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A Comparative Investigation into Some Engineering Properties of Soils from Two Selected Sites in Jos, Nigeria

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ABSTRACT
The continues use of inappropriate construction methods on building substructures by some building contractors within Jos and its environs relatively to an assumption that "the soils within Jos are stable", this assumption has led to many building contractors altering the balance between strength (stability/safety) and economy (cost) i.e. given more priority to economy than strength by not undertaking detail site investigation on site and in the laboratory to know the bearing capacity and behaviour of the soils prior to execution of the project, this in-turn has resulted to many structural defects on buildings and other infrastructures within Jos and as well as building collapse in some part of the state. Consequently, a comparative investigation was carried out on some selected construction sites within the area under view in order to determine if actually the initial assumption was true about soils in Jos. The results obtained clearly show that there was a high degree of variation considering the strength characteristics and behaviour of soils within Jos.
Keywords: construction methods; strength; economy; site investigation; bearing capacity; variation.

INTRODUCTION

Weathering is the chemical degradation and physical disintegration of rock and soil elements at and near the earth's surface, resulting in their alteration and breakdown (Geological Society Engineering Group Working Party Report, 1995) in (Read, Miller, Luxford & Olsen, 2005). To diverse groups of specialists who work with this material, the word soil has many varied meanings and implications. Soil is formed when rocks exposed to the atmosphere crumble and degrade due to mechanical, chemical, or both activity (wind, water, ice, and plants). The resultant debris can either stay put or be moved by water, glaciers, wind, or gravity and deposited far away from the parent rock (Army, 2012).

Geologists classify rocks into three basic groups:

1. Igneous (formed by cooling from a molten state).
2. Sedimentary (formed by the accumulation and cementation of existing particles and remains of plants and animals).
3. Metamorphic (formed from existing rocks subjected to heat and pressure)
4. There are frequently numerous levels (strata) of soil in a given place, each composed of a different type of soil. Strata can be as thin as a tenth of an inch or as thick as several feet. The topsoil, often known as agricultural soil, is the top layer. A soil profile is a vertical cross section across the earth that shows the depths and varieties of soil (Army, 2012).

Soil formation is a continuous process and is still in action today. The great number of original rocks, the variety of soil-forming forces, and the length of time that these forces have acted all produce many different soils. For engineering purposes, soils are evaluated by the following basic physical properties:

1. Gradation of sizes of the different particles.
2. Bearing capacity as reflected by soil density.
3. Particle shapes.

(Army, 2012).

An engineer extends soil evaluation by considering the effect of water action on the soils. With a complete evaluation, an engineer can determine whether or not the soil is adequate for the project (Army, 2012). Soil occurrence and distribution in nature differ from one area to the next. The kind of soil is determined by the rock type, mineral components, and local climate conditions. Soils are utilized as building materials, and civil engineering buildings are built on or on the earth's surface. The stability of civil engineering constructions is influenced by the geotechnical qualities of soils. The majority of soil geotechnical parameters interact with one another (Roy & Sanjeev, 2017).

The portion of a structure that conveys the structure's weight to the ground is called a foundation. Foundations are used to sustain all constructions built on land. As a result, a foundation serves as a connection between the structure itself and the ground underneath it. The maximum average contact pressure between the foundation and the soil that should not cause shear failure in the soil is known as the bearing capacity of the soil. A safety factor is included into bearing capabilities to avoid failure. So, without any safety features, the final bearing capacity would be its apparent point of failure. The fact that foundations for various types of structures lie on soils necessitates the requirement for varying bearing capacities (Eni, Oko, & Oka, 2013). The geotechnical qualities of the chosen location play a vital role in the feasibility of any realistic project since superstructures transfer load to the sub-soil through various structural components. As a result, selecting and designing appropriate substructure pieces that are compatible with the necessary structure is critical. Furthermore, because the building to be built is frequently planned ahead of time, such a selection is mostly influenced by sub-soil properties. To achieve such a difficult goal, regular laboratory experiments are used to investigate the subsoil and analyse its strength and compressibility properties. Following that, based on the sub-soil properties and building requirements, the bearing capacity of shallow and deep foundations that are viable for the planned construction is estimated using a standard codified approach. Customarily, bearing capacity of shallow and pile foundations is estimated using codal provisions developed after Terzaghi &

Meyerhoff and static formula respectively (Basak, Roy, Mukherjee & Sumit, 2009).

However, sophisticated field tests, such as the pressure meter test, have recently arisen to evaluate the carrying capacity of soils. In this respect, it becomes vital to investigate the differences in the findings acquired from these tests compared to the traditional one (Basak, Roy, Mukherjee & Sumit, 2009).
When determining the bearing capacity of soils beneath a strip footing, Terzaghi's bearing capacity theory comes in handy. This hypothesis only applies to foundations with small depths. He considered some assumptions which are as follows.

1. The base of the strip footing is rough.
2. The depth of footing is less than or equal to its breadth i.e., shallow footing.
3. He neglected the shear strength of soil above the base of footing and replaced it with uniform surcharge (γD_f).
4. The load acting on the footing is uniformly distributed and is acting in vertical direction.
5. He assumed that the length of the footing is infinite.
6. He considered Mohr-coulomb equation as a governing factor for the shear strength of soil (Terzagi & Pek, 1967).

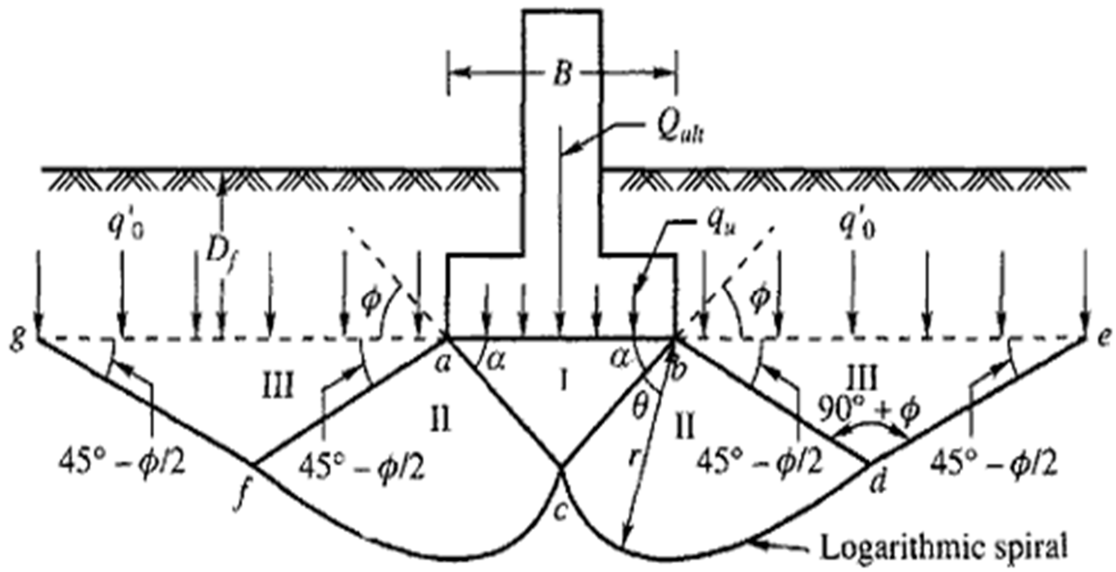

Figure 1: General shear failure surface as assumed by Terzaghi for a strip footing

(The sinking of Zone I creates two zones of plastic equilibrium, II and III, on either side of the footing. Zone II is the radial shear zone whose remote boundaries bd and af meet the horizontal surface at angles (45° - Ø/2), whereas Zone III is a passive Rankine zone. The boundaries de and fg of these zones are straight lines and they meet the surface at angles of (45° - Ø/2). The curved parts cd and cf in Zone II are parts of logarithmic spirals whose centers are located at b and a respectively). Terzaghi in (Smith, 2006) stated that a broad soil shear failure or a local soil shear failure causes a foundation's bearing capacity collapse. Vesic listed punching shear failure as a further form of bearing capacity failure (Smith, 2006).

It is impossible to overstate the importance of studying the subsurface qualities of the soil structure on which engineering constructions are built. If the subsurface qualities of the soil structure on which engineering structural structures such as buildings, roads, bridges, and dams are built are not adequately examined and evaluated, and suitable construction procedures are not used, they may collapse, resulting in death. Knowledge of subsurface soil shear strength is critical in any engineering construction projects including stability analysis, which may be utilized in the design, construction, and stability of structures' foundations, retaining walls, and earth slope stability. In practice, two separate loads are imposed on the soil, one vertically downward and the other horizontally, causing load strains to be transmitted to the foundation soil. If the soil is not in balance with these loads (forces/stresses), it may fail (Ryeshak, Wazoh & Daku, 2015).

GEOGRAPHICAL CONDITIONS

The study area is Jos-Bukuru metropolis in Plateau State, located near the centre of Nigeria. It covers 8600km^2 and is bounded by 300–600-meter escarpments around much of its circumference. With an average altitude of 1280 metres it is the largest area over 1000 metres in Nigeria, with a high point of 1829 metres in the Shere-Hills. The Plateau has given its name to the State, "Plateau State" in which it is found and is itself named for the state's capital, Jos (Pasquini & Alexander, 2005).

Geology of the Study Area

Three rock types dominate the Jos Plateau. The Late Cambrian and Orduvician eras are represented by the Older Granites. The Younger Granites are Jurassic emplacements that are part of a larger range that encompasses the Ar Massif in the middle Sahara. Since the Pliocene, several volcanoes and basalt sheets have erupted. Tin has been mined in the Younger Granites since the turn of the century, both during and after the colonial period. The Kaduna, Gongola, Hadejia, and Yobe rivers all have their origins in this area (Pasquini & Alexander, 2005).

Climate of the Study Area

The climate on the Plateau is the semi temperate climate with temperatures ranging from 18 °C (64.4 °F) to 25 °C (77.0°F) (Pasquini & Alexander, 2005).

SOILS

The framework for the classification and description of soil is provided in the following sections. For engineering purposes soil is grouped as shown in Table 2.1:

Table 2.1 Soil Groups

COARSE SOILS (granular soils or non-cohesive soils)		FINE SOILS (cohesive soils)		OTHER SOIL
Gravel	Sand	Silt	Clay	Organic Soils

Source: (Miller, Luxford & Olsen, 2005).

Soil behaviour always depends to some extent on grain size and this forms a starting point for the engineering classification of soils. On this basis soils are categorised as in Table 2.2.

Table 2.2 Grain Size Criteria

TYPE	COARSE								FINE		ORGANIC
	Boulders	Cobbles	Gravel			Sand			Silt	Clay	Organic Soil
			coarse	medium	fine	coarse	medium	fine			
Size Range (mm)	200	60	20	6	2	0.6	0.2	0.06	0.002		~~Refer to Section 2.3.5~~
Graphic Symbol											

Source: (Miller, Luxford & Olsen, 2005)

Different geotechnical qualities of soils affect the behaviour of structures in different ways. The load bearing capacity of soils is proportional to its specific gravity (Surendra et al., 2017). The density index is used to determine how compact coarse-grained soils are. Fine-grained soils can be utilized to build a low-permeable layer for solid waste disposal and core in earth dams because consistency limitations indicate the features of fine-grained soils. Particle size indicates the gradation of soils, which is used in the building of roads, dams, embankments, and filter designs, among other things. Soil carrying capacity is improved by compaction. The settling of buildings is indicated by the consolidation qualities of soils. Permeability conveys information on foundation stability, seepage via embankments, and so on. The most essential geotechnical feature of soils is shear strength, which aids in the stability of civil engineering constructions on or below the ground. Researchers may use the interplay between different geotechnical qualities of soils to help them construct foundations for various types of civil engineering structures. (Surendra & Sanjeev, 2017)

Although gravelly soil has the highest carrying capacity of all soil types, there are significant variances within this category that may be analyzed from a variety of perspectives. There are five types of gravelly soils. The properties of the foundation soil from the perspective of bearing capacity are set within the CSN 73 1001 in tables. However, this applies only to simple and small structures. Bearing capacity up to 1 meter differs not only grain size of soil also to the width of the foundations. Foundations width of 3m has the best values of bearing capacity in all classes of gravel. The largest value of bearing capacity 1000 kPa (100%) has G1 (GW) Well-graded gravel and smallest values of 250 kPa (25%) have G5 (GC) clayey gravel. It is such a difference of 750 kPa. The worst values of bearing capacity are then in all classes of gravel soils at the base a width of 0.5 meters. Where G1 (GW) reaches a maximum value of 500 kPa (50%) and G5 (GC) is 150 kPa (15%) (Plachý, Weiss, & Bartuška, 2016).

There is also a noticeable variation in the size of the gravel grains. Because of the large variety of gravel grains, well-graded gravel has a higher bearing capacity from the standpoint of a much better soil than badly graded gravel. With an increase in fine soil concentration, bearing capacity declines at the same rate. In the case of gravel, it can account for up to 35% of the overall soil content. Clay deteriorates fine-grained soil properties substantially (Plachý, Weiss & Bartuška, 2016).

The construction industry has made enormous progress in the design and construction of safe and cost-effective structures throughout the years. Today's designs are increasingly complicated in structure, necessitating the pursuit of greater stability and economy in building construction. As a result, determining the bearing capacity of the soils on which these buildings are to be stabilized requires the most appropriate and efficient technique, and with relevant information about the strength, behavior, and type of the soil, town planners could use this information to adequately plan for towns and cities. Because field testing is more expensive than building a structure, many contractors and engineers avoid them (Pravin and Karim, 2016). As such many building foundations in Jos and its environs are laid without evaluating the bearing capacity of the soils particularly with small structures like bungalows and duplex buildings and some contractors on construction sites within Jos tent to even omit the construction of the foundation predominantly with small structures base on the vague assumption that the soils on the Jos plateau are stable. The effect of this omission may result to uneven load distribution on the supporting soils and structural cracks on buildings thus may contribute to the causes of incessant collapse of buildings in the country.

Consequently, the following questions remain unanswered:

1. To what extent do Building Production Managers consider and actually carry out soil bearing capacity test at/during the design and construction phase of buildings in Jos?
2. Which type of soil would be most likely to emerge paramount with regards to the bearing capacity of soil within Jos-Bukuru metropolis?
3. How much of soil bearing capacity data bank (available information) concerning Jos-Bukuru metropolis is readily available and is being considered in the planning and allocation of building infrastructures within the area of study?

MATERIALS AND METHODS

The site investigation for this study was undertaken by the researcher and a number of laboratory test were carried out on soils.

Soil Sample Collection

Three trial pits were opened up to the depth of 0-1.5meters using the standard method of sampling for each selected site and necessary precautions of handling the soil samples from collection on site to the laboratory for testing were strictly observed. Disturbed samples were collected to the laboratory for necessary test to determine the behaviour and strength of the soils.

Method

The major method of data collection for this research includes:

1. Site surveys and
2. Laboratory experiment.

Surveys

A general survey was carried out on buildings within the case study of this research to ascertain the nature of construction of the sub-structure of new buildings and the physical characteristics of existing infrastructures. The results of this survey lead to the selection of the particular sites considered in this study. Such that, the buildings and other physical infrastructures around Ndagi-Faruk areas of Jos North Local Government Area were observed to have structural cracks particularly to their external wall, fences as well, their road structures were observed to have deteriorating surfaces and defective drainage systems, in addition to a collapsed building on the site. Whereas, the buildings and other physical infrastructures within the university of Jos permanent site were observed to have little or no defects as compared to Ndagi-Faruk area in Jos north local government area. The result of this survey prompt to the use of the succeeding method of data collection used for this study i.e., Laboratory experiment, in other to investigate the behaviour and strength of soils for each site and as well, to determine the degree of variations in the strength and behaviour of the soils of the different sites selected.

Furthermore, it was observed during this survey that the construction of substructures predominantly with small structures like detach houses and small bungalows are constructed without the foundation footing, on bases of the vague assumption that “the soils within Jos and its environs are stable without adequate investigation of the soil properties”.

Experiments

Experiments were carried out by the researcher to enable the collection of primary data in the laboratories. The following standard laboratory tests were carried out to determine the behaviour and strength of the soil:

1. Alterberg limit test determination (liquid limit; plastic limit and shrinkage limit);
2. Sieve analysis test determination;
3. Natural moisture content test determination;
4. Specific gravity test; and
5. Triaxial Soil bearing capacity tests

PRESENTATION OF TEST RESULTS

The test results are given in the summary sheet indicating the trial pits and the location of site. The soil profile/description for each borrower's pit varies and the results are presented for each borrower's pit.

Water Table

No water table was encountered at the time of this investigation.

Bearing Capacity

The average ultimate bearing capacity and safe bearing capacity were computed on the basis of Terzaghi shallow foundation theory using values of shares parameter and bulk density data obtained from Triaxial compression test carried out under unconsolidated undrained condition at lateral pressures (cell pressures) of 15, 30 and 45 P.S.I (x 6.89kN/m2). The average safe bearing capacity values were obtained by using three (3) as a factor of safety and results obtained are presented as follows in table 4.1:

Table 4.1: Summary of Laboratory Test Result

Site	Depth Meters	Sample No.	Natural Moisture	Bulk Density kg/m^3	Dry Density kg/m^3	Mechanical Analysis			Liquid Limit	PL	LS	Cohesion kn/m^2	Angle of Friction Degree	Specific Gravity	Ultimate bearing capacity (KN/m^2)	Safe bearing capacity (KN/m^2)
						Gravel 7mm	Sand 3.6mm	Silt/Clay 200μm								
UJP	1.50m	A	16.0	1.931	1.664	94	52	31	28.2	18.7	5.0	13.78	34°	2.45	741.086	247.029
UJP	1.50m	B	14.4	1.904	1.665	99	65	33	31.8	26.0	4.0	13.78	37 °	2.62	1008.436	336.145
UJP	1.50m	C	22.9	1.936	1.575	99	78	42	32.1	22.7	3.0	55.12	11°	2.61	142.011	47.337
NF	1.50m	A1	17.7	2.125	1.817	83	62	44	22.5	16.0	5.0	27.56	31°	2.56	1139.941	379.980
NF	1.50m	B1	20.4	1.800	1.496	80	45	33	44.0	29.0	7.0	20.67	32°	2.42	939.565	313.188
	1.50m	C1	19.0	2.028	1.704	93	82	73	32.2	25.0	8.0	68.9	12°	2.55	751.050	250.350

Source: Field work (2018)

DATA ANALYSIS

Mean and Standard Deviation of Results

The two statistical measures used to analyse the result obtain at the course of this study are mean and standard deviation. The mean (x-) is a calculated "central" value of the set of numbers while the standard deviation (SD) is a measure that is used to quantify the amount of variation or dispersion from the mean value of a set of numbers. The results obtain from the analysis were presented in Table 4.2:

Table 4.2 Mean and standard deviation of results

TEST	**UNIVERSITY OF JOS PERMANENT SITE**		**NDAGI-FARUK SITE**	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
LIQUID LIMIT	31%	2.17%	33%	10.8%
PLASTIC LIMIT	22%	3.74%	23%	6.6%
NATURAL MOISTURE CONTENT	18%	4.5%	19%	1.35%
SHRINKAGE LIMIT	4%	0.5%	7%	1.58%
ULTIMATE BEARING CAPACITY	**630.511 kN/m²**	**443.67 kN/m²**	**943.519kN/m²**	**194.48 kN/m²**
SAFE BEARING CAPACITY	**210.17 kN/m²**	**147.89 kN/m²**	**314.506 kN/m²**	**64 kN/m²**
BULK DENSITY	1.934kg/m^3	0.003%	1.984 kg/m^3	0.167%
DRY DENSITY	1.635 kg/m^3	0.163%	1.672 kg/m^3	10.8%
SPECIFIC GRAVITY	2.56	0.10	2.51	0.09

Source: Field work (2018)

Soil Grading Per Pit

Based on the visual inspection of the soils and the sieve analysis test carried out on the soil samples obtained the results deduced were as follows:

Table 4.3: Soil grading per pit

SITE LOCATION	TEST PIT	SOIL DESCRIPTION
UNIVERSITY OF JOS PERMANENT SITE	A	Sandy and Clay
	B	Sandy and Clay
	C	Sandy, Silt and Clay
NDAGI-FARUK	A1	Gravel, Sand and Clay
	B1	Gravel, Sandy and Loam (peat)
	C1	Gravel, Sandy and Clay

Source: Field work (2018)

Review of Findings with Relevant Literatures

According to Army (2012), "at a particular location are usually several layers (strata), one above the other, each composed of a different kind of soil and these layers may be a fraction of an inch or many feet thick", thus different kind of soils entails different geotechnical properties. In these investigation, different types of soil samples were obtained from different soil strata at 1.5m depth on each of the selected site, thus, it was observed that their bearing capacities vary considerably even on the same site with their ultimate bearing capacity values ranging from 142.011kN/m2 to 1008.436kN/m2 and from 751.050kN/m2 to 1139.941kN/2 - for the university of Jos permanent site and Ndagi-Faruk site respectively. Therefore, it is important that Building Production Managers and Design teams within the area of these study to carry out detail investigation of the various sub-strata that maybe encountered on site for every construction project with emphasis on the bearing capacity of the soils, putting into consideration that the supporting soil strata may have lower bearing capacity to the preceding soil strata and should be included in the design.

Whereas, it was observed from the laboratory test carried out on the different soil samples, that on the average, the ultimate bearing capacities of the soils were 630.511kN/m^2 having a standard deviation of 443.67kN/m^2 on the university of Jos permanent site and 943.519kN/m^2 with a standard deviation of 194.48kN/m^2 at the Ndagi-Faruk site. This entails that the soil at the University of Jos permanent site has comparatively lower bearing capacity with high degree of variation from the mean value. Comparing the mean value of the ultimate bearing capacity of the two sites selected, a difference of 313.008kN/m^2 was realized.

Different geotechnical properties of soils have different behaviour on the structure as well, the higher the specific gravity of soils, the higher the carrying capacity of soils (Surendra & Sanjeev 2017). From this investigation, it was observed that some soils with very low bearing capacity have higher specific gravity as in the case of sample C with a specific gravity of 2.61 greater than that of sample A (2.45), with a corresponding ultimate bearing capacity of 142.011kN/m2 and 741.086kN/m2. Similarly, sample B1 with a specific gravity of 2.42 was greater than sample C1 (2.55) having a corresponding bearing capacity of 939.565kN/m2 and 751.050kN/m2 respectively. On the average, it was observed that the soils at the Ndagi-Faruk site had higher bearing capacity compered to the university of Jos permanent site having lower specific gravity of 2.51 less than 2.56. Therefore, the specific gravity of soils alone should not be use as a determining factor for the carrying capacity of soils as "the specific gravity of soil also reflects the history of weathering (Tuncer et al, 1977)" and considering that "iron minerals have a larger specific gravity than silica (Bowels, 2012)", it implies that some soils could age with strength whereas some may age with diminishing strength (carrying capacity). The buildings and other physical infrastructures around Ndagi-Faruk areas of Jos North Local Government Area were observed to have structural cracks particularly with their external walls, fences as well, their road structures were observed to have deteriorating surfaces and defective drainage systems, in addition to a collapsed building on the site. From the site survey, laboratory test and the results presented in this study, it is now certain that the cause of the various defects stated at the Ndagi-Faruk area, not to have been as a result of poor carrying capacity of the soils but could be that other factors that are related to soils like the shrinkage limit i.e. "the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced (Reddy, 2017)" in other words it is the degree at which the soils decrease in volume upon drying such that, the soils at the Ndagi-Faruk area had an average shrinkage limit of 7% greater than 4% of the soils at the University of Jos Permanent site, i.e. the resulting shrinkage may possibly lead to excessive settlement. Whilst, other cause of the defects spotted could be construction related.

SUMMARY OF FINDINGS

Having carried out laboratory test and investigation on the soils from selected construction sites in Jos as presented in the various sections of this research work, the following findings were drawn from the results obtained:

1. That on the average, the ultimate bearing capacities of the soils were 630.511kN/m² and 943.519kN/m² at the university of Jos permanent site and Ndagi-Faruk site respectively. This entails that the soil at the University of Jos permanent site has comparatively lower bearing capacity with higher degree of variation between borrowers' pits.
2. Comparatively, the difference of the mean values of the ultimate bearing capacity of the two sites selected realized was 313.008kN/m².
3. It is not always the case, that "the higher the specific gravity of soils, the higher the carrying capacity of the soil" as observed by other literatures i.e. (Surendra et al., 2017). This is because it was observed within the case study of this research that some soils with very low bearing capacity have higher specific gravity as in the case of sample C with a specific gravity of 2.61 greater than that of sample A (2.45), with a corresponding ultimate bearing capacity of 142.011kN/m^2 and 741.086kN/m^2. Similarly, sample B1 with a specific gravity of 2.42 was greater than sample C1 (2.55) having a corresponding bearing capacity of 939.565kN/m^2 and 751.050kN/m^2 respectively. On the average, it was observed also, that the soils at the Ndagi-Faruk site had higher bearing capacity compered to the university of Jos permanent site having lower specific gravity of 2.51 less than 2.56. Therefore, the specific gravity of soils alone should not be use as a determining factor for the carriying capacity of soils as

"the specific gravity of soil also reflects the history of weathering (Tuncer et al, 1977)" and considering that "iron minerals have a larger specific gravity than silica (Bowels, 2012)", it implies that some soils could age with strength whereas some may age with diminishing strength (carrying capacity).

4. The observation made, at the Ndagi-Faruk site in Jos North Local Government Area, i.e. some of their buildings and other physical infrastructures within the area had structural cracks particularly with their external walls, fences as well as their road structures were observed to have deteriorating surfaces and falling drainage systems, in addition to a collapsed building on the site was not as a result of low/poor bearing capacity of the soils but that it could be other soils related issues or even construction related problems.

CONCLUSSION

From this study is certain that there was a high degree of variation considering the strength characteristics and behaviour of soils within Jos. Therefore it is important that Building Production Managers and Design teams within the area of these study not to relay on the general and vague assumption that the soils within Jos are stable, such that every soil is unique with location, timing and the chemical composition of the material but that they should carry out detail investigation of every site at various sub-strata pending on the type of construction work to be done, with emphasis on the bearing capacity of the soils, putting into consideration that the supporting soil strata may have lower bearing capacity to the preceding soil strata and thus should be included in the design of every type of physical structure to be built.

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