

Evaluation of Settlement and Bearing Capacity of Three Selected Buildings in Ibeju Lekki, Lagos

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Abstract This study assessed the geotechnical properties of soils at three locations with distressed buildings in Ibeju-Lekki, Lagos State, Nigeria. The aim was to identify possible geotechnical causes of structural impairments and ongoing deterioration, which led to occupant evacuation. Three buildings, labelled A, B, and C, were analyzed. Disturbed soil samples were collected from four corners at foundation depths to evaluate soil properties and their potential effects on structural performance. Index properties, including grain size distribution, moisture content, and specific gravity, were determined for soil classification. A triaxial test was conducted to determine cohesion and internal friction angles, while Terzaghi's equations were used to estimate bearing capacities. Consolidation tests were performed to compute both immediate and final settlements, providing insights into soil behavior under load. Results showed moisture content ranging from 2.02% to 16.04%, with the lowest in sample C4 (2.02%) and the highest in B4 (16.04%). Specific gravity values ranged between 2.55 and 2.65. Soil classifications were A3 (AASHTO) and SP (USCS), indicating poorly graded sands. Mean bearing capacities for buildings A, B, and C were 102.05 kN/m², 90.54 kN/m², and 96.25 kN/m², with standard deviations of 41.35 kN/m², 26.65 kN/m², and 48.39 kN/m², respectively. Final settlements averaged 0.3 cm, 0.24 cm, and 0.34 cm, with standard deviations of 0.09 cm, 0.06 cm, and 0.2 cm. Building C exhibited higher variability in settlement and bearing capacity, suggesting greater susceptibility to further structural distress. A correlation of -0.43 between bearing capacity and settlement confirmed that lower capacities correspond to increased settlements. The study emphasizes the importance of proper soil investigations and strict adherence to geotechnical recommendations during construction to prevent failures.

Keywords: Bearing capacity, Settlement, Buildings, Foundation

I. Introduction

In recent times, the number of building collapses is becoming rampant, particularly in Lagos State, Nigeria and geotechnical factors among other factors have been identified as a fundamental cause of these failures. The estimation of the level of settlement of a foundation in the soil layer is one of the major challenges confronting the building industry as it may be one of the factors contributing to some of the recent

building collapses in the country [1][2]. A foundation with the support of the underlain subsoil is satisfactory if shear failure of the soil does not occur and settlement of the structure does not impair the functionality of the structure; hence, the settlement must be within an allowable limit [3]. It is a difficult task to predict perfectly how a particular soil will behave when loaded. Hence, the designs or choices of suitable foundations for structures are

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borne by geotechnical engineers. The decision of the geotechnical engineer is usually based on the nature of the soil and the loading of the structure.

In recent years, the rate of development in the Ibeju-Lekki region has been exponential and it is often referred to as the new Lagos. As Lagos is surrounded by lagoons, land is scarce in the area, and the available ones are marshy. This has necessitated the construction of high-rise buildings as a way of optimizing the available space and solving the shelter problem in a densely populated region. Incidences of failures of structures are being noticed in major cities such as Lagos, Port-Harcourt, and Abuja, among others, and inadequate strength or quality of construction materials and poor structural design and construction have been identified and reported in several recent studies to be the primary cause of the failures. Poor structural design has received so much attention and identified as the main cause of building failures but the collapse menace persists. Also, cracks appearance on structural elements impairs the serviceability of structures, and this may be a result of differential settlement of the structures. Therefore, it is important to check the interaction between the buildings and soils, since this is a probable cause of the cracks or collapse. Many foundations are constructed regardless of the soil condition and sometimes, this is due to a lack of proper investigation of the soil condition. Mostly, the soil bearing capacity may be too low for the type of the foundation/building load, thereby, leading to a uniform or differential settlement of the structure. It is therefore important to study the geotechnical properties of the soil upon which these structures are supported, making it necessary to evaluate the bearing capacity and settlement of an identified local government

area (Ibeju-Lekki, Lagos) with known failed structures.

Compression of a soil deposit occurs in three stages [3]. The first is elastic compression, which causes immediate settlement. After the initial compression, the effect of the expulsion of water from the soil voids causes an additional reduction in soil volume, which is called the primary consolidation settlement. The secondary consolidation is the last step of compression, this decrease in volume is seen to occur at an unusually slow rate even after completely dissipating the excess natural hydrostatic pressure from the added pressure and finishing the primary consolidation. This is shown in most inorganic soils to be generally minimal [3].

II. Materials and Methods

A. Sample Collection

Three buildings were selected and labeled A, B, and C, for analysis, and disturbed samples were retrieved from 4 corners and at the foundation depth of each building. Figure 1 depicts the map of the three locations used in this study

All the test methods were adopted from the test procedures in BS 1377 of 1990 [4]

B. Methods

All the test methods were adopted from the test procedures in BS 1377 of 1990 [4]

i. Specific gravity and natural moisture content

The determination of the specific gravity and the natural moisture content of the soil samples was by BS 1377 of 1990.

ii. Grain size distribution

After washing the soil samples through BS sieve No 200, the particles retained on the sieve were dried in the oven for 24 hours and dry sieving was carried out on the dried sample to obtain its

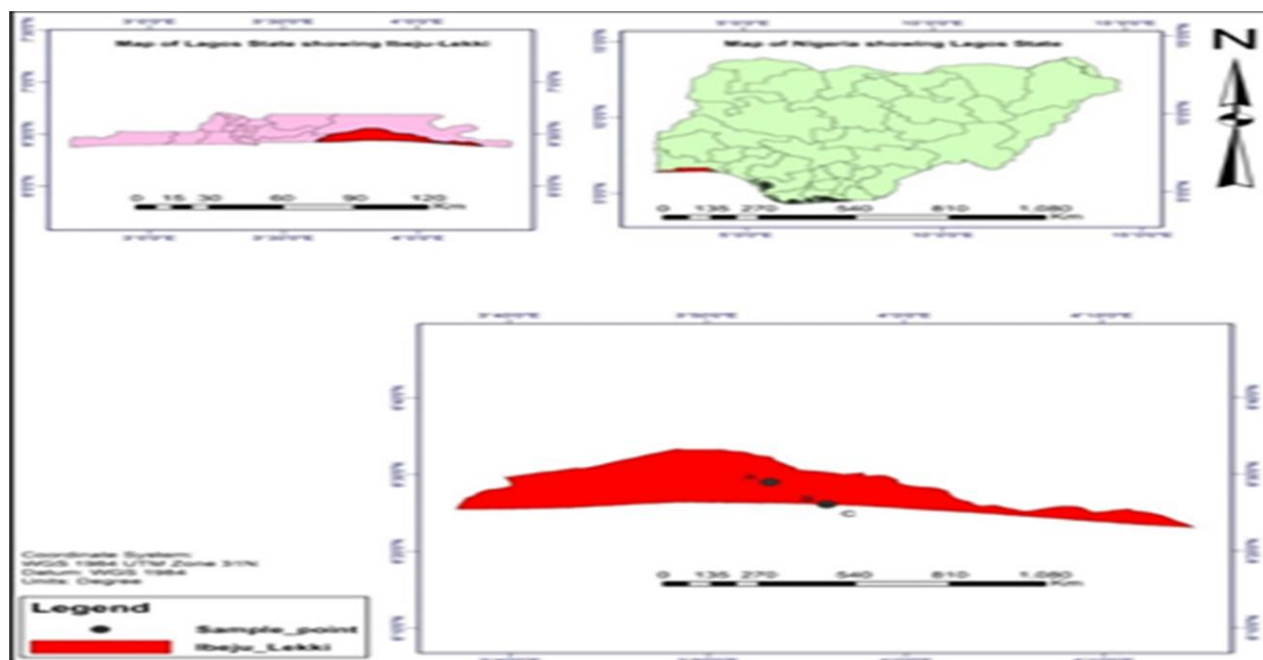


Figure 1: Location of buildings A, B, and C on the map

particle size distribution. Approximately 500 g was used to represent each sample and the sieving was done with a set of sieves and an automatic mechanical shaker.

iii. Shear strength

The soil samples were removed from the in-situ sampling tubes and they were 38 mm in diameter and 76 mm in height. In compliance with part 1 of BS 1377: 1990, the samples of the triaxial test were prepared and the triaxial cell was mounted on the compression unit. The triaxial compression test procedure was the method used and was performed in compliance with part 8 of BS 1377:1990. Compression was added to the specimen and the timer was simultaneously started. At intervals during the evaluation, sets of readings were reported for the deformation gauge, stress system, and pore pressure. To specifically identify the stress-strain curve

close to collapse, at least 20 sets of readings were taken.

iv. Load – settlement simulation

The load–settlement simulation was conducted using the soil consolidation test method with the Oedometer instrument following the specifications in part 6 of BS 1377:1990.

v. Bearing capacity of soil

Bearing capacities of the soils were computed using the results from the shear strength test and Terzaghi's bearing capacity equation as it is stated in equation 1

$$Qu = 1.3CN_c + \gamma DN_q + 0.4\gamma BN_\gamma \quad (1)$$

Equation 1 computes the bearing capacity for a shallow square footing.

Where C = cohesion (kN / m²); γ = unit weight of soil (kN/m³); D = footing depth (m); B =

base distance (m) and N_c , N_q and N_γ are bearing capability factors that depend on the angle of internal friction.

C. Statistical Analysis

Two statistical tools were used to analyze and interpret the results of the bearing capacity and consolidation tests. They are the correlation and the standard deviation tests. The correlation tool was employed to check for the agreement between the bearing capacities and settlement results of the soil samples. On the other hand, the standard deviation tool would be used to check the heterogeneity of the soil samples using bearing capacity and consolidation tests' results.

III. Results and Discussion

A. Natural Moisture Content

The summary of the results of the natural moisture contents of the soil samples is presented in Table 1. The results show a wide range in the natural moisture content (2.02% - 16.04%) The result shows that the majority of the soils contain a small amount of moisture. Soil B4 has the highest natural moisture content of 16.04%. However, the natural moisture content is not an inherent property of soil since its value is dependent on climatic conditions. The natural moisture content of any soil varies from season to season, being highest during the rainy season and lowest during the dry season and natural moisture content in soil may range from below 5% to 50% in gravel and sand [5].

B. Specific Gravity

The specific gravities of the soil samples are presented in Table 1. All the soil samples had their specific gravity equal to or greater than 2.60 except sample C4 which has a specific gravity value of 2.55. The specific gravity of 2.6 to 2.7 suggests the soils are sandy [6].

Table 1: Index Properties

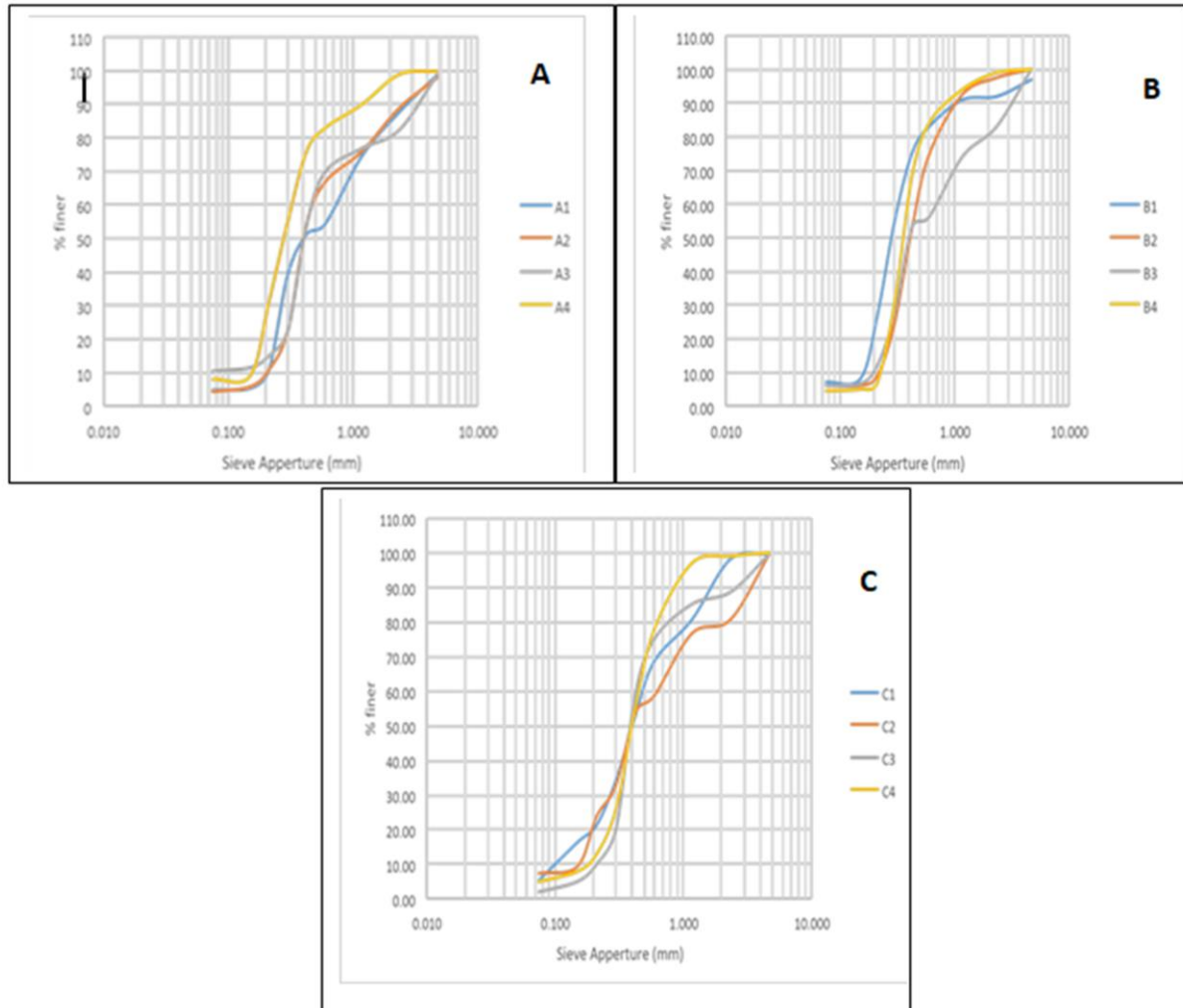
Soil sample	Natural Moisture Content (w %) (Gs)	Specific Gravity
A2	6.66	2.60
A3	8.22	2.60
A4	4.54	2.60
B1	6.51	2.64
B2	6.62	2.65
B3	4.49	2.65
B4	16.04	2.60
C1	3.08	2.65
C2	2.66	2.60
C3	2.68	2.60
C4	2.02	2.55

C. Soil Classification

The soils were classified according to AASHTO and USCS. The details of the result of the particle size distribution which was used for these classifications are presented in Table 2. The particle size distribution curves for the soil samples are shown in Figures2 (a-c). The coefficient of uniformity (C_u) and the coefficient of curvature (C_c) was computed for each sample. All the soil samples had a coefficient of uniformity (C_u) value of less than 6, which suggests that the soils are poorly graded [7]. The poor grading of the soils provides less area of contact and hence, reduces the strength characteristics of the soils [8].

Table 2: Classification of the Samples

SOIL POINT	C_u	C_c	AASHTO	USCS
A1	3.43	0.50	A3	SP
A2	2.40	1.13	A3	SP
A3	4.80	2.27	A3	SP
A4	2.37	1.12	A3	SP
B1	1.94	0.98	A3	SP
B2	2.18	1.03	A3	SP
B3	2.40	1.60	A3	SP
B4	1.74	0.98	A3	SP
C1	4.90	1.49	A3	SP
C2	3.88	0.79	A3	SP
C3	2.00	1.23	A3	SP
C4	2.37	1.12	A3	SP

**Figure 2: Grain Size Distribution of the Soil Samples at (a) Site A (b) Site B (c) Site C**

Based on the AASHTO classification, all soils were classified as A-3. They are considered fine sand materials because less than 10 % of the materials were finer than a 75 μm sieve (No 200). The soil samples are non-plastic according to the AASHTO classification system. By USCS classification, all soils sample are classified as SP (poorly graded sand) which implies poorly graded soil with little or no fines.

D. Bearing Capacity and Consolidation Settlement

The limit of maximum settlement of isolated pad foundation in sand and clay was set not to exceed 32mm and 45mm respectively and the maximum safe differential settlement in the sand and clay to range from 51-76 mm and 76-127 mm respectively [9]. Also, Terzaghi and Peck published that the maximum differential settlement of a foundation on sand should not exceed 25mm [10]. The settlements of all three buildings exceed the stated limits. The analysis of bearing capacities for some selected parts of Lagos, Nigeria showed that relatively good bearing capability was present in the inland areas of the State, and the values decreased towards the coasts [11]. Although the analysis did not cover the region of focus for this report, the surrounding neighborhoods of Victoria Island, Lekki, and Lagos Island were presented to have a range of bearing capacity of 20-100 kN / m^2 [11]. The results obtained for the study area fairly agree with the stated range regarding the bearing capacities of soils in that neighborhood as the mean bearing capacities of Buildings B and C were found to be less than 100 kN / m^2 .

E. Correlation - Bearing Capacity and Consolidation Settlement

The correlation result from Microsoft Excel shows that there is a -0.43 correlation between the bearing capacity and the consolidation settlement test results. The negative sign confirms that when the bearing capacity decreases, the consolidation settlement increases. The value (0.43) shows an average agreement between the two results. If the foundation had been constructed in error, the correlation value could be best explained by a negative value of one, meaning that an improper foundation was designed and the lower the bearing capacity, the higher the settlement. However, on the consideration of some other factors, like the differential loading effect, and the heterogeneity of soil layers, the value could never be -1. So, the value (-0.43) shows the average level of significance to agree that the bearing capacity test might not have been conducted, and hence, the foundation never went through proper designs.

F. Standard Deviation (Bearing Capacities and Consolidation Settlement)

The bearing capacity and consolidation settlement results are presented in Table 3 and Table 4 respectively. Table 3 presents the mean and the standard deviation of the bearing capacities of the three buildings. The high values of the standard deviation imply that the bearing capacities of each point are highly dispersed hence a high tendency of differential settlement is expected with time, and this is evident in Table 4.

The high values of the standard deviation of the mean from Table 4 show that differential settlement had occurred in the building, and building C which had the highest value of SD = 0.2m, experiences the most differential settlement. This agrees with the standard deviation of the values obtained from the

Table 3: Bearing Capacities

Point	Building A kN/m ²	Building B kN/m ²	Building C kN/m ²
1	66.02	67.90	109.00
2	128.58	128.07	159.28
3	146.05	76.06	55.25
4	67.53	90.11	61.48
Mean	102.05	90.54	96.25
SD	41.35	26.65	48.39

Table 4: Consolidation Settlement

Point	Building A (m)	Building B (m)	Building C (m)
1	0.22	0.17	0.17
2	0.44	0.20	0.16
3	0.22	0.26	0.66
4	0.31	0.33	0.38
Mean	0.30	0.24	0.34
SD	0.09	0.06	0.20

bearing capacities of the corners of building C. So, it follows that the more the variation in the bearing capacity values of the soil point under a particular building, the more the likelihood of the occurrence of differential settlement of the building if the foundation has not been properly designed.

IV. Conclusion

An experimental study was undertaken to investigate the settlement and bearing capacity characteristics of three selected buildings in Ibeju-Lekki, Lagos. The following conclusion has been drawn from the results obtained

- i. All the soil samples (sites A, B, C) taken were classified as A3 and SP (poorly graded sand) according to AASHTO and USCS classification systems respectively.

- ii. The shear strength results show that all the soils are neither purely cohesive nor purely cohesionless. All the soils have their respective cohesions and angles of internal friction.
- iii. Using the results of the shear strength test, Terzaghi's bearing capacity equation was employed and the net safe bearing capacity was calculated. There is a wide variation in the results obtained per location. The mean bearing capacity of all three sites was observed to be a little above 100 kN/m². Meanwhile, large standard deviation values confirm a great heterogeneity of the soil samples of all the locations. This may be said to have contributed to the buildings' settlement as it would be assumed that the footings never went through proper design.
- iv. The consolidation test simulation shows a final differential settlement for all the buildings. Building A has a mean settlement of 0.3cm and a standard deviation of 0.09cm, building B has a mean settlement of 0.24 cm and a standard deviation of 0.06cm and lastly, and building C is expected to have a final settlement of 0.34 cm with a standard deviation of 0.2cm. The results from building C are alarming because of the standard deviation of its settlement around the mean settlement. Therefore, more visible cracks might be seen around the structural elements of building C in the future.
- v. The comparison that was established between the bearing capacity and consolidation results using the correlation tool gave an expected result,

a negative value of 0.43, which implies that as the bearing capacity decreases, the settlement averagely increases.

From the drawn conclusion, the study following recommendations are made

- i. Proper soil investigation must be made by a geotechnical engineer to access the properties and strength of soil and to select a suitable and economic foundation type before the commencement of design and construction.
- ii. If need be, some ground improvement techniques may be employed to increase the bearing capacities of soil around the region before erecting any storey building in the area.

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