Geotechnical Indications and Shallow Bearing Capacity Analysis within Lekki Peninsula, Lagos using Direct Shear Analysis

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Abstract

It has become imperative for a review of the subsurface engineering properties of the Lekki Peninsula due to increase in urbanization. The study focuses on the shear strength parameters and ultimately the shallow bearing capacity of the subsoil using the direct shear method. With methods based on CPT, SPT, Particle Size Distribution and Direct Shear Analysis, an underlying loosed sandy layer of about 4m thick overlying a medium dense sand was revealed. Plot from direct shear analysis reveals zero cohesion and phi values = 170 indicative of a loosed soil. This loosed property of the soil was also revealed by the non-peaked plot of the direct shear test and the particle size distribution plot. Based on correlation for non-cohesive soils using N-values, compressibility parameters for the loosed sandy layer (N values=5) indicates Elastic Modulus < 3500Kpa, while the Medium dense sandy layer (N values=17) indicates values of about 13000Kpa. This implies high compressibility is expected within the loosed sandy layer. Settlement predictions based on a loading of 200KN/m² indicated a settlement of 74mm. Recorded Water level is less than 1m. Based on a shallow bearing capacity of 55kpa and intolerable settlements and CPT values within the study area, a raft foundation is most appropriate for multistory building while a deep foundation is apt for higher loads.

Keywords: Subsoil; Geotechnical; Bearing capacity; Foundation; Design; Lekki peninsula; Lagos

Introduction

Geotechnical site investigation is the process of collecting information and evaluating the conditions of the site for the purpose of designing and constructing the foundation for a structure, such as a building, plant or bridge [1,2]. Foundation studies usually provide subsurface information that aid in the design of structures [3,4]. Good planning for and management of a geotechnical site investigation is the key to obtaining sufficient and correct site information for designing a structure in a timely manner and with minimum cost for the effort needed [5,6]. The effort and detail of the geotechnical site investigation to obtain sufficient and correct site information to select and design a foundation for a building is complex [7]. It depends on the following; (a) design criteria of the proposed structure; (b) historic knowledge of general site conditions and building performance; (c) drilling equipment availability; (d) time of year the work needs to be done may determine the geotechnical site investigation method and finally; (e) the overall costs. With the increasing population growth in Lagos State, Nigeria, development activities have been on the rise around the coastal areas of the state. One of such cities is the Lekki Peninsula. The area of the city is about 800km² with a Population greater than 400,000 (Wikipedia). The review of the Subsoil is penitent in view of the high rate of urbanization within the area. This Study is to review the stratigraphy of the superficial deposit underlying the area to a depth of 10m, to determine relevant engineering characteristics of the deposits, to enable appropriate foundation design of the structure and ultimately estimates its Shear Strength parameters/shallow bearing capacity using the Direct Shear method. [8,9] states that the shear strength parameters (angle of internal Friction and cohesion) is the principal engineering property that determines...
the stability of soils under structural load. Investigative procedures comprise of one (1No.) boring and two Cone Penetrometer.

**Site Description and Geology**

Lagos metropolis is located within the Western Nigeria Coastal Zone, a zone of coastal creeks and lagoons [10] developed by barrier beaches associated with sand deposition [11]. The surface geology is made up of the Benin Formation (Miocene to Recent) and the Recent littoral alluvial deposits. The Benin formation consists of thick bodies of yellowish (ferruginous) and white sands [12]. It is friable, poorly sorted with intercalation of shale, clay lenses and sandy clay with lignite. The formation attains a thickness of about 200 m elsewhere [13] (Figure 1).

*Figure 1: Site Location.*

**Methods of Investigation**

**Soil borings**

Conventional boring method which consists of the use of the light shell and auger hand rig was used in the boring operation. During the boring operations, disturbed samples were regularly collected at depths of 0.75m intervals and also when change of soil type is noticed. Undisturbed cohesive soil samples will be retrieved from the boreholes with conventional open-tube sampler 100mm in diameter and 450mm in length. The open-tube sampler consists essentially of a lower end and upper end screwed into a box that splits across its middle. A confining normal force is applied and then a shear force is applied to cause relative displacement. The functional relationship between normal stress and shear stress on a failure plane can be expressed in the following form [15,16]. Though the failure occurs at a designated plane which might not be the weakest plane, it is a quick way of determining the stress parameters. BS 1377, Part 7, describes method of test for determining shear strength parameters of soils.

\[
\tau = f(\sigma)
\]

Where,

- \(\tau\) = shear stress
- \(\sigma\) = normal stress

From the test, the shear strength, which is a measure of the resistance to shear stress can be deduced from the equation below

\[
\tau = c + \sigma \tan \phi
\]

Where,

- \(\tau\) = shear strength
- \(c\) = cohesion
- \(\phi\) = angle of internal friction

The Theory implies that the failure occurs due to the combination of the normal and shear stress.

**Result**

**Soil stratigraphy**

The data from the soil sampling, standard penetration tests, and laboratory tests were carefully evaluated for the determination of the stratification of the underlying soils. The evaluation uncovered a primary soil zones beneath the site.

A typical soil profile characterizing the site is described below:

(i) Loosed sandy layer (0-4m)
(ii) Medium Dense Sandy Layer (4 - 10m)

The stratigraphy beneath the site showed significant uniformity. The ranges of thicknesses of the different strata are shown below (Table 1) (Figure 2).

**Table 1: Strata Thicknesses.**

| Description of Stratum   | Thickness (m) |
|--------------------------|---------------|
| Loosed sandy layer       | 4 - 10        |
| Medium Dense Sandy Layer | 6             |

The ranges of thicknesses of the different strata are shown below (Table 1) (Figure 2).

**Table 1: Strata Thicknesses.**

| Description of Stratum | Thickness (m) |
|------------------------|---------------|
| Loosed sandy layer     | 4 - 10        |
| Medium Dense Sandy Layer | 6           |

**Figure 2: Lithology for BH 1.**

**Table 2: Ranges of variation of engineering parameters @3m.**

| Parameter                        | Average (BH1, 3m) |
|----------------------------------|-------------------|
| Effective particle size d10 (mm) | 0.23              |
| Mean particle size d50 (mm)      | 0.5               |
| Coefficient of uniformity Cu     | 2.3               |
| Coefficient of curvature Cc       | 1.1               |
| SPT (N-value)                     | 5                 |
| Elastic Modulus ((Kpa))          | 3830              |

For design purposes, mean angle of internal friction of < 28° and cohesion zero are suggested for the sand layer. Unit weight of 20kN/m³ are suggested for this layer.

**Medium dense sandy layer**

Underlying the loosed layer is a layer of predominantly Poorly sorted, Medium densed sand. About 6m of the sand deposit was proved. The ranges of variations in the relevant engineering parameters of the sand are given below: (Table 3)

**Table 3: Ranges of variations of engineering parameters @9m.**

| Parameter                        | Average (BH1, 9m) |
|----------------------------------|-------------------|
| Effective particle size d10 (mm) | 0.16              |
| Mean particle size d50 (mm)      | 0.25              |
| Coefficient of uniformity Cu     | 3.4               |
| Coefficient of curvature Cc       | 0.45              |
| SPT (N-value)                     | 17                |
| Elastic Modulus ((Kpa))          | 13022             |

For design purposes, mean angle of internal friction of 31° and cohesion zero are suggested for the sand layer. Unit weight of 20kN/m³ are suggested for this layer.

**Particle size analysis**

Sieve analysis were carried out to determine grain size distribution based on relevant standards. Result from Coefficient of Uniformity and Coefficient of curvature indicates a Poorly sorted soil, hence higher in porosity than well graded soil. Though Muawia [17], stated the impact of clay on the frictional angle, the impact is expected to be insignificant due the quantity of clay which is less than 5% (Table 4) (Figures 3-5).

**Table 4: Particle Size Distribution.**

| Borehole No | Depth(m) | Effective particle | d30 | Mean particle size d50(mm) | d60 | Coefficient of uniformity | Coefficient of curvature |
|-------------|----------|--------------------|-----|---------------------------|-----|--------------------------|--------------------------|
| 1           | 3        | 0.25               | 0.38|                           |     | 2.36                     | 0.97                     |
| 1           | 9        | 0.16               | 0.2  | 0.25                      | 0.55| 3.4375                   | 0.4545455               |
Figure 3: Particle Size Distribution at depth of 3m.

Figure 4: Particle Size Distribution at depth of 6m.

Figure 5: Particle Size Distribution at depth of 9m.
Direct shear analysis

Due to the non-cohesiveness of the retrieved samples at shallow depths, Direct shear analysis was carried out based on methods from BS 1377, Part 7 (Direct Shear) ASTM D 3080. Constant confined normal stress of 50 KN/m² and 100KN/m² shows variation of shear stress and shear displacement using a shearing rate of 0.24mm/minute. Plot of Normal stress and Shear stress indicates an angle of friction of 150. Curves from the Stress / Strain Plot indicates a loosed sand, as indicated by the non-peaked curve; thus, a low bearing capacity is expected. This fact is also corroborated by the Particle Distribution Curve. The Linear curve from the Normal /Shear Stress Plot that passes through the origin also depicts a cohesionless soil with zero cohesion; this implies the soil will not stand as a cylinder if the confining pressure is zero. Hence, making the failure law to be simplified as follows:

\[ \tau = \sigma \tan \phi \] (3)

(Table 5) (Figures 6,7)

| Bore-Hole No | Depth Sample (m) | Normal Stress | 50   | 100  |
|--------------|------------------|--------------|------|------|
| 1            | 1.5              | Shear Stress KN/m² | 12   | 20   |
| Phi          |                  | Saturated unit weight | 170  |
| Specific Gravity |              |                      | 2.65 |
Cone Penetrometer Profiles were carried out within the area to a depth of less than 6m. Analysis of the tip resistance values indicates, values less than 60kg/cm$^2$ at depth less than 3.5m, while values greater than 60kg/cm$^2$ were observed at depth greater than 3.5m. An average depth of 10kg/cm$^2$ was observed within depth of 1-2m (Figures 8,9).

**Table 6: Allowable Bearing Pressure for Shallow Foundation.**

| Foundation Depth (m) | Width (m) | Undrained Shear Strength (KN/m$^2$) | Ultimate Bearing Pressure (KN/m$^2$) | Allowable Bearing Pressure (KN/m$^2$) |
|----------------------|-----------|-------------------------------------|-------------------------------------|-------------------------------------|
|                      |           | L/B = 1 | L/B = 1.5 | L/B = 5 | L/B = 1 | L/B = 1.5 | L/B = 5 |
| 1                    | 1         | 0       | 118.8 | 121.2 | 124.56 | 39.6 | 40.4 | 41.52 |
| 1                    | 1.5       | 0       | 66.6  | 68.4  | 70.92  | 22.2 | 22.8 | 23.64 |
| 1                    | 2         | 0       | 73.8  | 76.2  | 79.56  | 24.6 | 25.4 | 26.52 |
| 1                    | 2.5       | 0       | 81    | 84    | 88.2   | 27   | 28   | 29.4  |
| 1                    | 5         | 0       | 117   | 123   | 131.4  | 39   | 41   | 43.8  |
| 1                    | 10        | 0       | 189   | 201   | 217.8  | 63   | 67   | 72.6  |
| 1.5                  | 1         | 0       | 163.8 | 166.2 | 169.56 | 54.6 | 55.4 | 56.52 |
| 1.5                  | 1.5       | 0       | 89.1  | 90.9  | 93.42  | 29.7 | 30.3 | 31.14 |
| 1.5                  | 2         | 0       | 96.3  | 98.7  | 102.06 | 32.1 | 32.9 | 34.02 |
| 1.5                  | 2.5       | 0       | 103.5 | 106.5 | 110.7  | 34.5 | 35.5 | 36.9  |
| 1.5                  | 5         | 0       | 139.5 | 145.5 | 153.9  | 46.5 | 48.5 | 51.3  |

**Bearing capacity**

The conventional method of foundation design is based on the concept of bearing capacity or allowable bearing pressure of the soil. The bearing capacity is defined as the load or pressure developed under the foundation without introducing damaging movements in the foundation and in the superstructure supported on the foundation. Damaging movements may result from foundation failure or excessive settlement [18]. The two criteria used in the design of foundation are therefore:
1. Determination of bearing capacity of soil and the selection of adequate factor of safety, usually not less than 2.5cm.

2. Estimating the settlement under the expected load and comparison with the permissible settlement.

Modified Terzerghi Bearing Capacity equation [19] was used in the calculation of the ultimate bearing capacity of the soil for rectangular foundations:

\[ q_u = CN_u [1 + 0.3B/L] + \gamma D_f N_q + 12\gamma BN_f [1 - 0.2B/L] \]  

Where

- \( q_u \): ultimate bearing capacity
- \( N_u \), \( N_q \), \( N_f \): bearing capacity factors
- \( D_f \): depth of foundation
- \( \gamma \): unit weight
- \( B \): width
- \( L \): length

Undrained cohesion of 0 kPa and angle of internal friction of 17 were adopted for the bearing capacity analysis. Adopting methods from BS 1377, Part 7 (Direct Shear). Using appropriate bearing capacity factors, shallow bearing capacity is calculated as follows: (Table 6)

**Settlement of shallow foundation**

Settlement Analysis was done based on empirical method using Cone Penetrometer values. Tomlinson [20], stated method to calculate the compressibility parameters as follows:

\[ S = C_1C_2 \Delta \gamma \sum_{i=0}^{2b} \frac{I_x}{E_S} \Delta c \]  

Where

- \( S \): settlement
- \( C_1 \) = Depth correction factor
- \( C_2 \) = creep correction factor
- \( E_S \) = Dedormation modulus
- \( \Delta \gamma \): net increase of load on soil at foundation level due to applied load
- \( \Delta c \) = thickness of soil layer
- \( I_x \) = influence factor
- \( b \) = width

Based on relationships settlement estimates of 74 mm can be expected for a projected load of 200 KPa.

(Table 7) (Figure 10)

**Table 7: Settlements Parameters.**

| Sandy, 1.5m | Elastic Modulus, PA | 2450 |
| Cone Value, Kg/cm2 | 10 |
| Load, Kpa | 200 |
| Influence Factor | 0.5 |
| \( P_1 \) (elastic), mm | 74 |
| \( P_c \) (Primary), mm |  |

**Figure 10:** Variation of Settlement with foundation pressure.

**Discussion**

Field and Laboratory investigations shows that the surface is underlain by a Poorly loosed sandy layer (about 4m thick) with N-values < 10. The uniformity coefficient of the Particle size distribution curve, indicates values less than 6, depicting a loosed sand. This value is also corroborated by values of Coefficient of curvature which indicates less than 1.0 [21]. Also, the loosed layer is corroborated by Cone penetrometer values (Tip Resistance<60kg/cm²). The medium dense layer is correlated by Cone Penetrometer values (Tip Resistance>kg/cm²). Average Cone Penetrometer values (Tip Resistance) indicates lower values of about 10 kg/cm² within depth of 1m-2m. This implies a weak zone that is highly susceptible to shear failure. Using allowable bearing capacity equation proposed by Schmertmann [22] based on CPT values...
and considering the effect of water table, shows allowable bearing capacity of 58kpa (FS=3, square foundation) using a cone value of 10kg/cm².

Results derived from shear stress/ displacement plot were plotted with the Normal stress, Phi value of 170 and zero cohesion were obtained from the test. Application of these values in relevant bearing capacity equation above gave rise to low allowable bearing Capacities characteristics (1.5m: 55KN/m²). This value also correlates with the allowable bearing capacity values obtained from Cone Penetrometer values using schmertmann method

Based on correlation stated by Das [21] for non-cohesive soils using N-values, Compressibility Parameters for the loosed sandy layer (N value=5) indicates Elastic Modulus < 3500Kpa, while the Medium dense sandy layer (N value=17) indicates values of about 13000Kpa. This implies high compressibility is expected within the loosed sandy layer based on correlation stated by Tomlinson [20]. Settlement predictions based on a loading of 200KN/m² indicated a settlement of 74mm. Recorded Water level is less than 1m.

**Conclusion**

Based on the loosed nature of the sandy soil from the Particle Size Distribution, anticipated high settlement and low shallow bearing capacity of 55kpa at depth of 1.5m within the study area of the lekki peninsula with an intolerable settlement, raft foundation on a compacted layer is most appropriate for shallow foundation with foundation (footing) stress not greater 55kpa. For higher loads, a deep foundation will be most appropriate with founding depth > 5m. The study recommended that continuous foundation footings should not be placed on the identified clay soil unit. It should also be noted that foundations of large civil engineering structures in the area should be safely anchored in form of piles on competent sand materials for sustainability.

**Acknowledgment**

None.

**Conflict of Interest**

No conflict of interest.

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