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The Particle Size Distribution of Laterite Soil at Ekosodin, Benin City, Nigeria

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ABSTRACT: The laterite soil particle-size distribution provides a preliminary knowledge of the rate of failure and the strength of soil to resist load pressure and subsequent susceptibility to gully erosion. This study was carried out to determine the particle size distribution of laterite soil at Ekosodin, Benin City, Nigeria using appropriate standard methods. This was achieved by collecting a total of twenty soil samples from the gully zone of Ekosodin and carrying out sieve and hydrometer analyses on the recovered soil. The average percentage weight of fines smaller than the following grain diameters: 1.18mm, 0.425mm, 0.075mm, 0.040mm, 0.010mm, 0.003mm, and 0.001mm, were approximately 96%, 74%, 45%, 35%, 28%, 21%, and 15% respectively. The coefficient of uniformity and coefficient of curvature classified the laterite soil as a well graded soil consisting of a representative of all grain sizes in a good complementary proportion. However, the significant quantity of fine in the soil composition made it susceptible to gully erosion in the presence of intense water movement.

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The laterite soil of Ekosodin, Benin City, Nigeria, is a reddish-brown iron-containing earth that consist of both granular (sands and gravels) and fine (silt and clay) soil particles, coated with sesquioxide and clay minerals (Ikhile, 2016). Despite the good co-existence of the various soil particles, the lateritic soils do experience instability due to its swell-shrink nature when exposed to moisture variation. Also, the soil instability can be due to the fluctuation of fine grain quantity in the soil composition at different sites, owing to the area's hydrological cycle which causes fines to wash off at one spot and settle at another (Ikhile, 2016). In the dry season, laterite soil, regardless of the quantity of fines, has a good resisting strength under load stress and can withstand shear failure. This is due to the friction and tight interlocking bond between the fine and granular soil particles in contact. When laterite soils are subjected to loading, particle size and their associated voids play a vital role in the dissipation of energy (Sharma, et al., 2019; Roy and Bhalla, 2017).

A good understanding of soil resisting strength to load pressure through the distribution of the soil various particle sizes, is essential as it aids the analysis of several soil stability problems such as bearing capacity, slope stability, lateral pressure on earth-retaining structures, and pavement deformation (Andre- Obayanju and Ireaja, 2022; Ojeaga and Afolabi, 2022; Kayode-Ojo, and Odiase, 2020). Therefore, this study which was to carry out the particle size distribution of laterite soil at Ekosodin, Benin City, Nigeria.

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MATERIALS AND METHOD

Study Area: This study was carried out in Ekosodin of Ovia Northeast local government area which lies on the Latitude 6°24'29.80" N and Longitude 5°37'07.82" E, situated in the capital of Edo State, Nigeria. The state lies in the north-western part of the Niger Delta, west of the lower Niger valley and the southwestern plains. The study area is generally known as the most populated zone for students from the University of Benin due to the insufficient accommodation facilities in the university and the proximity of the community to the university (Ogeah and Ajalaye, 2011). However, the presence of the gully which has eroded some residents' properties and land investments, has been observed to be one of the reasons available accommodation facilities are expensive for occupants especially students. This gully also cut across some major roads that easily linked Ekosodin community to major commercial community in Benin city, limiting the business activities and fast community development (Ogeah and Ajalaye, 2011; Ojeaga and Afolabi, 2022).

Soil Sampling: A total of hundred soil samples were collected from Ekosodin area. The sample size was decided based on the range of sample sizes recommended from similar research (Surendra and Gurcharan, 2014; Purwana and Nikraz, 2014; Iyeke, et al., 2016). The soil was sampled at a 1.5m depth below the earth surface with the use of a hand auger. Although the water table was not encountered during the investigation for the various locations, the sampled soils were partly moist due to the microclimatic conditions in the site and the seasonal rainfall.

Figure 1: Map of Ekosodin Sampling Locations

Laboratory Testing of Soil Samples: The mechanical sieve analysis and sedimentation test was conducted on the recovered soil samples, and they were carried out according to BS EN 1997-2-2007.

The mechanical sieve analysis includes the process of separating soil aggregate into fractions using a set of different standard sieve sizes. The cumulative percent by weight of a soil passing a given sieve is referred to as the percent finer (BS 1377: Part 2, 1990). The percent fine of sieve No 14 (1.18mm), No. 36 (0.425mm) and No. 200 (0.075mm) were selected to generally represent the coarse, medium, and fine-grained soil in the soil classification based on the American Association of State Highway and Transportation Officials (AASHTO) system of classification. Other sieve analysis parameters such as D_{10}, D_{30} and D_{60} were used to determine the effective size, the uniformity coefficient, and the coefficient of gradation (also known as coefficient of curvature). D_{10} is the effective size of a soil through which 10% of the total soil mass is finer and 90% of the particles is coarser than D_{10}. This is the size at 10% finer by weight. Similarly, D_{60} is the particle size at which 60% of the particles are finer and 40% of the particles are coarser than D_{60} size. D_{30} is the size at which 30% is finer by weight and remaining 70% particles are coarser than D_{30} size. The uniformity coefficient and the coefficient of curvature help to classify the soil as well, gap or uniformly graded ones. A well graded soil has a good representation of all particle sizes. A gap graded soil has excess or deficiency of certain particle sizes. Lastly, a uniformly graded soil has particles of same sizes leaving relatively large voids within them.

The *coefficient of uniformity* (C_u) is defined as the ratio of D_{60} to D_{10}. A value of C_u greater than 4 or 6 classifies the soil as well graded. When C_u is less than 4, it is classified as poorly graded or uniformly graded soil. Beach sand is an example of soil under this category.

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

Coefficient of curvature (C_c) is given by the formula:

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

A soil with coefficient of curvature (C_c) between 1 and 3 is well graded if the cu is also greater than 4 for gravels and 6 for sands. For cases where the C_c of soil is less than 1 or greater than 3, the soil is gap graded.

Sedimentation test is conducted on soil with percent finer of sieve No. 200 (0.075mm) value greater than 35% (BS 1377: Part 2, 1990). This test is governed by stokes law on determination of the rate of settlement of a particle. The most recommended sedimentation test is hydrometer. This test determines the distribution of fines such as silt and clay in a soil composition.

RESULTS AND DISCUSSION

The sieve and hydrometer analyses showed particle sizes of soil in this area ranging from coarse grained sand to clay. The percentage of fines passing the various soil grain diameter or categorized under the given soil grain fraction according to the British standards (Das, 2019) are presented in the Table 1.

Table 1: The Soil Particle Size Distribution at the Investigated Region

Soil grain type	**Sand**			**Silt**			**Clay**
Soil grain fraction	**Coarse**	**Medium**	**Fine**	**Coarse**	**Medium**	**Fine**	**Fine**
Grain diameter (mm)	**1.18**	**0.425**	**0.075**	**0.040**	**0.010**	**0.003**	**0.001**
Ekosodin, Point 1	95.40	72.20	37.30	30.41	23.10	15.30	11.10
Ekosodin, Point 2	98.70	73.80	35.70	27.22	20.64	14.21	10.02
Ekosodin, Point 3	94.50	73.50	38.70	32.04	24.11	14.38	13.20
Ekosodin, Point 4	91.60	68.40	36.70	27.89	21.46	16.40	10.45
Ekosodin, Point 5	93.80	66.60	38.50	32.44	24.80	14.10	13.01
Ekosodin, Point 6	96.30	68.70	36.30	27.60	21.06	15.34	11.35
Ekosodin, Point 7	97.40	68.30	39.90	33.80	26.01	16.90	13.90
Ekosodin, Point 8	97.50	70.80	38.60	32.20	25.70	14.27	11.78
Ekosodin, Point 9	98.10	75.10	38.40	31.20	24.53	13.70	12.99
Ekosodin, Point 10	98.30	71.60	35.30	28.45	21.22	16.80	9.56
Ekosodin, Point 11	97.90	71.70	39.70	32.70	27.08	16.20	13.02
Ekosodin, Point 12	97.30	68.40	38.70	32.11	25.40	15.42	10.75
Ekosodin, Point 13	96.20	68.90	39.40	33.65	28.40	14.70	12.98
Ekosodin, Point 14	95.20	70.40	39.10	33.41	27.10	15.20	11.49
Ekosodin, Point 15	96.50	72.80	39.60	32.65	27.95	16.78	11.80
Ekosodin, Point 16	94.90	68.80	39.70	33.75	28.23	16.20	12.18
Ekosodin, Point 17	96.20	66.20	37.90	31.12	26.47	15.22	11.42
Ekosodin, Point 18	96.20	71.80	39.00	33.45	28.75	14.75	11.80
Ekosodin, Point 19	95.30	67.70	37.80	32.12	27.45	14.80	11.21
Ekosodin, Point 20	95.70	69.70	39.30	33.67	28.06	14.00	12.40

Table 2: The Percentage of Soil Grains Passing/Retained per Grain Diameter

Soil grain type	**Sand**			**Silt**			**Clay**
Soil grain fraction	**Coarse**	**Medium**	**Fine**	**Coarse**	**Medium**	**Fine**	**Fine**
Grain diameter (mm)	1.18	0.425	0.075	0.040	0.010	0.003	0.001
% Fine Passing	96.18	70.43	38.33	31.62	25.46	15.28	11.93
% Retained	3.82	25.74	32.10	6.71	6.16	10.19	3.34

The sieve and hydrometer analyses showed particle sizes of soil in this area ranging from coarse grained sand to clay. As can be seen in Table 2, the average percentage of fines passing the following categories: coarse sand was approximately 96%, medium sand was 70%, fine sand was 38%, coarse silt was 32%, medium silt was 25%, fine silt was 15%, clay was 12%. While the percentage of soil grains retained at each category was approximately 4% coarse sand, 26% medium sand, 32% fine sand, 7% coarse silt, 6% medium silt, 10% fine silt, 3% clay. From Figure 2, the average D_{10}, D_{30} and D_{60} were 0.0007mm, 0.02mm, and 0.3mm respectively. The coefficient of uniformity C_U and coefficient of curvature C_C were evaluated as in equations 3 and 4.

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.3\ mm}{0.0007\ mm} = 429 \qquad (3)$$

$$C_c = \frac{D_{30}{}^2}{D_{10} \times D_{60}} = \frac{0.02^2\ mm^2}{0.0007 \times 0.3\ mm^2} = 1.90 \qquad (4)$$

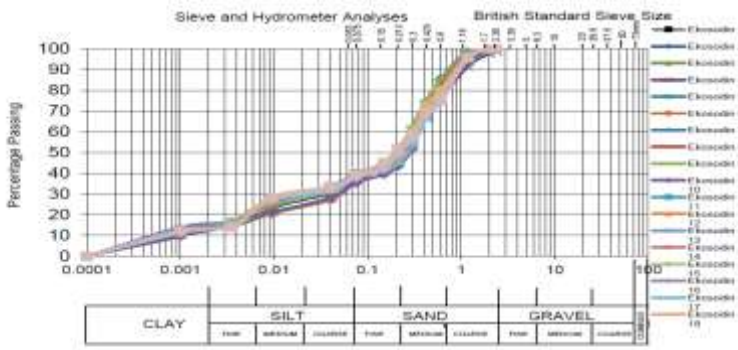

Fig 2: Particle Size Distribution of Soil Samples from Ekosodin Area

A value of C_U greater than 6.0 and C_C value between 1.0 and 3.0, classified the soil as well graded. As observed in Table 2 , compared to the percentage fine passing, the percentage of soil grains retained at each category or soil grains coarser than the specified diameters, the medium (25.74%) and fine (32.10%) grained sand are of more quantity than other soil grain fractions. The next major quantity was the clay content (15.27%) if the grain diameter range of 0.001mm to 0.0001mm as seen in Figure 2 was considered. The least soil fraction is the coarse sand (3.82%). This information explains a soil consisting of a representative of all grain sizes in a good complementary quantity (BS 1377: Part 2, 1990).

Conclusions: The particle size distribution analyses of laterite soil in Ekosodin, Benin city showed a grain distribution across coarse grained sand to clay however the significant quantity of fine in the soil composition made it susceptible to gully erosion in the presence of intense water movement.

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