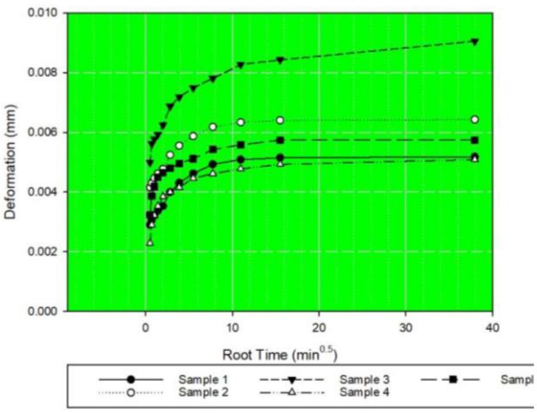

Figure 8a: Relationship between deformation and root time for NH site

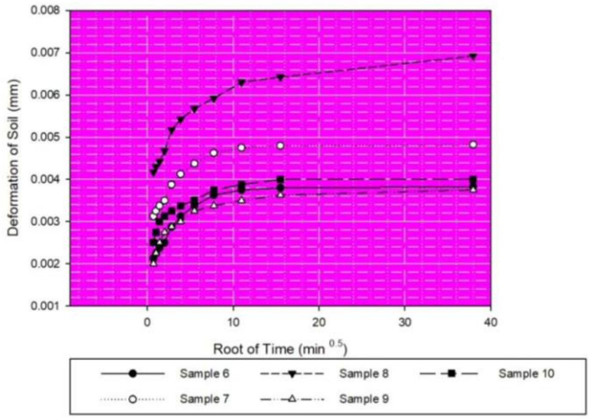

Figure 8b: Relationship between deformation and root time for FE site

From Table 2, the coefficient of compressibility of these soil samples was between 0.0002 and 0.0634, with an overall average of 0.0080, standard deviation of 0.016 and coefficient of variation of 204.114 %. These results revealed that these soil samples varied in compression indexes as well as coefficient of compressibility. Figure 8 relationship between void ratio and stress. It has been reported that the capability of soil to bear loadings is different depending on the type of soil (BS 8004, 2015). Generally, fine-grained soils have a relatively smaller capacity for bearing load than coarse-grained soils. Hence fine-grained soils, therefore, have a greater degree of compressibility. The variability of the compression index and coefficient of compressibility of the soil samples agree with the studies of Jain et al., (2015); Widodo and Ibrahim (2012). Literature such as Salahudeen et al. (2016) and Gopal (2017) used Cc to classify soil as follows: dense sand between 0.0005 and 0.01), loose sand in the range of 0.025 to 0.05), Firm clay between 0.03 and 0.06), Stiff clay between 0.06 and 0.15), Medium soft clay in the range of 0.15 to 1.0), and organic soil between 1.0 and 4.5). With reference to the compression indexes, soil samples from the site can be classified as dense sand, from firm clay to stiff clay soil. The foundation of any structure on a compressible soil layer leads to its settlement. The amount of settlement is related to the compression index Cc or coefficient of compressibility. It is defined as the decrease in volume due to the rearrangement of soil particles under the effect of pressure. Compression Index (Cc) is one of the parameters that is used in settlement estimation. The higher the value of Cc the higher will be the expected soil settlement. These results revealed that the foundation for the buildings at these sites should be the form that will prevent differential settlement of the soil. Engineering Assessment of the Soil: Allowable bearing capacities are essential ingredients in the settlement and compressibility of the soil Salahudeen et al.(2016). Settlement (service limit) controls the allowable bearing capacity in the design of shallow foundations while the ultimate limit (shear failure) usually controls the allowable bearing capacity in deep foundations design. Relationship between compression index and bearing capacities for the three construction project sites (Faculty of Engineering Building; FE, Faculty of Law Building, FL and New Hostel Building, NH) are as shown in Figure 9. The figure revealed that there is a non- linear relationship between these engineering properties of the soil. Table 3 presents average bearing capacities of the soil samples at these three sites. The average bearing capacities for the soil samples for the NH site was 131.4 kN/m^2 for continuous footing while it was 148.2 kNm-2 for square footing. The FE site had 434.0 kNm-2 as the bearing capacity for continuous footing while it was 360.7 kNm-2 for the square footing. The FL site had an allowable bearing capacity of 120.6 kN/m^2 for the continuous footing while it was 140.4 kNm^{-2} for the square footing. Allowable bearing capacity is computed using Equation (23) as follows:

$$q_{all} = \frac{q_u}{F.S} \quad (15)$$

Where: q_{all} is the allowable bearing capacity; q_u is the ultimate bearing capacity; F.S. is a factor of safety = 3.0.

Figure 10 presents the relationship between, the coefficient of compressibility, and bearing capacities for the three construction project sites. The figure revealed that there is a non-linear relationship between these engineering properties of the soil. The average allowable bearing capacity for the soil samples for the NH site was 43.8 kNm^{-2} for continuous footing while it was 49.4 kNm^{-2} for square footing. The FE site had 144.7 kNm^{-2} as the allowable bearing capacity for continuous footing, while it was 120.2 kNm^{-2} for the square footing. The FL site has an allowable bearing capacity of 40.2 kNm^{-2} for the continuous footing while it was 46.8 kNm^{-2} for the square footing (Table 3). The ultimate and allowable (safe) bearing capacity from the site's subsoil investigation revealed that the subsoil is characterized by fine loose dry sands, compact dry sand and compact gravels in some places as indicated by Gopal (2017). Therefore, the subsoil is a good foundation material and capable of supporting buildings constructed with shallow foundation footings such as pads or combined footings in the buildings' structural design. The bearing capacity results also show that the foundation depths for the Faculty of Law according to Meyerhof (1974) and Sadeeq and Salahudeen (2016) could be in the range of 1 – 3 m considering the allowable bearing capacity values are in the range of 80 – 150 kNm^{-2} while that for the Faculty of Engineering and the New hostel has to be lower in footings depth. It is also important that the groundwater profile and compressibility properties of the soil be put into consideration in addition to the soil-bearing capacity in the building's structural footing design.

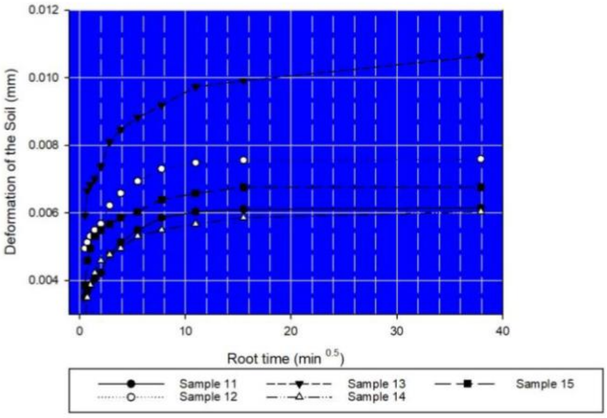

Figure 8c: Relationship between deformation and root time for FL site

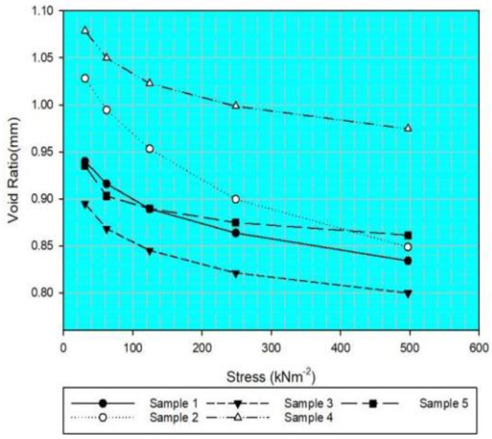

Figure 9a: Relationship between Stree and Void ratio for NH site

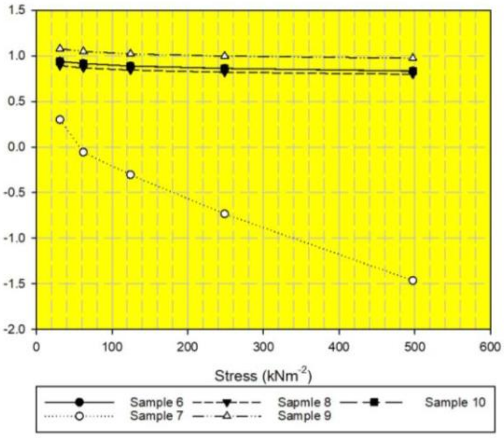

Figure 9b: Relationship between Stress and Void ratio for FE site

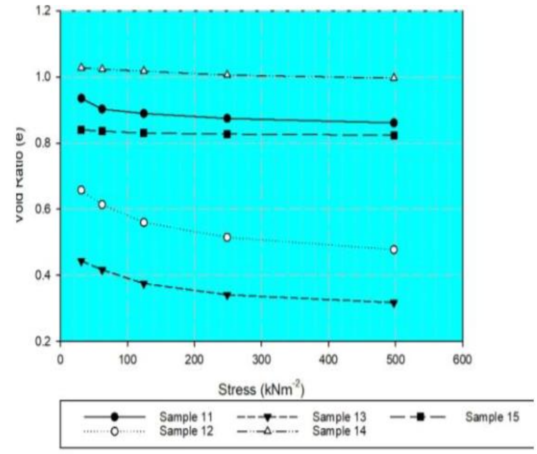

Figure 9c: Relationship between Stress and Void ratio for FL site

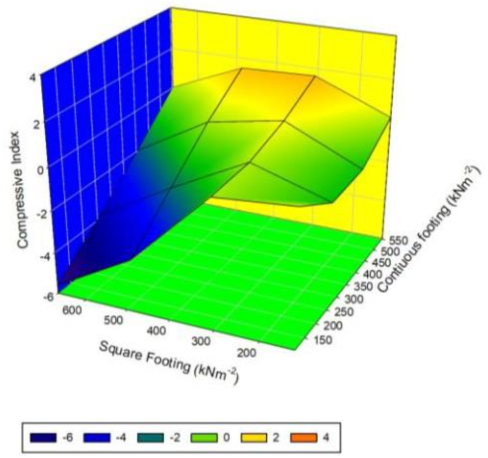

Figure 10: Relationship between Compressive Index and the bearing capacities at the three sites

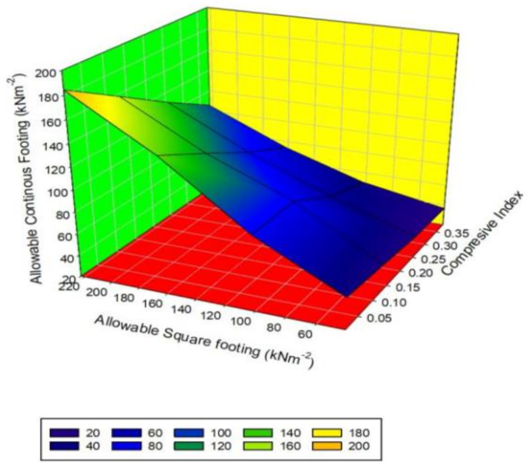

Figure 11: Relationship between Compress Index and allowable bearing capacities at the three sites

Statistical Analysis

The results of Analysis of Variance (ANOVA) conducted on the engineering index of the soil (moisture content, LL, PL, PI), and selected engineering properties (bearing capacity and compression index), and the bearing capacities of the continuous footings, square footings are as indicated in Tables 4, 5 and 6 respectively.

Table 4 presents effects of location on engineering index of the soil. Table 4 shows that there is a significant difference between engineering index along the locations ($F_{14, 42} = 2.63$, $p < 0.05$) at 95 % confidence level. The table revealed that there was a significant difference between engineering index ($F3, 42 = 92.17$, $p < 0.05$). Table 5 presents effects of location on engineering properties of the soil. Table 5 shows that there was a significant difference between engineering properties along the locations ($F_{14, 42} = 2.94$, $p < 0.05$) at 95 % confidence level. The table revealed that there was a significant difference between engineering properties ($F_{3, 42} = 31.86$, p

<0.05). Table 6 shows that there was a significant difference between ultimate bearing capacity along the locations ($F_{2,6}$ = 10.37, p = 0.01) at 95 % confidence level. The table revealed that there was a significant difference between ultimate bearing capacity of the soil samples ($F_{3,6}$ = 5.60, p = 0.04). Tables 7, 8 and 9 present further statistical analysis of effects of sampling points on the selected engineering properties and indexes. These results revealed that there were significant differences between both engineering index and properties of the soil along the locations, which indicated that location within the University has significant effect on both engineering index and properties of the soil in Elizade University Ilara – Mokin. This statistical analysis using ANOVA established that engineering index and properties of the soil are function of the locations (FE, NH and FL). These results ascertain that there are variabilities in the engineering index and properties of the soil. The results ascertain that there are variabilities in the engineering index and properties of soils at different locations, areas and regions which can be established in literature such as Afu et al. (2017), Agbede et al. (2015); Ajayi and Okonokhua (2024); Ayanninuola et al. (2023); Awe et al. (2018); Awe et al. (2021); Atilade et al. (2024); Ogbozige and Sani (2022); Ogbu et al. (2023); Oghenero et al. (2014); Ojeh et al. (2023); Ojetade et al. (2016); Oke and Amadi (2008); Oku et al. (2010); Olomo (2023); Olorunlana (2015); Olugbenga et al. (2021); Olusola. (2021); Olusola et al. (2023) Orimoloye et al. (2024); Oyebiyi et al. (2024); Oyediran and Durojaiye (2011); Oyediran and Falae (2018); Peter-Jerome et al. (2022); Poggio et al. (2021); Roy (2016); Roy and Bhalla (2017); Sayom et al. (2023); Sadiq et al. (2021); Sadiq et al. (2021); Saleh et al. (2022); Sayed and Khalafalla (2024); Zhao et al. (2022); Yusuf et al. (2019); Senjobi et al. (2013); Soliman et al. (2024); Wadoux et al. (2020); Wegbebu (2023); Yahqub et al. (2024); Yardım and Mustafaraj (2015); Youdeowei and Nwankwoala (2013) and Yusuf and Jauro (2024), Falae and Ogundana (2022); Falowo (2023a and b); Fasina et al. (2007); Laekemariamet al. (2018); Ganiyu et al. (2024); Gogoi and Laskar (2015); Gökmen et al. (2023); Ibrahim (2023); Ibrahim et al. (2022); Ibrahim et al. (2020); Ishaku et al. (2021); Jain et al. (2015); Jordan et al. (2024); Khaledian and Miller (2020); Koçak and Köksal (2010); Laskar and Pal (2012); Law-Ogbomo and Nwachok.or (2010); Mahmood et al. (2017); Mallo and Umbugadu (2012); Mashalaba et al.. (2020); Ngah and Nwankwoala (2013); Nwankwoala and Amadi (2013); Nwankwoala and Warmate (2014).

Table 3: Allowable bearing Capacities of the three sites

Locations	Bearing Capacity of Continuous footing (kN m^{-2})	Bearing Capacity of Square footing (kN m^{-2})	Allowable Bearing Capacity Continuous footing (kN m^{-2})	Allowable Bearing Capacity Square footing (kN m^{-2})
NH	131.4	148.2	43.8	49.4
FE	360.7	434.0	120.2	144.7
FL	120.6	140.4	40.2	46.8

Table 4: Results of ANOVA of the Engineering Index of the soils

Source of Variation (SV)	Sum of Squares (SS)	Degree of freedom(df)	Mean Sum of square (MSS)	F-value (Fv)	P-value (Pv)	F crit
Within the Locations	1036.457	14	74.03261	2.592212	0.008673	1.935009
Between the Index	7815.981	3	2605.327	91.22414	1.98×10^{-18}	2.827049
Error	1199.504	42	28.55963			
Total	10051.94	59				

Table 5: Results of ANOVA of the Engineering properties of the soils

SV	SS	df	MSS	Fv	Pv	F crit
Within the Locations	333076	14	23791.15	3.210318	0.001719	1.935009
Between the Properties	574925.8	3	191641.9	25.85969	1.23E-09	2.827049
Error	311255.2	42	7410.838			
Total	1219257	59				

Table 6: Results of ANOVA of the Ultimate and Allowable capacities of the soils

SV	SS	df	MSS	Fv	Pv	F crit
Within the Locations	81563	2	40781.60095	11.37325	0.009093	5.143253
Between the Capacities	68277	3	22759.15475	6.347116	0.027242	4.757063
Error	21514	6	3585.747635			
Total	171355	11				

Table 7: Results of ANOVA of the Engineering Index of the soils (for Table 1a)

SV	SS	df	MSS	Fv	P-value
Between sampling points	4070.9	14	290.8	2.143	0.014
Within the parameters	118113.9	8	14764.2	108.789	0.000
Error	15200.0	112	135.7		
Total	137384.7	134			

Table 8: Results of ANOVA of the Engineering Index of the soils (for Table 1b)

SV	SS	df	MSS	Fv	Pv
Between sampling points	691.0	14	49.36	0.01	1.00
Within the parameters	636092.0	5	127218.39	29.69	0.00
Error	299969.6	70	4285.28		

Table 9: Results of ANOVA of the Engineering Index of the soils (for Table 2)

SV	SS	df	MSS	Fv	Pv
Between sampling points	158670.73	14	11333.624	2.30	0.009
Within the parameters	1122498	7	160356.85	32.53	0.000
Error	483145.2	98	4930.0531		
Total	1764313.9	119			

CONCLUSION

Based on the findings from the study, it can be concluded that:

i. There was a significant difference between engineering index of soil between Elizade University at 95% confidence level ($F_{14, 98}$ = 2.30 and p = 0.009 within the sampling points and $F_{7, 98}$ = 32.53 and p = 0.000 with the engineering parameter);
ii. The soil on the campus can be classified from CL to ML and GW to SW;
iii. The values of specific gravity of the soil samples were similar, with a coefficient of variation of 1.18 %;
iv. The values of bearing capacities of the soil samples varied significantly, with coefficient of variation of 66.33 % and 68.84 % for continuous and square footings, respectively; and
v. There is variation among the engineering properties (Mc, P_I, L_L and bearing capacities) of the soil samples within the locations.

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