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Geotechnical Mapping Of Bearing Capacity For Urban Planning In Ojedeji Town Akinyele Local Government In Ibadan Oyo State Nigeria

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Abstract: *Rapid urban expansion in peri-urban areas of Ibadan, Southwestern Nigeria, has increased the need for reliable geotechnical information to support foundation planning and sustainable infrastructure development. This study investigates the spatial variability of soil engineering properties and develops a GIS-based bearing-capacity zonation framework for urban planning in Ojedeji Town, Akinyele Local Government Area, Ibadan. A total of 46 geo-referenced sampling locations were investigated using an integrated field, laboratory and GIS approach. Laboratory investigations comprised natural moisture content, bulk density, particle-size distribution, Atterberg limits and direct-shear testing. Bearing capacity was evaluated from the measured engineering properties, while GIS techniques were employed to spatially analyse and classify the allowable bearing-capacity distribution. The particle-size analysis indicates predominantly coarse-grained, sand-rich soils, with gravel, sand and fines contents ranging from 0–36.04%, 60.72–97.99% and 0–4.51%, respectively. Atterberg-limit results indicate 25 plastic and 21 non-plastic samples, with plasticity indices ranging from 6.84–28.30%. Direct-shear results show angles of internal friction ranging from 14.07° to 35.52°, reflecting variations in soil composition and particle interlock. The calculated ultimate bearing capacities range from 320.40 to 1078.96 kPa, while allowable bearing capacities range from 106.80 to 359.65 kPa. GIS-based zonation identified Medium and High bearing-capacity zones, representing 45.65% and 54.35% of the investigated locations, respectively, with no sampling location classified within the Low bearing-capacity category. The results demonstrate significant spatial variability in the engineering characteristics and foundation-support conditions of the study area. The developed geotechnical zonation provides a useful planning-level decision-support tool for preliminary foundation and urban-development planning in Ojedeji Town. However, site-specific subsurface investigation remains necessary for detailed foundation design and construction.*

Keywords: Geotechnical mapping; bearing capacity; GIS; soil characterization; foundation engineering; urban planning; Ojedeji Town; Ibadan.

1.0 INTRODUCTION

1.1 Background of the Study

The urban geology has a key role in the planning and mapping of the geological environment of the cities. In many cases it is synonymous with environmental geology (Baker, 1975) and can be defined as the study of land resources and geologic hazards as they relate to the development and expansion of urban areas (Fuchu et al., 1994). In addition to data collection and map production, urban geology provides planners and policy makers with the geological information necessary to make rational development decisions (Edbrooke et al., 2003; Haworth, 2003). Geotechnical mapping is an applied urban geology that converts the subsurface information to engineering parameters (e.g. bearing capacity, shear strength, compressibility) and thus gives spatial guidance for the safe extension of urban areas (Ozsan et al., 2007; El May et al., 2009).

The Ibadan metropolis, the capital of Oyo State in the Southwest of Nigeria is an illustrative case of a fast growing city that needs systematic geotechnical assessment. The city has been expanding its boundaries as the population and infrastructural needs grow with this growth leading to peri-urban development in areas like Ojedeji in Akinyele Local Government. The Basement Complex is underlain by tropical residual soils which exhibit significant spatial variability in strength and stiffness and whose engineering behaviour is influenced by parent rock, degree of weathering, moisture regime and topographic position (Adeyemi, 2007). Therefore, geotechnical mapping and zonation of bearing capacity becomes very important to ensure safe and economical development on these soils.

The theories of classical bearing capacity by Terzaghi (1943) and Meyerhof (1963) offer analytical means of calculating ultimate and allowable bearing capacity, but their application is reliable with localized field and laboratory data. Studies conducted in Ibadan have revealed high spatial variability in soil strength, and the importance of systematic geotechnical mapping for planning and design (Adeyemi, 2007; Oyedele & Olabode, 2016). However, many peri-urban settlements, including Ojedeji, are under-mapped or even not mapped at all, which is a knowledge gap that this study aims to fill. Hence, the project is based on geotechnical investigation and GIS-based zonation to generate construction suitability advice for Ojedeji town.

1.2 Aim and Objectives

1.2.1 Aim

This study is aimed at assessing the geotechnical properties of soils in Ojedeji town, Akinyele Local Government, Ibadan for the generation of geotechnical maps as it is a fast growing peri-urban settlement of the Akinyele Local Government where urban expansion from Ibadan metropolis is gradually converting the once rural land into residential and infrastructural activities. The peri-urban areas are subject of high construction activity, which is sometimes carried out with little or no site-specific geotechnical studies.

Ojedeji town is chosen because it has typical geological and soil conditions of the Ibadan Basement Complex terrain which is characterized by weathered crystalline rocks and tropical residual soils with highly erratic engineering properties with short spatial variations. This spatial variability is very favorable for a geotechnical mapping and bearing capacity zonation study, because the use of generalized foundation assumptions would result in unsafe designs.

Moreover, though Ojedeji has a population base that is growing and a demand for housing, there is very little localized geotechnical data available on the area compared to more central parts of Ibadan where some studies are already available. There is a lack of detailed information on soil strength and bearing capacity, which has led to instances of foundation distress, differential settlement and structural cracking in similar peri-urban settlements.

1.2.2 Objectives

The specific objectives are to:

1. Perform experiments in the laboratory to ascertain the engineering characteristics of soils in Ojedeji town.

2. Evaluate ultimate and allowable bearing capacities by employing geotechnical principles and relationships established by the theory of Terzaghi and Meyerhof.

3. Generate geotechnical maps and zone for bearing capacity using GIS for the study area.

4. Evaluate the feasibility of various types of foundations such as shallow and deep foundations for the various zones generated.

5. Efficient recommendations will be made based on geotechnical results.

1.3 Research Questions

This study is guided by the following research questions:

1. What is the nature of soils properties (geotechnical properties including index and engineering properties) in Ojedeji town?
2. What are the ultimate and allowable bearing capacities of soils in representative sites of the study area?
3. How do soil properties and bearing capacities vary with space in Ojedeji town?
4. Which zones are good for shallow foundations, and which ones need deep foundations/ground improvement?
5. How can geotechnical mapping and zonation inform safer and more sustainable urban planning decisions in Ojedeji?

1.4 Justification of the Study

This study is justified on technical, socio-economic and policy grounds. Technically, it provides the site-specific geotechnical data required to apply classical bearing capacity theories reliably and to select appropriate foundation systems. Socio-economically, it reduces the risk of foundation distress and building collapse events that impose high financial and human costs (Falowo, 2021). For planners and policymakers, the geotechnical maps produced by this study serve as decision-support tools that enable land-use allocation based on engineering suitability, thereby improving the resilience and sustainability of urban expansion. Academically, the study fills a documented research gap by producing localized geotechnical maps for a peri-urban town that is currently under-represented in the literature (Oyedele& Olabode, 2016).

1.5 Scope of the Study

This research focuses on Ojedeji town in Akinyele Local Government Area of Ibadan, Oyo State. The scope includes:

- Laboratory tests to determine index properties (Atterberg limits, grain-size distribution, natural moisture), and shear strength (direct shear / triaxial or UCS where applicable).

- Estimation of ultimate and allowable bearing capacities using TerzaghiandMeyerhof formulations.

- GIS-based spatial interpolation and production of thematic geotechnical maps and bearing capacity zonation.

The study does not extend to full structural design of buildings or economic cost analyses for foundation options. Instead, its emphasis is on geotechnical appropriateness and design at the site and town level.

3.1 Introduction

The methodology used in the research on geotechnical mapping and zonation of soil bearing capacity in Ojedeji, Akinyele Local Government of Ibadan, Oyo State, Nigeria is presented in this chapter. The methodology describes the systematic procedures that have been followed in field investigations, laboratory analyses, data interpretation and map preparation. The methodology provides scientific rigor and reliability in achieving the study objectives, which include assessment of geotechnical properties, estimation of bearing capacities, and the creation of geotechnical maps.

3.2 Research Design

The research design is a combination of field, laboratory and GIS. The study starts with the reconnaissance survey and soil sampling, and then the engineering properties of the soil are determined by laboratory tests. Classical bearing capacity theories (Terzaghi and Meyerhof) are used to analyze the results. The results are then analyzed in a GIS to produce geotechnical maps and bearing capacity zonation. The evaluation of soil bearing capacity and the preparation of zonation maps for urban planning are carried out in an integrated geotechnical mapping manner using field investigation, laboratory testing, analytical modeling and spatial analysis. The methodology adopted is in line with the standard geotechnical investigation procedures as recommended by internationally recognized codes and modified to suit the geo-morphological conditions of Ojedeji.

The design framework can be summarized as:

1. Preliminary Reconnaissance – sampling point and route identification.

2. Field Investigation – soil sampling & GPS data collection.

3. Laboratory Analysis – determination of Atterberg limits, grain size distribution, moisture content, shear strength.

4. Bearing Capacity Estimation – use of classical equations (Terzaghi and Meyerhof) for determining ultimate and allowable bearing capacities.

5. Geotechnical Mapping – Spatial Interpolation of Soil Parameters & Zoning of Bearing Capacities on GIS.

6. Interpretation and Recommendations – evaluation of the suitability of the foundations and implications for planning.

3.3 Study Area Description

3.3.1 Location and Accessibility

Ojedeji town is situated in Akinyele Local Government Area of Ibadan metropolis, Oyo State in the Southwest region of Nigeria. The area is within latitudes 7.660476N and longitudes 3.785262E. It can be reached by Moniya major feeder roads which links with Ibadan urban core and peri-urban settlements.

3.4.2 Soil sampling and location of sampling points

Soil samples will be taken from disturbed areas in several places throughout the study area to represent spatial variation. Sampling points will be chosen according to:

- Land use
- Accessibility
- Geological uniformity

A handheld GPS receiver was used to geo-referenced each sampling location. The coordinates (latitude, longitude and elevation) of each sample location were taken and subsequently entered into GIS software.

Coordinates will be given in a table (Table 3.1: Coordinates of Soil Sampling Points) and will consist of:

- Sample ID
- Latitude (N)
- Longitude (E)
- Elevation (m)
- Block Sampling

This helps in the replicability and scientific validity of the study.

3.4.2.1Soil Sampling

- A total of 46 disturbed soil samples will be collected from representative points 50m apart across Ojedeji town.
- Sampling depths: Between 0.7 m to 1.5 (representing shallow foundation depths).
- Tools used: Digger, shovel, measurement tape and hand-held GPS device (to record coordinates).
- Disturbed samples were sealed in polythene nylon to preserve natural moisture conditions.

3.5 Laboratory Investigations

Laboratory tests were conducted as per British Standard (BS 1377, 1990). Tests conducted included:

1. **Moisture Content (Water Content) Test**

Introduction

The moisture content or water content of soil is defined as the ratio between the weight of water contained in a soil sample and the weight of dry soil, which is represented in terms of percentage. This is an important geotechnical parameter since it influences the soil's strength, compressibility, permeability, and bearing capacity (Das, 2015). The test is conducted as per the requirements set forth in standards like BS 1377: Part 2 (1990) or ASTM D2216.

2. **Atterberg Limits Test — Procedure**

Atterberg limits (Liquid Limit, Plastic Limit, Shrinkage Limit) characterise the water-related consistency of fine-grained soils and are essential for classification (USCS/AASHTO), estimating compressibility and engineering behaviour, and for zoning soils in geotechnical mapping (BS 1377; ASTM D4318).

Standards.
Perform tests in accordance with ASTM D4318 (Liquid and Plastic Limits, and Plasticity Index) and BS 1377: Part 2 (1990) for UK practice. Where available, follow local laboratory standard operating procedures that implement these standards.

3. **Particle Size Distribution (Sieve and Hydrometer Analysis)**

Introduction

Particle size distribution test is performed in order to obtain the composition of gravel, sand, silt, and clay in the soil sample. Such classification gives very useful data on foundation work, permeability, compaction, and settlement characteristics of soils. Coarse fractions are examined by the sieve analysis method, while fine fractions by the hydrometer analysis method.

A. Sieve Analysis (Coarse-Grained Soil Fraction)

B. Hydrometer Analysis (Fine-Grained Soil Fraction)

4. **Shear Strength Test (Direct Shear)**

Purpose of Shear Strength Tests

Shear strength of soil refers to the highest resistance that soil can offer to sliding on a plane of failure. Determining shear strength is crucial for:

A. Direct Shear Test (DST)

5. **Bulk Density Test**

3.6 Bearing Capacity Estimation

Calculation of allowable and ultimate bearing capacity was done through classical equations:

1. Terzaghi (1943):

$$qult = cNc + \gamma DfNq + 0.5\gamma BN\gamma q$$

2. Meyerhof (1963): Incorporating shape, depth, and inclination factors.

- The values were compared across locations to identify spatial variations.

3.7 Geotechnical Mapping and Zonation

Purpose:
To create maps of spatial distribution of soil properties (e.g. bearing capacity, soil type, moisture content) and to zone for different foundation designs. This will assist urban planners, engineers and designers to make informed decisions.

3.7.2 Map Production

Purpose:

To create thematic maps to visually present soil properties over a study area. These maps are useful for engineers, planners and stakeholders to understand the spatial variation in soil conditions and for making informed decisions about foundation or pavement design.

4.1Field Reconnaissance Survey

A reconnaissance survey was conducted within the Ojedeji town along Moniya of Ijaye/Ojedeji Ward, Akinyele Local Government Area, Ibadan, Oyo State, Nigeria, prior to detailed geotechnical assessment. The survey was undertaken to obtain preliminary information on site conditions and to guide the spatial distribution of sampling locations across the study area. The survey covered the geo-referenced sampling grid established around the reference coordinate of Ojedeji Town (7.660476°N, 3.785262°E), where forty-six (46) sampling points were systematically distributed at 50 m intervals.

4.2 Atterberg-Limit Analysis

- **Table 4.2: Summary of Atterberg-Limit Results**

Parameter	Result
Total samples	46
Plastic samples	25
Non-plastic samples	21
Minimum PI	6.84%
Maximum PI	28.30%
Mean PI	18.09%

The Atterberg results indicate a mixture of non-plastic coarse-grained soils and plastic fine fractions. The highest PI occurs at SP26 (28.30%), followed by SP09 (27.48%), SP40 (27.28%) and SP38 (26.15%). Such locations require greater attention to moisture variation and possible volume-change behaviour.The variation in plasticity across the study area demonstrates the heterogeneous nature of the residual soil profile. Samples with relatively low plasticity are expected to exhibit greater dependence

on particle interlock and friction for shear resistance, while samples with higher plasticity may be more sensitive to changes in moisture condition. The highest-plasticity locations therefore require particular consideration in foundation planning, especially where structures are sensitive to differential movement.

4.3 Particle-Size Distribution

Sieve results are available for SP01–SP46. The results show predominantly sand- and gravel-rich materials with relatively low fines contents. D10, D30 and D60 were obtained by logarithmic interpolation.

The sieve-tested soils are predominantly SP and SW, demonstrating a dominance of sand-sized particles. Gravel proportions are also substantial at many locations. The generally small fines contents support the predominantly coarse-grained character of the study area.The predominance of sand and gravel is significant because these materials generally derive much of their shear strength from friction and particle interlock.The relatively low fines content observed at many locations also explains why several samples exhibit non-plastic behaviour.The particle-size results therefore provide an important link between the index properties and the direct-shear results discussed in Section 4.5.

4.4 Direct Shear Test

Direct shear testing was carried out at normal stresses of 50, 100 and 150 kPa. The peak shear stresses were fitted using the Mohr-Coulomb relationship. The friction angle ranges from 14.07° to 35.52°, with a mean R2 of approximately 0.996.

Important interpretation of negative cohesion

The report retains the negative regression intercepts as laboratory regression results. It does not silently replace them with assumed values. For your thesis discussion, however, we can state that the negative intercepts occur in predominantly frictional materials and should not be interpreted as a physical negative cohesion. The principal strength parameter in those samples is the high friction angle.Direct-shear testing was used to determine the shear-strength parameters of the soils, principally the cohesion, c, and angle of internal friction, ϕ.The direct-shear results show considerable variation in the shear-strength behaviour of the 46 samples.

4.5. Cohesionless/Gravelly-Sand Samples

Some samples produced slightly negative cohesion intercepts in the direct-shear regression. For the samples containing gravelly sand, the negative numerical values for the intercepts do not denote physically negative cohesion, but instead denote that the envelope of failure falls just below the point of origin. For engineering considerations, it can be said that such soils behave as soils having no cohesion and the strength is a function of friction alone. This becomes especially significant in the case of soils having high angle of internal friction and low cohesion.

4.6.2 Shear-Strength Behaviour

Two broad behavioural groups are evident from the direct-shear results:

- samples with friction angles approximately 15–18°; and
- samples with friction angles approximately 34–36°.

The higher-friction category usually belongs to the high bearing capacity category. This point is crucial since the friction angle affects the bearing capacity factors and, therefore, the ultimate bearing capacity value.

4.7 Bearing Capacity

Ultimate and allowable bearing capacities are provided for all 46 samples in the processed dataset. Allowable capacity is equal to one-third of ultimate capacity, which corresponds to a factor of safety of 3, foundation depth of 1.2m, and width of 0.6m.

These values are the actual processed results. These processed direct shear properties have been utilized to estimate the bearing capacity. From the calculation results, it is clear that there exists considerable variability in the ultimate and allowable bearing capacities from one location to another. Areas of high bearing capacity tend to be related to high friction angles, implying that the friction component in the bearing capacity formula is relatively high. The overall calculated ranges are:

Parameter	Minimum	Maximum
Ultimate bearing capacity, qult	320.40 kPa	1078.96 kPa
Allowable bearing capacity, qallow	106.80 kPa	359.65 kPa

4.8 QGIS Spatial Analysis and Bearing-Capacity Zonation

The 46 data points of the bearing capacity were inputted into QGIS in WGS 84 (EPSG:4326). Interpolation of the bearing capacity layer produced a continuous raster image of the study area. The output surface was then reclassified based on the following thresholds:

Zone	Allowable bearing capacity
Low	<100 kPa
Medium	100–200 kPa
High	>200 kPa

The layout of the final QGIS consists of the sampling points and their labeling, legend, north arrow and scale bar.

Figure 4.1: Geotechnical Bearing Capacity Zonation Map of Ojedeji Town, Ibadan



The map is the official Geotechnical Bearing Capacity Zonation Map of Ojedeji Town, Ibadan, showing the Medium (100–200 kPa) and High (>200 kPa) bearing-capacity zones.

The final zonation contains:

- 25 High-capacity locations — 54.35%
- 21 Medium-capacity locations — 45.65%
- 0 Low-capacity locations — 0%.

High-capacity zones prevail in the central and northern zones and those associated with the ridges, while medium capacity zones prevail in the western and lower zones of transition. This shows the significance of geotechnical mapping over the assumption of homogeneity of the foundation throughout the study area.

4.8.1 Bearing-Capacity Zonation Summary

Table 4.7: Bearing-Capacity Zonation Summary

Zone	Samples	Percentage (%)	Mean qallow (kPa)	Minimum (kPa)	Maximum (kPa)	Mean qult (kPa)
High (>200 kPa)	25	54.35	332.82	233.89	359.65	998.47

Zone	Samples	Percentage (%)	Mean qallow (kPa)	Minimum (kPa)	Maximum (kPa)	Mean qult (kPa)
Medium (100–200 kPa)	21	45.65	144.10	106.80	151.09	432.30
Low (<100 kPa)	0	0.00	—	—	—	—

From the findings, it shows that the high zone makes up the majority percentage of the total tested area since it accounts for 54.35 percent of the area. The average allowable bearing capacity of the high zone is 332.82 kPa, which is much higher compared to 144.10 kPa, which is the average of the medium zone.

4.9 Bearing Capacity by Sampling Block

Block	Samples	Mean qallow (kPa)	Minimum	Maximum	Mean qult (kPa)
Block 1 SP01–SP16	16	213.80	106.80	359.65	641.41
Block 2 SP17–SP32	16	224.93	141.30	336.57	674.78
Block 3 SP33–SP46	14	309.07	146.97	353.68	927.22

Interpretation

Block 3 has the largest mean permissible bearing strength (309.07 kPa), Block 2 (224.93 kPa) and Block 1 (213.80 kPa). It shows an increase in the degree of difference in the support conditions of the foundations in the study area. Also, there is a clear indication that the pattern of bearing strength cannot be attributed to elevations alone. Elevations vary between 203 to 261 m.

5.0 Discussion of Results

The results prove that the geotechnical properties of Ojedeji Town exhibit spatial variability. The direct shear results show two general classes of soil behavior, with friction angles approximately 15-18° and 34-36°. The higher-friction group generally corresponds with the High bearing-capacity class. This relationship is consistent with the bearing-capacity results because an increase in the angle of internal friction produces larger bearing-capacity factors and therefore increases the calculated ultimate bearing capacity. The Atterberg-limit results provide an additional indication of local variation. Samples with higher PI contain more plastic fine material and may be more sensitive to moisture changes than the predominantly granular materials. The particle-size distribution further confirms that the soils are predominantly sand- and gravel-rich. Such soils commonly derive a significant proportion of their strength from friction and particle interlock. The elevation data range from approximately 203 to 261 m, but the bearing-capacity pattern is not controlled by elevation alone. This indicates that soil engineering properties and spatially varying residual-soil conditions are more important controls on the final bearing-capacity surface. The QGIS zonation therefore provides a more useful representation of the spatial engineering conditions than elevation or any single laboratory parameter considered independently.

5.1 Discussion of the QGIS Zonation in Relation to Urban Planning

The principal objective of the zonation exercise is to provide a spatial engineering reference that can support preliminary urban planning. The High bearing-capacity zone (>200 kPa) represents areas with comparatively favourable foundation-support conditions based on the investigated parameters. The Medium zone (100–200 kPa**)** represents areas where foundation conditions are generally adequate for development but where foundation-specific assessment becomes increasingly important. Since there is no sampled point that belongs to the Low category, the study did not detect a sampled point that has allowable bearing capacity less than 100 kPa. However, this zonation is only a planning exercise and should not substitute the detailed investigation for individual buildings. This is clearly indicated in the source report, which lists settlement, groundwater, footing design, loading and soil variability as factors that need to be considered in the design of foundations.

5.2 Limitations of the Study

The results and conclusions must be considered in light of the limitations of the investigation. First, each of the 46 sampling locations is a point in a spatially variable soil environment. Actual conditions may thus vary from the interpolated values between sampling points. Second, the QGIS zonation is dependent on the distribution and quality of the available sampling data. Third, bearing capacity alone is inadequate for a complete evaluation of the foundation design, since the settlement, ground water, footing geometry and structural loading should be considered. Finally, the zonation map should thus be viewed as a geotechnical map for planning purposes and is not intended to replace a site-specific foundation investigation.

5.9 Recommendation

The official QGIS bearing-capacity zonation map should be adopted as the initial geotechnical planning tool for future development in Ojedeji Town, and detailed geotechnical investigation should be carried out before final foundation design of individual building. Special consideration shall be given to the Medium zones, high-plasticity areas and transition between the Medium and High zones.

The existing 46-sample database should also be retained as a baseline database to be updated and refined in the future as the geotechnical zonation is updated.

5.10 Conclusion

The investigation was successfully able to characterize the geotechnical conditions of Ojedeji Town based on the 46 geo-referenced sampling locations, laboratory testing, direct-shear analysis, bearing-capacity calculations and QGIS spatial modelling. The results show that the soils in the study area are mainly sandy and gravelly soils with varying plasticity and shear-strength properties. The allowable bearing capacity is different significantly in the investigated locations ranging from 106.80 to 359.65 kPa. The final classification in QGIS shows 25 High-capacity locations (54.35%) and 21 Medium-capacity locations (45.65%) and no location sampled has a value of less than 100kPa. The study therefore confirms that geotechnical mapping and bearing-capacity zonation provide a useful framework for preliminary urban planning and foundation assessment in Ojedeji Town, while detailed site-specific investigations remain essential before final foundation design.

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