SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V8I5P101

Volume 8 Issue 5, 1-5, Sep-Oct, 2021

Research Article

Soil Investigation of a Collapsed Building Site in Jos, Nigeria

Timothy Danjuma[1], Mbimda Ali Mbishida[2], Ephraim Maude Haruna[3], Benjamin Yusuf Mailafiya[4]

[1,2,4] Department of Building Research, Nigerian Building & Road Research Institute (NBRRI) North-Central Zonal Office Jos, Plateau State, Nigeria
[3]Department of Road Research, Nigerian Building & Road Research Institute (NBRRI) North-Central Zonal Office Jos, Plateau State, Nigeria

Received: 18 August 2021 Revised: 23 September 2021 Accepted: 05 October 2021 Published: 16 October 2021

Abstract - *This investigation was conducted on soil samples collected from a site of the collapsed building in Jos, Nigeria, with the aim to serve as a reference document to Engineers, Designers, and Builders in the building profession. Two test pits of 0.4m x 1.2m located within the premises of the collapsed building were excavated at a depth of 0.6m, 1.0m, and 1.2m, at which samples were collected at each depth. The Soil Investigation was drawn in such that only vital tests that will provide the parameters required for the desire and construction of the foundation were carried out. These tests conducted include Sub-soil investigation, sieve analysis using the wet sieving procedure, Atterberg limit test in order to classify the soil according to the Unified Soil Classification System, and shear strength using triaxial compression test, which was further used to determine the soil bearing capacity. The results obtained show that the soil has slight to medium expansion and compressibility with poor drainage. The shear strength parameters obtained from trial pits MAE 2 at 1.0m yielded the least angle of internal friction of 6^0 with high cohesion values of $150N/m^2$. The highest cohesion values obtained were from test pit 1, which suggests that the soil contains an appreciable amount of clay and silt fractions. The allowable/safe bearing value was found to be $234.5\ KN/m^2$, which suggests that the soil is cohesive, consisting of clayed materials.*

Keywords *- Soil, Bearing capacity, Shear strength, Atterberg limit.*

1. Introduction

Building collapse is a global phenomenon but is more prevalent in developing countries. Between 2011 and 2012, high incidences of building collapse were recorded in Nigeria, with the highest in Lagos (60%), followed by Abuja (20%), Port Harcourt (10%), and others (10%). The frequency of its occurrence though reduced, is of great concern to every Nigerian, especially stakeholder in the built environment [1].

Buildings are primarily used for living, working, and storage. They can be categorized into three broad types. The first is the monumental structures which comprise religious buildings like Churches and so on, city halls, and sports arenas. The second is the institutional structures represented by the more usual kind, such as a block of flats and tertiary institutional buildings for academic and administrative purposes. The third group comprises the industrial structures represented by ordinary small-scale industrial types [2].

The site of the collapsed building is located along Gero Road Bukuru, Jos South Local Government Area of Plateau State, Nigeria (the savannah vegetation belt of Northern Nigeria). The collapsed building was constructed to provide accommodation for teaching and learning for the pupils of the Bukuru community of Jos. The collapsed building is a 1-storey building viz; ground floor and first floor with a courtyard surrounded by existing adjourning classrooms and neighbouring houses. The Building Structure includes a hall, laboratory, and five (5) classrooms with a narrow single loading corridor at the first-floor level. Bordering the site eastwards, west, and southwards are buildings constructed with either laterite blocks or sandcrete. Lying north is an access road. As a result of many years of weathering and decomposition in a tropical environment, the soil on the site has transformed into laterite soil. The underlying rock seems to have decomposed, leaving a relatively hard material that has a grave texture mixed with some clayey materials.

It was reported that this building collapse was the third incident that occurred in that community in the span of two (2) years. As such, this paper is intended to investigate the soil on which the said structure was built and hence serve as a reference document to Engineers, Designers, and Builders in the building profession. The recommendations will also help to reduce the rate and severity of building collapse, especially in that particular community and the nation at large.

Plate 1 The partially collapsed areas

Source: field survey

2. Materials and Method

The investigation was conducted on soil samples collected from the site of the school. Two test pits of 0.4m x 1.2m located within the premises of the school were excavated. Burrow Pit 1 was at a coordinate of 9.7977N and 8.8635E. Burrow Pit 2 was at a coordinate of 9.9799N and 8.8638E. A summary of the detailed borehole drilling is given in Table 4. There was continuous sampling with inspection for logging purposes throughout the depths of the test pits. The pits were dug manually to a depth of 0.6m, 1.0m, and 1.2m. Samples were taken at these depths (by driving in the sampler) in polythene bags and plastic tins so as to preserve the natural moisture content of the samples.

The Soil tests were conducted in accordance with standards [3]. Field logging was in line with the international format. Results for the test are presented in tabular form.

2.1. Materials and Equipment

The material used includes the soil sample dug from the site, while the equipment used includes the following, Compaction Rammer, Compaction mold, Electronic top-loading Balance, Semi-Automatic Digital Cone Penetrometer – BS:1377, Spatula, Sieve Brush, Aluminum Scoop, Glass Plate, Moisture Content Tin, and Laboratory Oven.

2.2. Method

2.2.1. Sieve Analysis through the Wet Sieving Procedure

Firstly, the specimen to be used for the simple dry sieving analysis was obtained from the original sample obtained from the site by riffling or by subdivision using the cone-and-quarter method. The specimen was placed on a tray and was allowed to dry overnight in an oven maintained at 105-110 °C [4]. Thereafter, it was allowed to cool and was weighted.

The dried soil sample was then placed in the topmost sieve and was shaken long enough that all particles smaller than each aperture size could pass through. The whole nest of sieves with receiving pan was placed in the shaker, the dried soil was placed in the top sieve, which was then fitted with the lid, and the sieves were securely fastened down in the machine. The sand retained on each sieve is transferred to a weighed container. Any particle lodged in the apertures of the sieve was carefully removed with a sieve brush, the sieve being first placed upside-down on a tray. These particles were added to those retained on the sieve. The masses retained (Ms_1, Ms_2, etc.) were recorded against the sieve.

2.2.2. Atterberg Limit Test

The Atterberg limit tests, which were basically moisture contents at different limit levels, were carried out to determine the plastic and liquid limits of the fine-grain soil. Engineering properties of the soil were correlated to those limits and were used to classify the fine soil according to the Unified Soil Classification System. The test was performed in accordance with the recommendations of [5].

2.2.3. Shear Strength of the Soil using Triaxial Compression Test

Shear strength is defined as the maximum shear stress that the soil may sustain without experiencing failure. Shear strength is a critical parameter in geotechnical projects. It is needed to derive the bearing capacity, design retaining walls, evaluate the stability of slopes and embankments, etc. [6]. The triaxial test is highly versatile; a variety of stress and drainage conditions can be employed. The cylindrical soil specimen is enclosed within a thin rubber membrane and placed inside a triaxial cell. The cell is then filled with fluid. As pressure is applied to the fluid in the cell, the specimen is subjected to hydrostatic stress. Drainage from the specimen is provided through the porous stone at the bottom, and the volume change was measured [7].

3. Results and Discussion

Table 1 presents the borehole drilling details, which include the sampling depth excavated, pit size, drilling method, and type of sampling.

Table 1. Borehole drilling details

Test Pit No.	**Sampling Depth Excavated [m]**	**Pit Size [m]**	**Drilling Method**	**Type of Sampling**
1	0.6, 1.2	0.4X1.2	Manual	Undisturbed
2	1.0, 1.5	0.8X1.2	Manual	Undisturbed

3.1. Sub-Soil Investigation

Details of the strata encountered during boring showed little variation in test pits 1 and 2 and are given on the borehole log. The detailed descriptions are summarized as follows:

3.1.1. Top Soil

The top is dark grayish sandy soil, which is certainly not suitable for any engineering foundation works. It is shallow, ranging from 0 to 0.30m. A loamy soil layer with some gravel was visible in the boreholes from the topsoil to 0.30m depth. At the depth, the soil was moist and reddish in color and of a medium-dense structure.

3.1.2. Lower Soil Stratum

At the bottom of the borehole [0.6m – 1.5m], the stratum consists of red iron oxide color and is moist. At 0.5m, water was encountered in test pit 1. The topsoil is a principal of a medium sandy nature with some gravel and fine material in both test pits.

Generally, the test pits tended to reveal the existence of a profile of bedrock or decomposing rock material.

3.2. Atterberg Limit Test

Table 2 shows the results of the Atterberg limit tests performed on the soil samples.

Table 2. Result of the atterberg limit test

Sample No	LL (%)	PL (%)	PI (%)	NMC (%)
MAE (Pit1) @ 0.6m	35	31	4	25.2
MAE (Pit 1) @1.5m	35	27	8	22.45
MAE (Pit 2) @1.0m	31	19	12	22.6
MAE (Pit 2) @1.5m	36	30	6	21.0

Plasticity Index was obtained from the two limits;

$$PI = LL - PL\ (\%) \tag{1}$$

Where PI = Plasticity Index

LL = Liquid Limit

PI = Plastic Index

From Table 2 using the Unified Soil Classification System (USCS) [8], the soil samples could be said to fall within the clayey sand (SC) group. Since the plot of LL against PL was above line A of the USCS chart, it shows that the soil is composed of inorganic clays of medium plasticity. These soils generally have slight to medium expansion and compressibility with poor drainage.

3.3. Shear Strength Parameters

Table 3 showed high values of cohesion 'c', which may subsequently increase the value of the bearing capacities of the soil.

Table 3. Shear strength parameters

LOCATION	Shear Strength Parameters	
	Cohesion, c (KN/m^2)	Angle of Shearing Resistance Ø (^{0})
MAE1 (Pit1) @0.6m	120	22
MAE1 (Pit1) @1.5m	200	22
MAE1 (Pit 2) @1.0m	150	6
MAE1 (Pit 2) @1.5m	150	25

The triaxial test is one of the most versatile and widely performed geotechnical laboratory tests, allowing the shear strength and stiffness of soil and rock to be determined for use in geotechnical design. Advantages over simpler procedures, such as the direct shear test, include the ability to control specimen drainage and take measurements of pore water pressures. Primary parameters obtained from the test may include the angle of shearing resistance ϕ', cohesion c', and undrained shear strength cu, although other parameters such as the shear stiffness G, compression index Cc, and permeability k may also be determined [7].

The shear strength parameters obtained for the soil samples collected at 0.60m, 1.0m, and 1.5m depths are presented in Table 3. Samples collected from trial pits MAE 2 at 1.0m yielded the least angle of internal friction of 6^0 with high cohesion values of $150N/m^2$. The highest cohesion values obtained were from test pit 1, which suggests that the soil contains an appreciable amount of clay and silt fractions [1]. The values were used as indices to determine the bearing capacity factors N_c, N_q, and N_y, respectively.

3.4. Soil Bearing Capacity

Undisturbed specimens were extracted from the depth of 0.60m and 1.5m for triaxial tests in test pit 1 and at a depth of 1.0m and 1.5m in test pit 2. Laboratory extrusion of undisturbed specimens for the triaxial tests showed low soil recovery at 1.5 meters for both pits 1 and 2, possibly because of their nature which was either decomposed rock mineral or sand with some gravel.

Based on the Mohr-Coulomb failure envelope [7, 9] obtained from the triaxial shear test, the values of soil cohesion, c, and angle of internal friction, were obtained and used to obtain the internal bearing capacity of the soil in accordance with rigorous bearing capacity formulae for square and strip footings, with partial safety factors of 1.25, 1.50 and 1.75 for unit weight, angle of internal friction and cohesion, respectively, with a global load Safety factor of

3.0. The undisturbed specimen from 1.5 metres depth was used to compute. The bearing capacities were computed based on the rigorous process using the first principle to yield the equation:

$$Q_{ult} = (1 + 0.3\frac{B}{L}).c.\ N_c + \gamma.\ z.\ N_q + (1 - 0.2\frac{B}{L}).\ \gamma\ .\ B\ .\ N_\gamma \quad (2)$$

Where:

$N_q = e^{\pi.\tan.\o}\ .\tan^2(\frac{\pi}{4} + \frac{\o}{2}\ );$

$N_c = (N_q - 1)\cot \o;$

$N_\gamma = 1.5\ (N_q - 1)\tan \o$

Known as bearing capacity factors, while:

c is the cohesion in KN/m^2

γ is the soils unit weight in KN/m^3

$z = D_f$ is the depth of the foundation in meters

B and L are the lateral dimensions in meters, which for square footings, B = L, and applying other factors, gives the Terzaghi equation for square foundations as:

$$Q_{ult} = 1.3cN_c + \gamma.\ z.\ N_q + 0.4\gamma BN_\gamma \quad (3)$$

Based on partial safety factors of 1.25, 1.50 and 1.75 on γ, ø, and c, respectively, and a load factor F = 3.0, the computations of ultimate, $q_{ult;}$ safe, q_s; and allowable, q_{all}, bearing capacity can be made based on:

$$Ø_s = \tan^{-1}(\frac{\tan \o}{f\o});\ \ q_{all} = \frac{qs}{F} \quad (4)$$

Table 4. Bearing capacity factors: N_c, N_q, and N_γ

PIT	Depth M	Factors For Ultimate Bearing Capacity				Factors For Safe Bearing Capacity			
		Ø	N_q	N_c	N_y	$Ø_s$	N_{qs}	N_{cs}	N_{ys}
1	0.6	22.0	7.82	16.88	4.13	15.1	3.98	11.04	1.21
	1.5	22.0	7.82	16.88	4.13	15.1	3.98	11.04	1.21
2	1.0	6.0	1.72	6.81	0.11	4.0	1.43	6.19	0.50
	1.5	25.0	10.66	20.72	6.75	17.3	4.90	12.54	1.82

Ø in Degrees

Taking the groundwater table on the ground surface for the worst conditions based on a nominal footing width of 1.0metre, the unit weights based on measurements are as follows:

Table 5. Bearing capacity factor values (KN/m^2)

PIT	Depth M	Average Densities		Average Unit Weights		γ_{sat}, KN/m^2	C, KN/m^2
		e_b, g/cc	e_b, g/cc	γ_b, KN/m^2	γ_b, KN/m^2		
1	0.6	1.95	1.56	19.13	15.30	21.81	120
	1.5	2.09	1.80	20.50	17.66	22.81	200
2	1.0	2.02	1.63	19.82	15.99	21.81	150
	1.5	1.92	1.59	18.84	15.60	20.81	150

An average saturated unit weight, γ_{sat}, of 21.81 KN/m^2 was adopted for all computations.

Table 6. Bearing capacity factor values (KN/m^2)

PIT	Depth M	Bearing Capacity Values, KN/m^2		
		q_{ult}	q_s	q_{all}
1	0.6	2709.4	1011.7	337.2
	1.5	4549.4	1702.2	567.4
2	1.0	1349.1	703.5	234.5
	1.5	4264.7	1474.9	491.6

From the table, the least allowable bearing capacity obtained for the site is 234.5 KN/m^2, which is adopted as the design allowable bearing capacity to be used for all foundation computations.

4. Conclusion and Recommendation

The following conclusions were drawn from this investigation:

- Based on the result of the Atterberg limit test obtained and using [5], the soil tested is composed of inorganic clays of medium plasticity. These soils generally have slight to medium expansion and compressibility with poor drainage.
- For pad foundation practice, it is recommended that the footing levels should be of a minimum depth of 1.5m below the natural ground. However, what was measured on site was less than 1.5m.
- The allowable/safe bearing capacity obtained from the site is 234.5 $KN/m^{2,}$ which should have been adopted as the design allowable bearing capacity to be used for all foundation computations, but that was not used.
- The soil at the site seems to be made up of ground.
- Lastly, it is strongly recommended that the design and construction of the future superstructure at the site should be carried out in accordance with good engineering practice as embodied in recognized codes of practice such as the British Standard institutions BS 6031: 1981, Code of Practice for Earthworks and BS 8004: 1986, Code of Practice for Foundation.

References

[1] D. S. Matawal, "Engineers and the Issue of Combating Incidents of Collapsed Structures," *NSE Golden Jubilee Aniversary Public Lecture, Nigeria,* pp. 11-22, 2008.

[2] Mbimda Ali Mbishida, Yakubu Isheni, Timothy Danjuma, "Assessment of Building Failures in Nigeria: A Case Study of Jos Metropolis, *International Journal of Advanced Engineering and Science*, vol. 6, no. 2, pp. 1-9, 2017. [Publisher Link]

[3] British Standard Institution (BS), 1377-2, Methods of Testing for Soils for Civil Engineering Purposes, Classification Tests, British Standard Institution, London, 1990. [Google Scholar]

[4] American Standard for Testing Materials (ASTMD) 422-63, Standards Test Method for Particle Size Analysis of Soil, ASTM Standard, 2007. [Online]. Available: https://www.astm.org/d0422-63r07e02.html

[5] American Standard for Testing Materials (ASTMD) 43180, Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of soil. ASTM Standard, 2010. [Online]. Available: https://shop.iccsafe.org/astm-d-4318-05-test-methods-for-liquid-limit-plastic-limit-and-plasticity-index-of-soils-pdf-download.html

[6] Geo Engineer, Shear Strength of Soils, 2021. [Online]. Available: www.geoengineer.org

[7] S. Rees, Introduction to Triaxial Testing, Part One, 2013. [Online]. Available: www.gdsinstruments.com

[8] Technical Report on Collapsed School Building at Abuni'ima, Bukuru Jos, NBRRI Report N0.36, NBRRI Publication. Abuja, Nigeria.

[9] Tien H. Wu, Soil Strength Properties and Their Measurement, Landslides, Investigation and Mitigation, Transportation Research Board, National Research Council, Special Report 247, pp. 319-336, 1996. [Google Scholar] [Publisher Link]