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Original Article

Assessement of Geotechnical Properties of Soil Underlying O Collapsed Structure along Iman Street, Uyo, Nigeria

Atat, J. G.[1*], Edet, A. C.[2], Ekpo, S. S.[3]

Department of Physics, University of Uyo, Uyo, Nigeria.

Corresponding Author: Atat, J. G

ABSTRACT

Samples of soil were obtained from two pits, about 1.8m from a collapsed location along Iman Street in Uyo, Akwa Ibom State, Nigeria. These soil samples were analysed in a laboratory using different sieve sizes to separate dried grains with the help of a sieve shaker. Microsoft Excel was used for the processing of this information and computations. The paint package of Windows 7.1 software was also used to deduce the necessary parameters for gradation result. The result of the grain size distribution yielded the uniformity coefficient, coefficient of gradation and sorting coefficient as 2.71, 0.91 and 1.64. This information classified the soil as poorly graded and more susceptible to soil liquefaction; most of the particles are approximately of the same size; they are not suitable for construction as they may not be compacted better like well-graded soil. The average percentage of natural water content was achieved as 23.99%. However, from the Atterberg limit investigation, the water content where the liquid limit corresponds to the number of blows as 25 is 45.56%. The plasticity index obtained is 18.58%. For better assessment information, some indices results were necessary which include Activity Index = 0.4494%, Liquid Index = - 0.61609, Consistency Index = 1.1609, Flow Index = 1.4390, Toughness Index = 12.9117 and Group Index = 3.7042. The plasticity index is high. This may show a marked reduction in bearing capacity with increase moisture content. The soil (laterite) clay mineral is Kaolinite which has low shrink-swell potential. It can hold large amount of water and still stay in plastic state. It is medium compressible since its liquid limit is within 30% to 50%. It is cohessionless and with the value of the group index obtained, the soil subgrade may be predicted as belonging to a fair class.

Keywords: Soil, Plasticity Index, Gradation, Laterite, Collapsed Structure

Introduction

Soil may be solid, semi-solid, plastic and liquid and the boundary between each state can be defined based on a deviation in the performance of the soil. In order to study this, soil gradation [which is achieved through sieve analysis] and Atterberg limit investigations are adequate. This information is necessary for soils which have been design to have structures on them. These assessments are mostly used on clay or silt soils since they expand and shrink when the moisture content varies. These tests are extensively used in the initial stages of design of buildings to know the shear strength. Soil compaction for all structures is necessary to achieve the desired strength, compressibility and permeability characteristics of the soil (McCarthy *et al*., 2007).

The continuous foundation disaster in Nigeria is frequent. This failure could be from the geological material, salinity, poor foundation design and poor building materials (Fatoba *et al*., 2010). This may affect the bearing capacity of the soil. If the structure is constructed on the poor soil, many complications will follow after construction as the structure will crack due to settlement of the soil.

Soil that changes or is unstable is active or expansive because of how it swells when is in contact with moisture and may later shrink when water dries. The major variance between active and inactive soil is seen in its alignment and how it is affected by environmental conditions.

Many Scientists have conducted researches on soils. Terzaghi and Peck (1995) worked on the evaluation of soil engineering properties and concluded that soil conditions vary from one location to another. Therefore, no construction site presents soil conditions exactly like any other (Braja, 2006). According to Burland (2005), the strength of the soil originates from two sources, specifically cohesion and frictional resistance between particles. Bulk density reflects the soils ability to function as structural support (Krammer, 2000). Nigeria as a third World country gives little consideration to soil analysis before construction which could be one of the strong reasons for recurrent structure collapse leading to causalities [both human and material resources] in Nigeria and other parts of the world (Onunkwo et al 2011).

The aim of this research is to assess the soil gradation and Atterberg limits for proper classification of soil underlying a collapsed structure at Iman Street, Uyo for accurate investigation of the failure. In order to achieve this, measurement of the weight of soil samples, separation of soil particles into different sizes, determination of percentage of fine grain passing through the sieve, determination of moisture content, liquid limit, plastic limit and plasticity index as well as percentage of clay fraction investigation, determination of the activity index of the soil, determination of uniformity, gradation and sorting coefficients, and estimation of the liquid, consistency, flow, toughness and group indices are essential. To attain the safety and the firmness requirements, the engineering properties of the soil beneath or on the structure must be accurately identified. By finding the index properties of soils, the engineering properties can be predicted adequately from empirical correlations (Blotz *et al*., 1998).

Location and Geology of study Area

The study area is located at latitude $5^{0}01^{1}59^{11}$N and longitude $7^{0}55^{1}27^{11}$E (Figure 2). The collapsed building is along Iman Street, Aka Offot, Uyo, Akwa-Ibom, South-South, Nigeria. Iman Street has latitude and longitude of approximately 5.03^{0}N and 7.93^{0}E respectively, in two places of decimal; Uyo is the capital of Akwa Ibom State, Nigeria located in the Niger Delta region (Figure 1). It lies within latitude $5^{0}05^{1}$N to 4^{0} 55^{1}N and longitude $8^{0}00^{1}$E to $7^{0}50^{1}$E. The city has a hilly or undulating nature and semi equatorial type of climate. The major vegetation belt noted in the area is fresh water swamp and rainforest (Ekwere *et al*., 1994). The area is categorized as coastal plain sands which is the Benin Formation (Mbipom et al., 1996). The Benin Formation is the uppermost unit of the Niger Delta Complex that lays on top the Agbada Formation. The Benin Formation is Oligocene and the youngest formation of the Niger Delta sedimentary basin. It is composed of continental flood plain sands and fluvial deposits. Rich mineral and forest resources, among which are gravel, silica, sand, clay, and timber are available. Agricultural produce like cassava, yam, vegetables and plantain are in abundance including large deposits of crude oil. Also experienced are the dry and the wet seasons (Atat et al., 2020a; 2012).

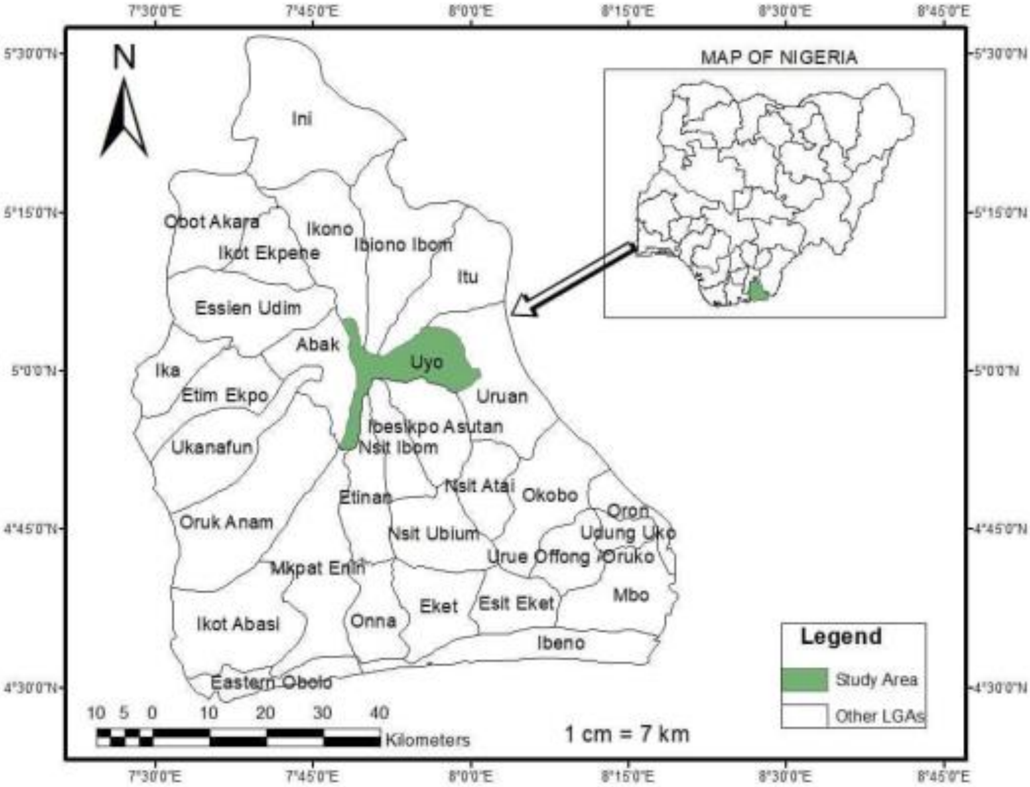

Figure 1: Map of Akwa Ibom State indicating Uyo location (Okon *et al*., 2019).

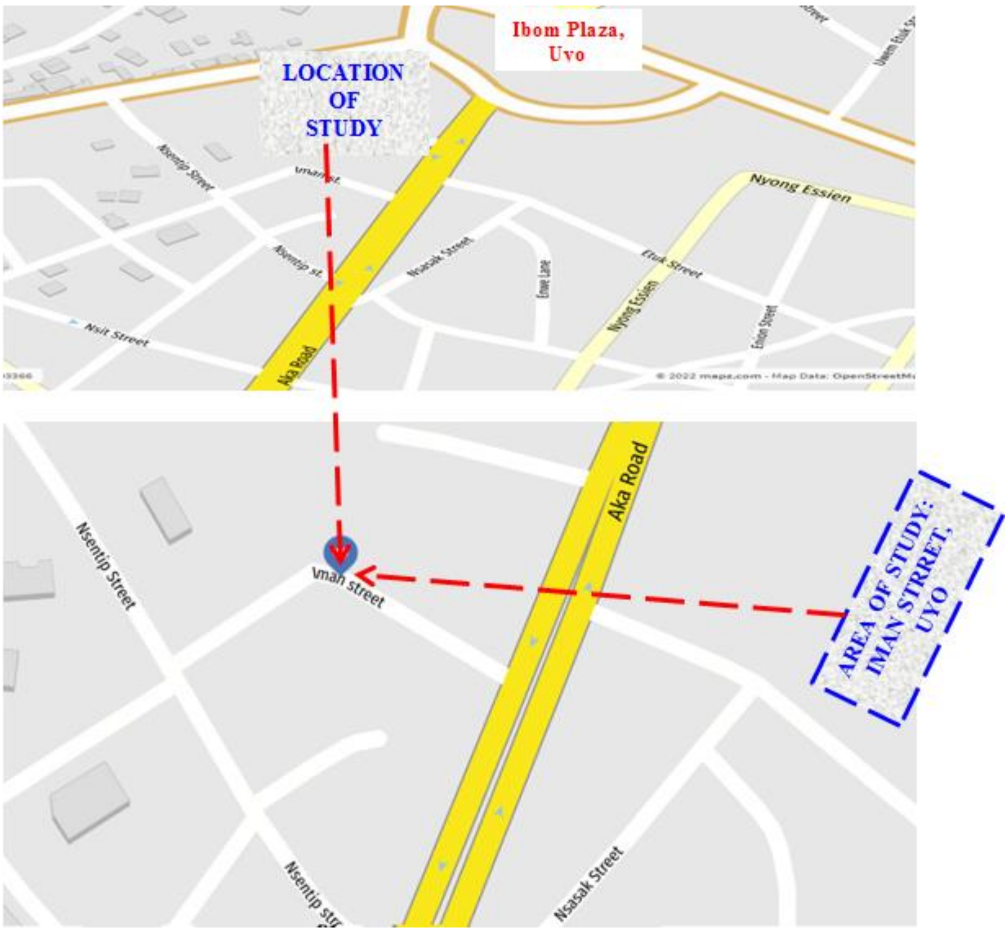

Figure 2: The location of the study in Uyo

Theoretical Background

Soil gradation gives an indication of the particle distribution of the soil. Measures of soil gradation include C_u, C_c and S_0 which are defined as shown in Equations 1 to 3.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{D_{30}^2}{(D_{60} \times D_{10})} \quad (2)$$

$$S_0 = \left(\frac{D_{75}}{D_{25}}\right)^{0.5} \quad (3)$$

Where D_{10} is the effective grain size for which 10% of the sample is finer

D_{30} is grain size for which 30% of the sample is finer

D_{60} is grain size for which 60% of the sample is finer

S_0 is the sorting coefficient

According to the Unified Soil Classification System (USCS), gravel may be categorized as well graded if C_u is greater than 4 and $1 < C_c < 3$. If these conditions are not met, the gravel is classified as poorly graded. Also, soil may be classified as well graded if $C_u \geq 6$ and $1 < C_c < 3$. If this not true, the soil is categorized as poorly graded (Holtz and Kovacs, 1981). The sorting coefficient may be computed from the ratio of grain size distribution for which 75% of the sample is finer to 25% of the sample is finer. It is the quantitative measure of sorting which ranges from extremely well sorted to very poorly sorted (Adunoye et al., 2019; Folk and Ward, 1957; Atat et al., 2022; Atat et al., 2018; Oladipo et al., 2018; Blott and Pye, 2001). The interpretation of the sorting coefficient is seen in Table 1.

Table 1: Classification of textural parameters (Atat et al., 2022; Atat et al., 2018; Oladipo et al., 2018; Blott and Pye, 2001).

S/N	Parameters	Range of values	Interpretation/Classification
1	Sorting	Less than 0.35	Very well sorted
2	Sorting	0.35 to 0.50	Well sorted
3	Sorting	0.51 to 0.70	Moderately well sorted
4	Sorting	0.71 to 1.00	Moderately sorted
5	Sorting	1.01 to 2.00	Poorly sorted
6	Sorting	2.01 to 4.00	Very poorly sorted
7	Sorting	Greater than 4.00	Extremely poorly sorted

To get a clear concept of range of water contents of soil in the plastic state, Atterberg (1911) proposed the limits of soil consistency. These limits of consistency, also known as the soil Atterberg limits, are plastic limit and liquid limit. Plastic limit is the edge between semi-solid and plastic state, and liquid limit separates plastic state from liquid state (Campbell, 2011). The plasticity index (which is the arithmetic difference between liquid limit and plastic limit) has been found useful for characterization, classification and prediction of the engineering behaviour of fine soils. The significance of gradation and Atterberg limits of soil has encouraged a concern to examine the relationship between gradation and Atterberg limits of certain soils (Adunoye et al., 2019).

The water content of a soil is the ratio of the quantity of water removed from the wet soil after drying to the dry soil mass (Equation 4) (Joyce, 1982; Ez Eldin et al., 2007).

$$W = \frac{m_w}{m_s} \times 100\% \quad (4)$$

Where W is Water content

m_w is the mass of water removed after drying the soil

m_d is thedry mass of the soil

Materials and Method

Materials

The samples were collected and taken to the laboratory for analysis. The major materials used are stated in Table 2.

Table 2: List of equipment used

S/N	Equipment	Purpose
1	Set of standard sieves	Sieve analysis
2	Atterberg apparatus	Determination of Atterberg limit
3	Sensitive balance	Weighing
4	Measuring cans	Containing soil samples for measurement
5	Mechanical balance	Weighing
6	Electric oven	Drying of soil sample
7	Wash and separating bowls	Washing and separation of soil particle

Methods

Digger and Spade were used to open up the pit to about 1.8m deep (Figure 3); the samples were collected with sample bags and taken to the laboratory.

Figure 3: Depth of Sample collection and location

Moisture Content approach

The moisture content containers were cleaned and weighed to the nearest 0.01g as M_1. A representative sample was then crumbled and loosely placed in the container. The container with the wet sample was then weighed on the balance and recorded as M_2 and placed in the oven to dry at a temperature of 105°C for about 16 hours. After drying, the container containing the dried sample was weighed and recorded as M_3. The data obtained resulted in the moisture content information.

The mass of water content [or moisture content] was determined by first measuring the mass of the empty sample containers; then mass of both the wet sample and the container. Measurement of both the mass of dry sample and the container mass was also noted. The difference of the mass of both the wet sample and the container, and the mass of dried sample and the container yielded the result (Equation 5). Also, the mass of dried sample was determined by subtracting the mass of the empty sample container from the mass of dry sample and the container (Equation 6).

$$M_w = M_2 - M_3 \quad (5)$$

M_w is the mass of water content in grammes

M_2 is the the mass of both the wet sample and the container

M_3 is the mass of dry sample and the container

$$M_d = M_3 - M_1 \quad (6)$$

M_d is the mass of dried sample in grammes

M_1 is the mass of the empty sample container

M_3 is the mass of dry sample and the container

Grain Size Analysis

The sample was soaked in a tray filled with water and stirred, washed, sieved through sieve No.200 (75μm) until the water became clean. This was done to get rid of impurities. The particles retained in the sieve was then collected into the crucible and oven dried for about 24 hours to expel moisture content in preparatory for dry sieving. Dry sieving was accomplished by passing the particles through assemblage of sieves of various sizes. These sieves were fixed in a sieve shaker for separation after which the weight of soil retained on each sieve was noted.

Atterberg Limit Test (Consistency Test)

Casagrande approach was adopted in conducting liquid limit test (Casagrande, 1958; 1932). The apparatus used were Casagrande machine (liquid limit device), flat glass plate, two spatulas, electric oven, weighing balance, sieve 425 mm micron, moisture content tins, distil water, grooving tools, glass desiccators, mortar. For the Plastic limit test, roller method was adequate. A dried portion of the sample was added to homogenous paste so it could be rolled and moulded into a ball. The ball was then rolled into a thread of uniform diameter of about 3 mm throughout its length which began to crumble and could no longer be rolled. The crumbling indicates the satisfactory end point. The portions of the crumbled soils were collected and placed in moisture content tins and placed in an electric oven at a temperature of 105 to 110ºC for moisture content determination.

Results and Discussion

Results

Engineering behaviour of the geomaterial underlying a collapsed structure at Iman Street has been assessed. Soil particles obtained about a depth of 1.8 m were subjected to sieve analysis, gradation, Atterberg limits and other assessment of the soil. The result of the grain size analysis is presented in Table 3. Figure 4 highlights the plot of finer passing versus sieve diameters which aids the deduction of other useful parameters. Table 4 has the atterberg limits information describing the geomaterials underlying the collapsed structure. The water content-number of blows curve (Figure 5) was also plotted to deduce the FI information for perfect interpretation.

Table 3: Result of grain size analysis

S/N	Sieve diameter (mm)	Weight of soil retained (g)	% of Soil retained on each sieve	% of Cum retained	Finer passing (%)
1	4.750	0.0	0	0	100
2	3.350	0.0	0	0	100
3	2.360	0.0	0	0	100
4	1.180	14.7	2.511103519	2.51110352	97.48889648
5	0.850	47.2	8.062863000	10.5739665	89.42603348
6	0.600	89.9	15.357020840	25.9309874	74.06901264
7	0.400	98.1	16.757772460	42.6887598	57.31124018
8	0.250	149.3	25.503928940	68.1926888	31.80731124
9	0.150	146.2	24.974376490	93.1670653	6.832934745
10	0.075	35.3	6.030064913	99.1971302	0.802869833
11	PAN	4.7	0.802869833	100.00000	0.00000000
	Total	585.4			

Table 4: Atterberg limits measurements

Measurements	**Liquid limit**								**Plastic limit**	
Number of blows	15	15	23	23	31	31	38	38		
Mass of c (g)	22.1	21.70	20.80	20.80	17.7	18.2	18.2	22.1	21.3	17.6
Mass of wet soil+ c (g)	37.2	42.10	38.30	42.50	38.7	32.3	38.3	44.6	44.8	40.7
Mass of dry soil + c (g)	32.4	35.70	32.80	35.70	32.2	27.9	32.1	37.6	39.6	36.0
Mass of moisture (g)	4.8	6.40	5.50	6.80	6.5	4.4	6.2	7.0	5.2	4.7
Mass of dry soil (g)	10.3	14.00	12.00	14.90	14.5	9.7	13.9	15.5	18.3	18.4
Moisture content (%)	46.6	45.71	45.83	45.64	44.8	45.4	44.6	45.2	28.4	25.5
Ave. moisture content (%)	46.16		45.74		45.09		44.88		26.98	

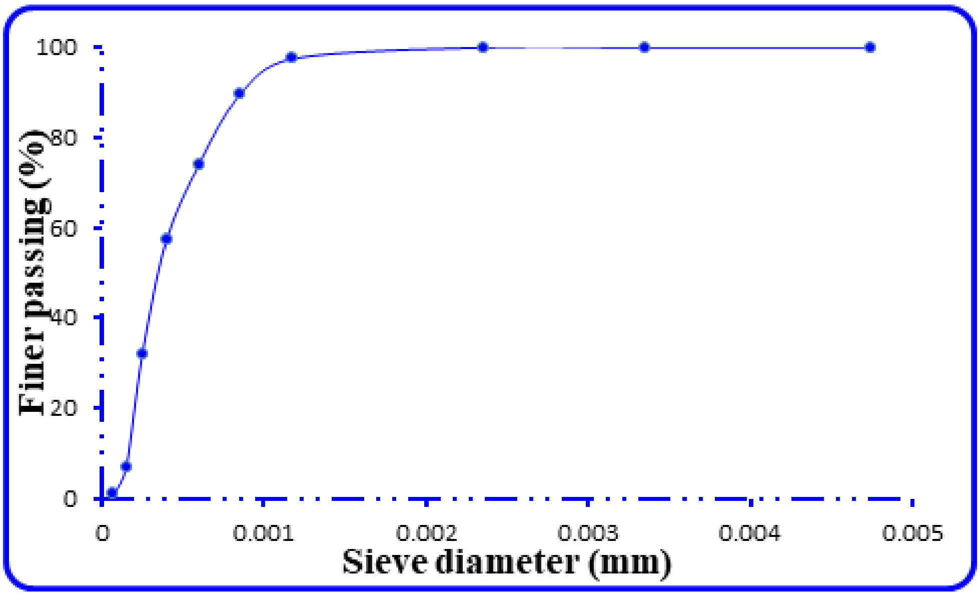

Figure 4: Gradation parameters deduction curv

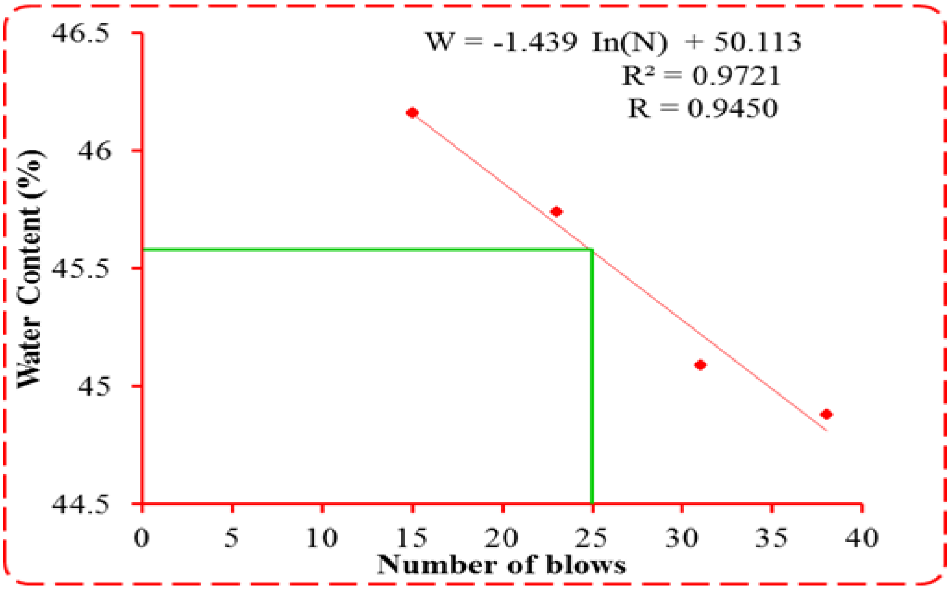

Figure 5: Water Content-Number of blows curve

Discussion

Soil samples collected about a depth of 1.8m were analysed. The results obtained are presented in Tables 3 and 4. Figures 4 and 5 also have other result information.

Water content determination

The percentage of water content or moisture content (W) was achieved using Equation 4. The results as presented in Table 4 show the highest value obtained from liquid limit test as 46.16% [with an average of 45.47%] and the lowest from plastic limit test as 26.98%. However, the liquid limit is the moisture content at N = 25 [that is, where the number of blows is 25] and this value corresponds to 45.56% from Figure 3. This result is necessary for the determination of the plasticity index.

Determination Gradation parameters

Table 3 presents the result of sieve analysis. Sieve analysis was conducted to sort the samples into different sizes so as to yield grain-size distribution of the soil. Necessary deductions from this curve enable the determination of gradation parameters. Equations 1 and 2 were used to obtain the uniformity coefficient and the coefficient of gradation respectively. Equation 3 was adequate for the sorting coefficient.

The total weight of the sample retained in grammes (585.4g) was used to obtain the percentage of cumulative of sample retained (Table 3). This aids the determination of the percentage of finer passing. This is shown below for the results in the fifth row in Table 3.

The total weight of the sample retained (W_{tsr}) = 585.4g

Weight of sample retained (S_r) = 47.7g

Computing for the percentage of the sample retained on the sieve, Equation 7 is adequate.

$$S_{rp} = \frac{S_r}{W_{tsr}} \times 100\% \tag{7}$$

This yields S_{rp} for the fifth row as 8.062863%

Where S_{rp} is the percentage of the sample retained on the sieve.

In order to compute the percentage of cumulative of sample retained (C_{sr}), Equation 8 was used.

$$C_{sr(5,4)} = C_{sr(4,5)} + S_{rp(5,4)} \tag{8}$$

Where $C_{sr(5,4)}$ is the percentage of cumulative of sample retained for the fifth row.

$C_{sr(4,5)}$ is the percentage of cumulative of sample retained in row four and column five.

$S_{rp(5,4)}$ is the percentage of the sample retained on the sieve in row five and column four.

Lastly, the percentage of finer passing was calculated using Equation 9.

$$F_p = 100 - C_{sr(5,4)} \tag{9}$$

F_p is the percentage of finer passing

Moreso, the deduced values of D_{10}, D_{25}, D_{30}, D_{60} and D_{75} from Figure 4 yielded the results of uniformity coefficient (C_u), coefficient of gradation or curvature (C_c) and sorting coefficient (S_0). These parameters play important role in soil characteristics and their values were deduced as presented below.

D_{10} = 0.35mm [which is the diameter of soil particles that make up 10% of the finer passing].

D_{25} = 0.51mm [which is the diameter of soil particles that make up 25% of the finer passing].

D_{30} = 0.55mm [which is the diameter of soil particles that make up 30% of the finer passing].

D_{60} = 0.95mm [which is the diameter of soil particles that make up 60% of the finer passing].

D_{75} = 1.37mm [which is the diameter of soil particles that make up 75% of the finer passing].

Equations1 to 3 were employed to obtain the results of C_u, C_c and S_0 as 2.71, 0.91 and 1.64. This shows that the soil is classified as poorly graded as $C_u \geq 6$ and $1 < C_c < 3$ (Holtz and Kovacs, 1981) and poorly sorted from the S_0 information (Atat et al., 2022; Atat et al., 2018; Oladipo et al., 2018; Blott and Pye, 2001). Since it is poorly graded soil, it does not have a good representation of all sizes of particles from No. 4 to 200 sieves (Holtz and Kovacs, 1981). It is more susceptible to soil liquefaction than well-graded soil. Poorly graded implies, most of the particles are approximately of the same size. Well graded soils are more suitable for construction than poorly graded soil because the permeability of poorly graded soil is more than well graded soil. The gradation of the on-site soil (or in situ) controls the design and ground water drainage of the site. Therefore, it has a better drainage than well graded soil. A well graded soil can be compacted more than poorly graded soil. From Figure 4, more than 50% of the sample sizes are less than 0.075mm. Therefore, the soil is fine grain soil.

Determination of Plasticity Index

Equation 5 was used to determine plasticity index. Plasticity is the ability of the soil to change shape on application of load and retain the new shape after removal of the load. High PI shows a noticeable reduction in bearing capacity with increase moisture content. The liquid limit is the moisture content at N = 25 [that is where the number of blows is 25] which corresponds to 45.56% from Figure 5. The plastic limit value computed = 26.98%. The plasticity index obtained = 18.58%. The greater the plasticity index, the greater the compressibility of the soil. A soil with these three parameters whose activity ranges from 0.3 to 0.5 has a clay mineral defined as Kaolinite (Kaliakin, 2017). Clay is compressible; gravel and sand are not. Kaolinite clay is classified as one with low shrink-swell potential. Shrink-swell behaviour of a soil is that quality which controls its volume change under changing moisture environments. With the result of the liquid limit, this soil has medium compressibility since liquid limit is within 30% to 50%; if it were low compressibility, liquid limit would be less than 30% [or high compressibility, if the liquid limit is greater than 50%]. Also, since PI is not lower than 10% and LL is not less than 20% implies the soil is not cohesionless as cohesionless soils have PI values less than 10% and LL values lower than 20%. Moreso, PI of the soil sample obtained = 18.58% is highly plastic (Sowers, 1979; Arora, 2009). High PI shows that soil can hold large amount of water and still stay at plastic state because it contains high amount of clay. This indicates that excess clay results in greater plasticity.

Determination of Activity Index

The index of activity of the soil was determined by the use of Equation 10 (Coduto, 2004) as 0.4494%. The ratio of the percentage of PI to the percentage of C_f yielded this result. According to Skempton (1953), the clay present is considered as inactive which is Kaolinite clay when PI and LL values are compared to this result. The soil is highly plastic or fat clay.

$$AI = \frac{PI}{C_f} \qquad (10)$$

Where AI is the Activity index

PI is the plasticity index

C_f is the clay fraction (particle size) less than 0.002 mm.

(Ez Eldin et al., 2007)

High activity signifies large volume change when wetted and large shrinkage when dried. Soils with high activity are very reactive chemically. When the activity of clay is within 0.75 and 1.25; in this range clay is called normal. It is assumed that the plasticity index is approximately equal to the clay fraction (AI = 1). When AI less than 0.75, it is is considered inactive. When it is greater than 1.25, it is considered active (Skempton, 1953).

Liquid Index and Consistency Index Calculations

The liquid index (LI) is used for scaling the natural water content of the soil sample to the limits. It serves as a measure of soil strength. If LI is less than zero, the soil is in a semisolid state characterized by high strength and brittle response characterized by sudden fracture of the soil. If $0 < LI < 1$, the soil is in a plastic state characterized by intermediate strength; it deforms like a plastic material. If LI is greater than one, the soil is in a liquid state characterized by low strength; it deforms like a viscous fluid (Kaliakin, 2017).

Consistency index indicates the firmness of the soil. Soil at the liquid limit has consistency index of zero; soil at plastic limit will have CI of 1 and if W is greater than LL, CI is negative. This means the soil is in the liquid state. However, the sum of LI and CI is equal to one.

A separate test was conducted to determine the average natural moisture content (W) as 23.99%. Recall PI value as 18.58%, LL = 45.56%, PL = 26.98%. Equation 11 was employed to obtain LI.

$$LI = \frac{W-PL}{LL-PL} \tag{11}$$

$$LI = \frac{23.99-26.98}{45.56-26.98} = \frac{-2.99}{18.58} = -0.1609$$

Since LI is less than zero, the soil is in a semi-solid state characterized by high strength (Kaliakin, 2017).

Equation 12 was considered to calculate the consistency Index.

$$CI = \frac{LL-W}{LL-PL} \tag{12}$$

$$CI = \frac{45.56-23.99}{45.56-26.98} = 1.1609$$

Since CI is approximately equal to 1, the soil is at the plastic limit.

Deduction of Flow Index

Equation 13 deduced from Figure 5 was compared to Equation 14 (Jamal, 2017) and the flow index is obtained as $FI = 1.439$.

$$W = -1.439 logN + 50.113 \tag{13}$$

$$W = -FI \log N + C \tag{14}$$

FI is the flow index obtained from the slope of the graph

N is the number of blows

Toughness Index determination
Equation 15 was used to evaluate this index.

$$TI = \frac{PI}{FI} \tag{15}$$

$$TI = \frac{18.58}{1.439} = 12.9117$$

Group Index Estimation

Equation 16 was adequate for this result and yielded GI as 3.704224. This indicates that the soil subgrade is classified as fair. A higher value of the group index means that the poorer the soil as subgrade material. If the Group index is in the range of 0 to 1, soil is good for pavement design; 2 to 4, soil is fair; 5 to 9, soil is poor and 10 to 20, soil is very poor. Subgrade of soils relates linearly with bearing pressure (Atat et al., 2020b). Equation 2.10 defines group index approach.

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \tag{16}$$

F_{200} is sample passing No. 200 sieve (Day, 2009).

Conclusion

The study has made available necessary information on the Engineering behaviour of soil. The water content of the soil indicates that the soil is in a semi-solid state characterized by strength. The gradation parameters classified the soil as poorly graded which has no good representation of all sizes of particles; the particles are more susceptible to soil liquefaction and the particles are also poorly sorted. The plasticity index is high. This may show a marked reduction in bearing capacity with increase moisture content. The soil (laterite) clay mineral is Kaolinite which has low shrink-swell potential. It can hold large amount of water and still stay in plastic state. It is medium compressible since its liquid limit is within 30% to 50% and cohessionless. However, from the value of the group index obtained, the soil subgrade belongs to a fair class but a good class is recommended for pavement design.

Declaration

Competing interests

No potential conflict of interest

Authors' contributions

All the authors took part in field measurements, data processing and write-up. In addition to already mentioned involvements, the corresponding author also engaged in the plotting of curves, interpretation/discussion and assembled all the write-ups, in a manuscript form for submission/publication.

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Availability of data and materials

This is a primary data obtained directly from the location of the collapsed building after different soil samples have been taken about 1.8m at the foundation (footing) level. The experimental procedure was carried out in Civil Engineering Laboratory, Department of Civil Engineering, University of Uyo, Nigeria.

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