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Comparative Analysis of Some Geotechnical Properties of Decomposed Solid Waste and Natural Soil Site for Foundation Engineering

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ABSTRACT

Optimization of landfills as a result of increasing population and demand for infrastructural development has necessitated intensified investigation among engineers. Examining the engineering properties of soils from these landfills is of great concern. This paper presented the bearing capacity of soils from dump sites of municipal solid wastes and natural soil using their shear strength parameters obtained from direct shear tests, after preliminary tests had been carried out to determine index properties of the soil samples. Samples were obtained at 1m, 1.5m, 2m, 2.5m and 3m depth from Jettu site in Edo State, Nigeria. The maximum and least cohesion values were observed to be 24kN/m^2 and 17kN/m^2, 15kN/m^2 and 5kN/m^2; and the maximum angles of internal-friction were 22^{o}C and 24^{o}C, while the least internal friction angles were 6^{o}C and 9^{o}C for NS and SWSS samples respectively, which denotes that the samples are fine soils with good shear strength and can serve as reliable structural foundation materials

1. Introduction

Solid wastes consist of both biodegradable and non-biodegradable waste materials [1]. These materials have a harmful impact on both soil and groundwater [2]. To ensure a healthy and safe environment, solid waste management techniques are adopted. Solid waste management activities include; waste segregation, collection, transportation, treatment and disposal [3-5]. The various waste disposal methods used are composting, recycling, landfilling and incinerating. Wastes found in open dump sites often result in scavengers retrieving items and reusing them, leading to serious health implications due to the transmission of infectious diseases [6-7].

In this study area, landfills are the most preferred method of waste disposal. These include sanitary, engineered, controlled and uncontrolled landfills (open dumping). The occurrence of numerous biochemical reactions within the waste body in the landfills produces biogas and leachates which contribute to air, water and soil pollution [8].

The system of open dumping of solid wastes attracts varying environmental and health concerns [9, 10]. Solid waste disposal sites have, to a great extent, managed this challenge over time. A solid waste disposal site is a type of landfill site that collects municipal solid waste from homes, businesses, and institutions

The growing population and demand for infrastructural development have led to the optimization of all lands, both old and new landfills [11, 12]. The need to determine the safety of structural foundation soils have made engineers to focus on investigating the properties of soils from solid waste sites [13].

The component of a structure that conveys the loads precisely to the underlying soil is regarded as a foundation [14, 15]. The choice of foundation type depends on the nature and strength of soil. Foundation soil is meant to sustain the loads from any engineered structure placed upon it without a shear failure and with the resulting settlements being tolerable for that structure, to ensure satisfactory performance [16].

The shearing resistance offered by the foundation soil determines the stability and integrity of engineering structures erected on any soil [17]. The strength evaluation of foundation soils is very critical in the design of foundations. Owoyemi and Awojobi [18], consider the constituent study of foundation soil as a preventive approach to foundation failure. To overcome the collapse of structures, a detailed Geotechnical investigation of the foundation soils is needed [19, 20] and this validates the essence of this study.

Municipal solid waste is frequently generated at Jattu-Uzairue, Edo State as it is occupied with human settlements, commercial activities and small industries. Economic development and the population growth promotes the production of these solid waste. Approaching the challenges linked with improper waste management and disposal in this area is a non-negotiable alternative for a sustainable environment and a heathy living.

Various soil geotechnical properties are affected by indiscriminate disposal of waste and citation of open dumpsites. Beneath dumpsites, different contaminants are trapped in the soil, results in long term contamination of the underlying soil in terms of geotechnical characteristics [20]. Alignment of structural foundation with the engineering characteristics of available soil in the construction site is a matter of concern for engineers and builders [21].

The primary aim of this study is to assess the geotechnical properties of the soil at the dumpsite at Jattu, Edo State, Nigeria. The geotechnical properties like particle size distribution and shear strength were carried out for samples from dump sites and natural soil. Shear strength parameters such as angle of internal friction ϕ and cohesion C were used to estimate the bearing capacity of the soil.

2. Related Studies

The potential of municipal-solid-waste finer-fraction as sustainable structural fill material was evaluated by Dalal et al., [22]. The authors examined in detail the bearing capacity, settlement and modulus of subgrade reaction for the shallow foundation of different sizes and shapes resting on soil with low subgrade modulus and the soil improved with a layer of MSW-FF as structural fill. To understand the upshot of soil and foundation stiffness on the foundation design parameters, STAAD Pro. The software was employed for soil-structure interaction analysis.

Thakur et al., [10] presented the impact of open-dumping on soil behaviour and degradation-settlement-analysis of soil in non-engineered-landfill. Their study considered settlement analysis and the investigation of Geotechnical features of waste soil and its comparison was done with natural soil. Energy Dispersive X-Ray Spectroscopy and Scanning-Electron-Microscopy (SEM) were employed for geochemical analysis. Tests carried out on samples of waste and the natural site includes particle size distribution, specific gravity, compaction, maximum dry density (MDD), permeability, California bearing ratio (CBR) and shear strength.

The preferred location in Port-Harcourt was studied by Nwankwoala and Warmate [23]. They investigated the geotechnical behaviour of the soil sample and recommended the use of a pile foundation to carry the imposed load from the cellar to the underlying sand stratum during structural construction. Alawode et al., [24] assessed the suitability of soils as foundation materials. Their focus was on selected soils in Ile-Ife, Osun State, Southwestern Nigeria. The authors analyzed the carrying capacity of collected soil samples and characterized them. Ige and Ogunsanwo [25] also evaluated the geotechnical properties of foundation soils in Ilorin, Southwestern, Nigeria.

Investigations on shear strength parameters employing triaxial and direct-shear-box methods were carried out by Oluwapelumi [26], Otuaga [27], and Egbe et al., [28]. They addressed soils in Akure, Owo Local Government Area of Ondo, and Calabar South, Nigeria respectively. A safe-bearing-strength of 139.01 kN/m2 was recommended in [27] for adoption in foundation design.

This work intends to fix the gap in previous works as there is no documentation pertaining to soil characterization and bearing capacity assessment of dumpsite soils at Jattu, Edo State, Nigeria. The population of the residents in this area and the demand for infrastructural development amplifies the necessity of this research. This is because, lack of waste management in the area has resulted to lack of available natural site for building construction thereby posing the danger of shortage of houses to service the in-flux of resident which increase on the daily basis. The outcome of this study will be of great assistance to engineers and contractors in the study area and will add to the body-of-knowledge on bearing strength in relation to the behavior of the natural soil, compared to the municipal solid waste soils in order to achieve the suitability of the later for foundation engineering. In this study, engineering properties of the selected-soil is evaluated, strength parameters and carrying strength of the soil is determined. The studied soil is characterized and suitable foundation type corresponding to the bearing-strength of the soil is recommended.

3. Methodology

3.1 Location of the study area

Soil samples were collected from municipal solid waste dumpsite located at Jattu Uzairue in Edo State, Nigeria. Jattu is a town in Edo state Nigeria. It is the headquarters of the Uzairue - Clan in Etsako-West Council of Edo State, Uzairue Clan consist of twenty-one villages which comprises of Jattu and others. It is geographically located within the coordinates N 7^o 5’ 31” Latitude and E 6^o 17’ 47” Longitude. Figure 1 shows the township map of Jattu and neighboring communities, highlighting settlements and road networks. Figure 2 depicts the site considered in this study. The samples used were gotten from the site at depths of 1m, 1.5m, 2m, 2.5m and 3m. The materials excavated from the study site are solid wastes from homes, industries, institutions, and farms. The major-components of studied-soil sample are biodegradable materials such as food waste, paper waste, spoiled food grains, biodegradable plastics, agricultural remains and ashes.

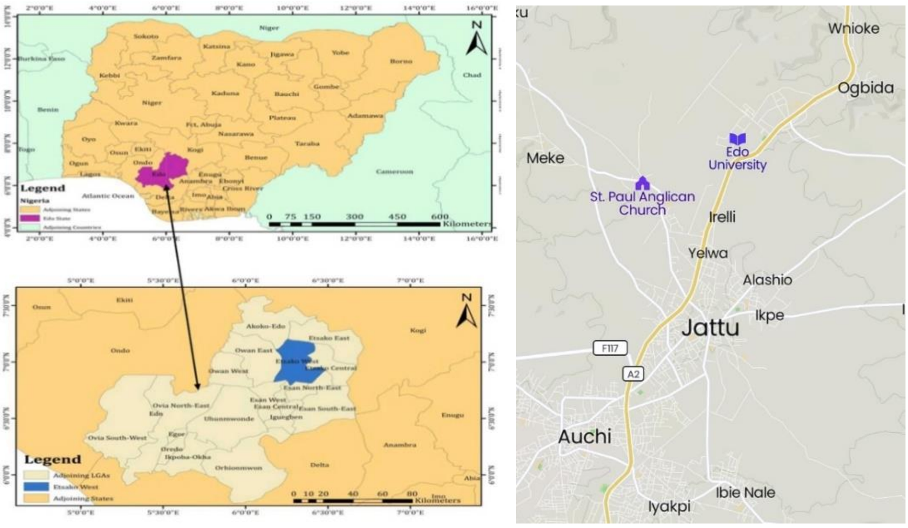

Figure 1. Map Showing Location of Jattu in Etsako West Council of Edo State.
Source: Ministry of lands, surveying and housing, Edo State, 2008

Figure 2. The Study Site at Jattu Uzairue, Edo Nigeria.

3.2 Experimental Procedure

Preliminary tests were conducted on the soil samples (natural soil and solid waste site soil) to examine their index properties for proper identification and to determine their suitability for foundation works. The soil tests were carried-out in accordance to the specifications of British Standard BS 1377 [29]. The tests include; Sieve Analysis, Atterberg Limits, Specific Gravity, and Moisture Content. The shear-strength parameters of the soils were also evaluated and presented.

3.2.1 Sieve Analysis

The test was carried out in the laboratory in conformity to British Standard (BS 1377) using BS sieve sizes of 4.75mm, 2.36mm, 1.18mm, 600µm, 425µm, 300µm, 150µm, 75µm, and a pan. The weight of the materials retained on each sieve size was recorded and employed during computations for plotting the grain size distribution curve.

$$\text{Percentage retained} = \frac{\text{weight of soil retained}}{\text{Total weight of sample}} \; X\,100 \qquad (1)$$

Percentage passing = 100% cumulative – percent retained (2)

3.2.2 Atterberg Limits

In accordance with the specification of British Standard (BS 1377) and using the Cassagrande apparatus, the liquid-limit, plastic-limit and plasticity index were determined in the laboratory and computed. The water-content at which the soil transforms from semisolid to plastic-state is regarded as the plastic limit (PL) whereas the water content at which soil changes from plastic to a liquid state is called the liquid limit (LL). The plasticity-index (PI) is given by;

PI = LL – PL (3)

3.2.3 Moisture content

Moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil or the percentage of water present in a soil mass by its weight [30]. This test was carried out in accordance with British Standard (BS 1377).

$$\text{Moisture content (\%)} = \frac{W_w}{W_s} X\ 100\% \quad (4)$$

Where; $W_w = weight\ of\ water$

$W_s = Weight\ or\ dry\ soil$

3.2.5 Shear Strength

Soil shear-strength is the extent of shear stress that will result in yielding a soil-mass under load which exist due to interaction of particles brought about by cohesive and frictional forces [31]. The soil-shear-strength is evaluated in terms of cohesion and angle of internal-friction of the soil particles. Shear strength determines the capacity of a soil to support a loading from a structure. The cohesion property of the soil, angle of internal-friction and shear-strength of the individual soils was determined using the direct shear box apparatus.

3.2.6 Bearing Capacity

The maximum-pressure the soil can sustain without shear failure is termed as an ultimate - bearing-capacity of the soil [32]. The parameters obtained from direct-shear-test were applied in Terzaghi's bearing capacity equations (5) to (7) to obtain the ultimate-bearing-capacity of the soils for different types of footing-circular footing, square footing, and strip footing respectively. The corresponding values of the bearing-capacity-factors were derived from Das [33]. For each of the footings, safety factor of 3.0, unit width and unit depth were adopted.

$$Q_U = 1.3cN_c + \gamma DN_q + 0.3\gamma BN_\gamma \quad (5)$$

$$Q_U = 1.3cN_c + \gamma DN_q + 0.4\gamma BN_\gamma \quad (6)$$

$$Q_U = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma \quad (7)$$

Where Q_U = Ultimate bearing capacity (kN/m3)

C = Cohesion (kN/m3)

γ = bulk unit weight of soil (kN/m3)

D = depth of footing (m)

B = width of footing (m)

N_c, N_q, N_γ are bearing capacity factors which depend on the values of angle of internal friction φ.

Allowable bearing capacity of soils q_{allow} was determined using;

$$q_{allow} = \frac{Q_u}{F_s}$$

Where F_s is the factor of safety.

4. Results and Discussion

4.1 Sieve Analysis

The percentages of fine in the soil particles collected from the dumpsite in the present study was between 12.15 to 15.35 % for SWSS sample as shown in Table 1 while that of NS sample ranged from 10.75 to 14.36 %. The contaminated soil samples had higher percentages of fine content when compared to that of the uncontaminated soil used as the control due to fine particles arising from the decayed municipal solid waste which dominates the soil. This aligns to similar work carried out by Krishna et al. [34] and Estabragh et al. [35]. Soils can be categorized as coarse grained (sand or gravel), fine-grained (clay or silt) and highly organic soils, according to USCS system of classification. According to Unified Soil Classification System (USCS), NS sample is made of sand-silt mixtures, while SWSS sample consists of sand-clay mixtures.

Table 1: Results of Particle size distribution of the contaminated and uncontaminated soil samples

Sieve Sizes (mm)	% Passing									
	1.0m SWSS	1.5m NS	2.0m SWSS	2.5m NS	3.0m SWSS	1.0m SWSS	1.5m NS	2.0m SWSS	2.5m NS	3.0m SWSS
4.75	100	100	100	100	100	100	100	100	100	100
2.36	80.36	93.75	85.70	95.93	86.62	96.54	90.20	94.66	90.15	92.64
1.18	73.12	81.56	77.32	87.76	79.46	85.45	84.12	83.56	86.36	86.4
0.6	66.35	62.48	69.80	72.60	72.58	76.40	76.30	60.72	78.45	64.15
0.425	47.50	52.42	42.52	44.34	50.50	53.74	52.32	56.40	53.64	54.35
0.3	31.04	36.46	33.08	58.36	36.76	56.55	45.65	42.56	46.90	36.90
0.15	15.24	17.24	17.44	24.19	18.65	22.16	35.72	25.80	37.21	28.86
0.075	12.15	10.75	13.28	12.36	14.10	13.48	13.70	13.42	15.35	14.36

4.2 Atterberg Limits

From Table 2, it was observed that there were low PI values for uncontaminated soil sample as a result of the paltry quantity of clay existing in among the soil particles. The contained soil samples had high PI values due to decrease in the effective porosity rising from the clogging impact of pore space because of the increased number of microorganisms in the leachate. The Atterberg limits provides a quantitative description on the effect of varying water content on the consistency of fine grained soils. Generally, they are used in classification of soils and assessment for engineering purposes. The Atterberg limits of NS and SWSS samples were presented in Table 2. The liquid limit for the SWSS sample varied from 32.50% to 39.50%, while that of NS sample varied from 36.80% to 41.70%. The plastic limit and the plasticity index varied from 19.10% to 25.10% and 27.30 to 33.40%, 13.40 to 14.50 and 7.60 to 9.50 for SWSS and NS samples respectively. The reduction in the plastic limit of the SWSS samples is attributed to the increase in cohesion of the soil particles including its resistance to cracking.

Table 2: Results of Particle Atterberg limits for NS and SWSS samples

Sample Depth (m)	SWSS Sample			NS Sample		
	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)
1.0	32.50	19.10	13.40	36.80	27.30	9.50
1.5	34.00	20.50	13.50	37.60	28.80	8.80
2.0	35.70	21.20	14.50	38.20	30.60	7.60
2.5	37.70	23.50	13.60	40.10	31.30	8.80
3.0	39.50	25.10	14.40	41.70	33.40	8.30

4.3. Specific Gravity Test

In Figure 3, the result of the specific-gravity of both soil samples were tabulated. The specific-gravity of the NS - sample increased from 2.60 at 1m depth to 2.75 at 3m depth. For SWSS specimen, it increased from 2.45 at 1m depth to 2.52 at 2m and reduced to 2.40 at 2.5m with a rise of 3m. The least value of specific-gravity (2.40) recorded at 2.5m depth is due to the dominance of clay-sized particles at this depth. The specific-gravity of clayey and silty soils varies from 2.6 to 2.9, according to Das [33]. This implies that most of the soil samples collected were silty-clayey in nature.

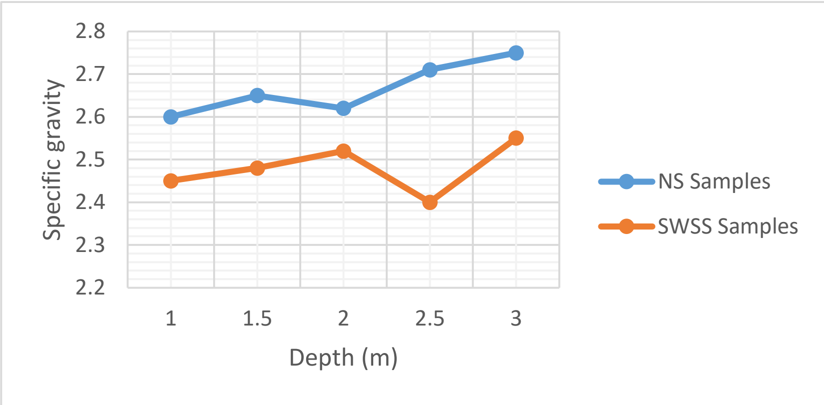

Figure 3. Variation of specific gravity with depth for NS and SWSS specimens.

The specific gravity of NS is larger compared to that of SWSS with a maximum and a minimum percentage variation of 7.84% and 4.84% respectively. This implies that both soil samples are suitable for construction although Prakash and Jain [36] confirms that the higher the value of specific-gravity of a sample, the more strength it has for the foundations and roads. The attenuation of SWSS values is due to the decomposition of particles of the organic content present in the soil [37]. The behavior of these soils was in conformity with the studies carried out by Thakur et al., [10, 38, 39].

4.4. Shear Strength

Table 3 captured the values of shear-strength parameters (c and ϕ) obtained from direct-shear-test. The maximum and least cohesion values were observed to be 24 kN/m2 and 17 kN/m2, 15 kN/m2 and 5 kN/m2 for NS and SWSS samples at 1m and 3m depth respectively. The highest internal friction angle was 22ºC and 24ºC, while the lowest internal friction angle was 6ºC and 9ºC for NS and SWSS samples respectively. The internal friction angle lies within 26ºC and 48ºC for granular soils, while internal friction angle less than 26 o is for fine soils [40, 41]. The results obtained as the angles of internal-friction indicates that the samples are fine soils [42]. Both NS and SWSS possess good shear-strength and can serve as good foundation materials for structures.

Table 3: Shear strength parameters for NS and SWSS samples

Soil Type	Depth (m)	Cohesion (kN/m^2)	C	Angle of Internal Friction (ϕ)
Natural soil	1.0	24		6
	1.5	22		10
	2.0	20		12
	2.5	19		15
	3.0	17		22
	1.0	15		9
	1.5	12		11

Solid waste site soil	2.0	10	13
	2.5	7	17
	3.0	5	24

4.5 Bearing Capacity of soil

The results of bearing capacity evaluation were presented in Table 4 (a, b, and c). The shape of the footing determines the variation in the bearing-strength of soil samples. The square-footing was found to have the greatest bearing capacity for each of the soil samples, followed by circular footing while strip footing has the least bearing capacity. The coefficients applied in the bearing capacity equations and the varying values of the bearing-capacity-factors contributed to these observations. The samples were c-ϕ soils and are good foundation materials.

Table 4(a): Bearing capacities of the soils at varying depths for strip footing

Soil Type	Depth (m)	Ultimate Bearing Capacity Q_u (kN/m^2)	Safe Bearing Capacity Q_{safe} (kN/m^2)
Natural Soil	1.0	215.74	71.91
	1.5	258.41	86.14
	2.0	273.97	91.32
	2.5	326.76	108.92
	3.0	373.08	124.36
Solid waste site soil	1.0	161.20	53.73
	1.5	166.81	55.60
	2.0	170.13	56.71
	2.5	190.51	63.50
	3.0	213.46	71.15

Table 4(b): Bearing capacities of the soils at varying depths for circular footing

Soil Type	Depth (m)	Ultimate Bearing Capacity Q_u (kN/m^2)	Safe Bearing Capacity Q_{safe} (kN/m^2)
Natural Soil	1.0	270.76	90.25
	1.5	320.06	106.69
	2.0	335.84	111.95
	2.5	395.25	131.75
	3.0	442.00	147.33
Solid waste site soil	1.0	198.95	66.32
	1.5	201.52	67.17
	2.0	201.55	67.18
	2.5	215.26	71.75
	3.0	230.17	76.72

Table 4(c): Bearing capacities of the soils at varying depths for square footing

Soil Type	Depth (m)	Ultimate Bearing Capacity Q_u (kN/m^2)	Safe Bearing Capacity Q_{safe} (kN/m^2)
Natural Soil	1.0	271.08	90.36
	1.5	320.95	106.98
	2.0	337.19	112.40
	2.5	414.38	138.13
	3.0	505.06	168.35
Solid waste site soil	1.0	199.43	66.48
	1.5	202.45	67.48
	2.0	232.62	77.54
	2.5	313.11	104.37
	3.0	396.06	132.02

5. Conclusion

From the observations and findings made, the following conclusions were deduced; the uncontaminated soil within and around the waste site is relatively consistent, though there are few divergences. The contaminated soil has lower specific gravity and this indicates the presence of organic content in the soil.

According to Unified Soil Classification System (USCS), the uncontaminated soil sample is made of sand-silt mixtures, while sample from the dumpsite consists of sand-clay mixtures. Soils from this dumpsite should be stabilized using additives in order to enhance its engineering properties and its suitability to serve as a good foundation material. Utilization of the soil for construction largely solves the problem of groundwater pollution and release of hazardous gases to the atmosphere.

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