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The Potential of Soil Properties in the Stability of Buildings a Case Study of Collapsed Building in Kwang Jos, Nigeria

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Abstract: **The investigation of soil properties is vital in determining causes of building collapse in Nigeria today, but most times the geotechnical tests and analysis are neglected and site engineers are held responsible for the collapse. This paper seeks to investigate the soil properties of a collapse building site in order to emphasize the need for a geo-technical investigation as a vital tool in the built environment. Investigation of soil properties which includes sieve analysis, moisture content, specific gravity, Atterberg limits and shear strength were conducted on samples collected from the site. Two foundation bases were exposed (Base and Trial pits). Disturbed and undisturbed samples labeled Sample 1/1, Sample 2/1 and Sample 2/2 and recorded as Base 1, Trial pit 3 and Trial pit respectively were collected at the foundation depths of the exposed foundations by driving the sampler at various depths of 0.8m, 0.8m and 0.5m and tested. The soil's silty nature and low bearing capacity of 36.37KN/m^2 as the investigation revealed was a major cause of the collapse and that the building collapse site was a made-up ground. There was no geo-technical investigation prior to the building construction. Other causes such as the used of sub-standard materials, poor construction quality, quackery and supervision boils down to the lack of soil investigation which has caused the building foundation to fail and has resulted to the collapse of the building.**

Keywords: **Building Collapse, Foundation, Atterberg Limit, Bearing Capacity.**

I. INTRODUCTION

Buildings are structures that serve as shelters for man, his properties and activities. They must be properly planned, designed, constructed and subjected to the desired use in accordance with rules, regulations and specifications in order to obtain the desired satisfaction from the environment [1]. A building is an assemblage that is firmly attached to the ground and that provides total or nearly total shelter for machines, processing equipment, performance of human activities, storage of human possessions, or any combination of these [2]. A building is a human aesthetically and artistically created space that provides habitat for humans and other living things for their comfort to prevent the adverse effects of natural and artificial environmental conditions for their survival [3]. A building is made up of various components which can be divided into two main groups, namely, the structural and non-structural components. Structural components (columns, slabs, beams among others) are those that bear the entire weight of the whole structure and transmit it to the ground effectively, while non-structural components (windows, doors, partition walls among others) only bear their own weight and transmit it to the structural components [4, 5].

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Preliminary works are operations which include site investigation and foundation. Site investigation is to determine the properties of the soil strata. No matter how strong, rigid or structurally stable a building may be, its satisfactory performance depends exclusively upon the ground which supports it. Adequate site investigation prevents the issue of foundation problem because it would ensure that the most appropriate foundation is prescribed. The depth of soil strata in response to the loadings from the structure has to be located properly in order to safely bear the foundation of the building. Otherwise, the structure will fail [6]. Hence, before the commencement of any building, it is expected that a geotechnical investigation should be carried out. This is the process by which physical properties of a site are evaluated in order to determine if the site is suitable and safe for the proposed purpose. Geotechnical investigation seeks to investigate the geologic conditions and subsurface soil, in order to analyze the impact of such conditions on construction cost, to determine how adequate the foundation support is, for the proposed construction, and the stability and suitability of the site. Benefits of geo-technical investigation on the building site before construction cannot be overemphasized. Where any of these are compromised, buildings fail and in extreme cases collapse [7].

Building collapse is a global challenge, but more prevalent in the developing countries. Between 2011 and 2015, high incidence of building collapse were recorded in Nigeria with the highest in Lagos (60%), followed by Abuja (20%), Port Harcourt (10%) and others (10%) [8]. The frequency of its occurrence though reduced, is of great concern to every Nigerian, especially stakeholders in the built environment. The emerging scenario necessitated the swift intervention of Institutions such as the Nigerian Building and Road Research Institute (NBRRI) to investigate and provide solutions towards zero tolerance.

As such, this paper aims to increase the awareness of the need for preliminary study of any construction site. The importance of a geo-technical investigation cannot be overemphasized as it revealed the soil civil qualities for general constructions and will determine the foundation strengths for buildings. The study is also aim to suggest soil appropriate by Standards for building construction due to texture, composition and strength as well as to serve as a reference document to Engineers, Designers, Builders and other professionals in the building construction industry.

II. MATERIALS AND METHODS

A. Materials

Material used includes the soil sample dug from the site, while the equipment used includes the following: Soil Hand Sampler, Sampling Polythene Bags, Compaction Rammer, Compaction Mold, Electronic Top Loading Balance, Spatula, Sieves, Sieve Brush, Aluminum Scoop, Glass Plate, Moisture Content Tins and Laboratory Oven.

B. Methods

The study adopted field observation, soil sampling and analysis. The field investigation involved anthropogenic activity that could have led to Earth mass disturbances within the foundations of the building thereby leading to its collapse. Non Destructive tests were carried at the site of the collapsed office/hall complex in accordance to ASTM C805/805M (2013) [9].

Geotechnical investigation was conducted on the soil samples collected at the building collapse site. Two foundation bases of the collapsed building were exposed. Disturbed and undisturbed samples were collected at the founding depths of the exposed foundations and tested. A test pit was also dug besides the building where disturbed and undisturbed samples collected at various depths. Samples were collected by driving the sampler at various depths of 0.8m, 0.8m and 0.5m at Base pit, trial pit 3 and trial pit respectively in polythene bags and plastic containers so as to preserve their natural moisture content for analysis [8].

Laboratory tests aimed at establishing the characteristics, classification, shear strengths and consolidation characteristics of the soil under investigation were carried out. The tests carried out include sieve analysis, moisture content, specific gravity, Atterberg limits, and shear strength test all in accordance to their repective standards [10, 11].

C. Site Location

The site of the collapsed building is located at Gura-Zot B, Kwang, Jos South Local Government Area, Plateau State. The site lies in the savannah vegetation belt of Northern Nigeria with coordinates of N09.878º and E008.918º. Bordering the site eastwards is an automobile workshop and buildings constructed with either earth bricks or sandcrete. Lying North is an access road leading to Rayfield eastward and Lamingo northward.

Plate 1: Inspection of the Collapsed Building and Physical Survey of the Soil

Plate 2: Inner Portion of the Collapsed Building showing a sunken column

III. RESULTS AND DISCUSSIONS

A. Physical Observation

A critical look at the debris reveals the structural weakness of the construction materials used. Sub-standard and inadequate materials were used in the construction of the building, which includes the reinforcement bars, concrete mixture ratio, etc. The mixture of the concrete was not distributed evenly. Therefore, it could be obtained that the workmanship during the construction of the collapsed building was poor. This must also have contributed to the weak structural members such as columns, beams and slabs which led to the unsafe nature of the building.

The soil encountered in this site is very soft and silt concentrated obviously by physical observation. This shows that the site is suspected to be a made-up ground possibly from an originally covered mine pit which has not been properly reclaimed and has led to mass movement underground, resulting in the voluntary collapse of the whole building.

A sunken circular column was discovered in the collapsed building, penetrating some feet down into the ground as further evidence to the fact that near the whole site was an improperly reclaimed abandon mine pit, possibly from the activities of Tin mining done a long time ago.

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B. Soil Investigation

Laboratory tests aimed at establishing the characteristics, classification, shear strengths and consolidation characteristics of the soil under investigation were carried out. The tests carried out include sieve analysis, moisture content, specific gravity, Atterberg limits and the shear strength tests. The summary of soil sampling information is given in the table below:

Table 1: Soil Sampling Detail

S/No	Sample No	Location	Sample depth excavated (m)	Drilling method	Types of Sampling
1	Sample 1/1	Base 1	0.80	Manual	Disturbed/Undisturbed
2	Sample 2/1	Trial Pit 3	0.8	Manual	Disturbed
3	Sample 2/2	Trial Pit	0.5	Manual	Disturbed/Undisturbed

C. Atterberg Limit Test

The Atterberg limit tests were conducted in accordance of the specifications of BS 1377 (1990) [11, 12]. The results of the Atterberg limit tests are presented in Table 2. The engineering properties of the soil were correlated to those limits and were used to classify the soil according to the Unified Soil Classification System. Based on the results of Atterberg limits tests, all the soil samples tested were classified as ML, Silty soil with low plasticity.

Table 2: Atterberg Limit Test Result

S/N	Sample No	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	Sample 1/1	19.40	17.06	2.10
2	Sample 2/2	19.40	14.21	5.19

LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index; NMC = Natural Moisture Content.

D. Shear Strength Parameters

The shear parameters were obtained from triaxial tests box tests. The shear strength parameters; cohesion (C) and angle of internal friction (Ø) obtained for the soil samples are presented in Table 3.

Table 3: Soil Sampling Detail

S/N	Sample No.	Sample Depth	C (KN/m^o)	Ø (^{o})
1	Sample 1/1	0.80	5.0	20
2	Sample 2/2	1.50	0	29

Table 3 above shows low values of cohesion c which may be an indication of low bearing capacity of the soil.

E. Soil Bearing Capacity

Undisturbed specimens were extracted at depths of 0.8m and 1.5m for the triaxial test in Test Pit 1 Test Pit 2. Laboratory extrusion of undisturbed specimens for the triaxial test shows low recovery of the soil at all depth and for both pits possibly because of the silt nature of the soil.

Based on more columns failure envelope obtained from the trial tests, the value of soil cohesion c, angle of internal friction (phi) were measured and were used to calculate the bearing capacity of the soil in accordance with rigorous bearing capacity formulae for square foundation with partial safety factors of 1.25, 1.50 and 1.75 for unit weight, angle of internal friction and cohesion respectively, adopting a global load factor of 3.0. The bearing capacities were computed using first principles to yield the equation as given in the subsequent equation [9, 13].

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

Where:

$\mathbf{N_q} = e^{\pi.\tan.ø}\ .\tan^2(\frac{\pi}{4} + \frac{ø}{2})$; $\mathbf{N_c} = (N_q - 1)\cot ø$; and $\mathbf{N_\gamma} = 1.5\ (N_q - 1)\tan ø$ … 2

Known as bearing capacity factor

C = the cohesion in KN/m^2

γ = the soils unit weight in KN/m^3

z = D_f is the depth of foundation in metres

B and L are the lateral dimensions in metres, which for square footings,

B = L, and applying other factors, gives the Terzaghi equation for square foundations as:

$\mathbf{Q_{ult}} = 1.3cN_c + \gamma.\ z.\ N_q + 0.4\gamma BN_\gamma$ … 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:

$\mathbf{ø_s} = \tan^{-1}(\frac{\tan ø}{fø})$; $\mathbf{q_{all}} = \frac{qs}{F}$

The saturated unit weight of the soil samples used for the bearing capacity computations were calculated using the formular;

$\gamma_{sat} = \gamma_w \frac{(GS + e)}{(1 + e)}$ … 4

where

γ_{sat} = Saturated density

γ_w = Density of water

G_S = Specific gravity of the soil

e = Void ratio of the soil

The submerged unit weight of the soil samples were obtained from

$\gamma' = \gamma_{sat} - \gamma_w$ … 5

Table 4 shows the bearing capacity factors as obtained from the aforementioned equations.

Table 4: Bearing Capacity Factors

Sample No	Depth(mm)	Ø (°)	Øs (°)	N_{qs}	N_{cs}	$N_{s\Upsilon}$
Sample 1/1	0.8	20	3.46	3.46	10.15	0.95
Sample 2/2	1.5	29	6.57	6.57	15.08	3.09

In computation of the bearing capacity, the water table was assumed to be at the ground surface for the worst conditions based on a nominal footing width of 1.0m and soil unit weights as shown in table 5.

Table 5: Unit Weights of Soil Samples

Sample No	Location	Depth (mm)	Dry Density	Specific Gravity	Void Ratio	Saturated Unit Weight (KN/m^2)
Sample 1/1	Base 1	0.8	1.61	2.55	0.584	19.41
Sample 2/2	Pit 2	1.5	1.65	2.55	0.546	19.65

Table 5 shows the saturated unit weight of the soil samples obtained for each pit.

The computed safe and allowable bearing capacity of the soil samples are presented in table 6.

Table 6: Soil Bearing Capacity

Sample No	Location	Depth (mm)	Safe bearing Capacity (KN/m^2)	Allowable Bearing Capacity (KN/m^2)
Sample 1/1	Base 1	0.8	96.20	32
Sample 2/2	Pit 3	1.5	109.10	36.37

From the results in table 6, the allowable bearing capacity was found to increase with depth of sample, and the maximum allowable bearing capacity at 1.5m was found to be 36.37KN/m^2 which is considered to be extremely low for such a structure at that depth [14]. This poor bearing capacity of the soil must have contributed very significantly to the collapse of the building.

IV. CONCLUSION

The conclusion is categorized under two headings, namely; Pre-construction stage and Post-construction stage.

A. Pre- Contract Stage

1. There was no geotechnical investigation of the site

B. Post- Contract Stage

From the results in the soil bearing capacity, the allowable bearing capacity was found to increase with depth of sample and the maximum allowable bearing capacity at 1.5m was found to be 36.37KN/m2 which is considered to be extremely low for such structure at that depth. This poor bearing capacity of the soil must have contributed very significantly to the collapse of the building

V. RECOMMENDATIONS

1. Geotechnical investigation should be carried out on sites before any construction is done in order to avoid structural failure and ultimately, building collapse.

2. The clients are strongly advised to use the services of registered licensed professionals in the execution of their projects.

3. Regulating agencies should be on the site and ensure that the relevant tests have been done, and they should be around to supervise and ensure that standard materials are used for construction.

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