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LOCALIZED FEATURES IN SUBSOIL INVESTIGATION AND IMPLICATIONS FOR FOUNDATION WORKS: CASE STUDY FROM ILORA, SOUTHWESTERN NIGERIA

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ABSTRACT

Subsoil investigations involving geoelectric depth sounding, boring and sampling with *in situ* and laboratory tests were carried out at an interchange location in a typical basement complex terrain of Ilora, Southwestern Nigeria with the objective of detailing the subsurface characteristics and appropriate foundation. The geotechnical investigations utilized 2 Numbers exploratory boreholes while geoelectric depth soundings were carried out at seven (7) points along the traverse using the Schlumberger array. An allowable bearing capacity of $>$800 kN/m^2 was observed for the bedrock revealed at 4.00 and 6.95 m, respectively. The geoelectric depth sounding delineated the bedrock (of resistivity $>$3000 Ωm) occurring at varying depths of 4.00 to 12.00 m with structural features diagnostic of faulting (resistivity of 1082 / 1282 Ωm) and clayey saprolite of significant thickness (resistivity of 58 / 66 Ωm; thickness of 12 m) localized within about 45 m span. Integration of the data sets indicated that the drilling programme could not decipher the localized features which could be hazardous to the stability of the structure despite the good correlation observed at the points of investigation. This study underlines the need to complement traditional geotechnical testing with geophysical exploration methods for optimal results in subsoil investigation.

I. INTRODUCTION

Subsoil investigation, consisting of *in situ* tests either independently or in combination with laboratory tests, has become a prerequisite for civil engineering projects. It provides geotechnical information which would inform the safe design of the substructure elements. Amongst the main challenges of the procedure is the determination of exploratory borehole (BH) locations. The borehole locations for collection of subsoil samples are often picked by the rule of thumb. It has been identified that one common cause of structural failures is inadequate subsoil investigation resulting in poor foundation design [1, 2, 3].

In geotechnical site investigation, it is often difficult to determine the spacing of borings before an investigation begins in any drilling programme without any specific pre-drilling guide such as the geophysical investigation methods. The subsurface geology of the proposed site remains the primary determinant.

The thrust of this study is to consider mapping localized features that could heighten post construction failure of built structures amidst the borehole spacing constraint, with a view to forestalling the attendant consequences on foundation works.

II. THEORETICAL REFERENCE

The stability of a structure depends greatly on the nature of the foundation which is anchored on the geologic conditions of the underlying geomaterials. The spacing adequate enough for reliable results demands requisite attention. Otherwise, some inherent features might be inevitably missed out as exploratory boreholes provide information only at discrete locations [3, 4, 5].

The crystalline basement rocks exhibit structural features (joints, fissures and fractures/faults) which are produced by weathering and tectonic processes. The features are associated with enhanced secondary porosity and permeability. Most often, occurrence of these water-bearing features in this terrain is localized and confined to weathered/fractured zones. These features must be avoided in foundation works as the watered joints and faults are more likely to be problematic in engineering construction works. Most embankment problems occur from low compressive strength subsoil, high void ratios and unfavorable water content in the soil [1, 3, 6].

An efficient location of boring and *in situ* test points is required to furnish adequate subsoil information. It is essential that borings should penetrate all strata that could shear or consolidate materially under the load of the structure. However, it is almost impracticable to drill boreholes at very close intervals. Foundation failures are often traceable to concealed geologic features within the subsurface which may precipitate differential settlement leading to failure or collapse of structures [7, 8, 9].

II.1 SITE DESCRIPTION AND GEOLOGY

The area of study is located on the Ilora - Oyo road (Figure 1). It is underlain by undifferentiated basement complex rocks of the Southwest, Nigeria. The crystalline basement complex is highly fractured and jointed. Minor folds, lineations, shearing, bondinage and axial plane foliation are among the most prominent structural elements in these rocks.

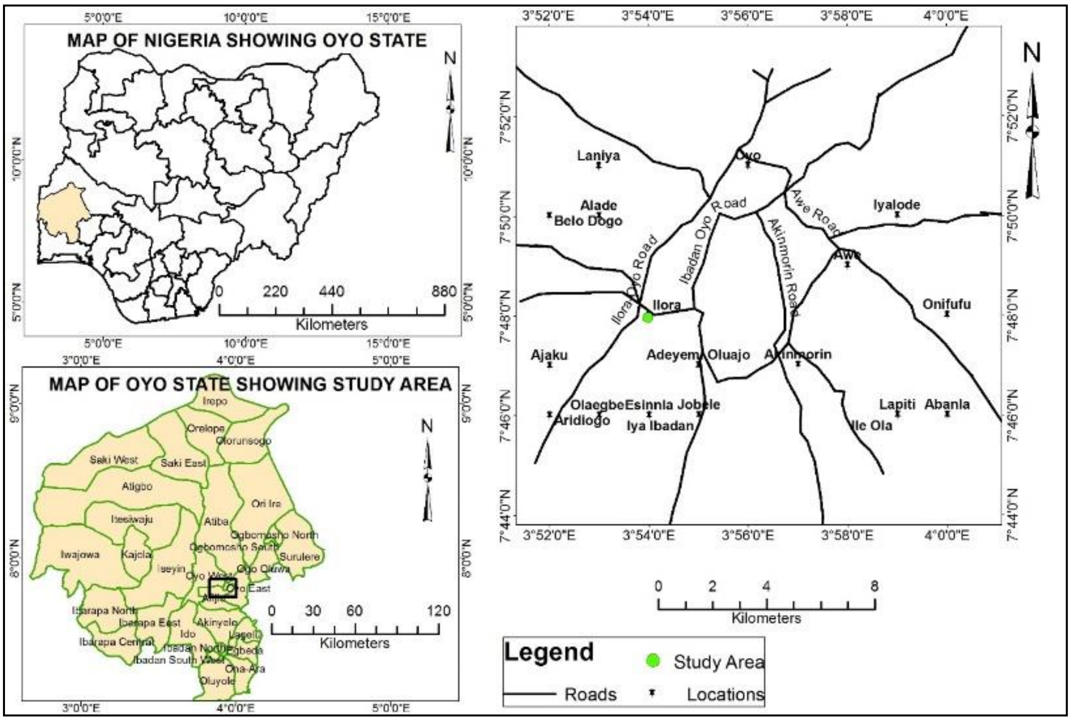

Figure 1: Location map of Ilora.
Source: Authors, (2022).

The dominant rock types in the area include migmatite, undifferentiated schist and gneiss, silicified sheared rocks and quartz veins (Figure 2). The region is characterized by faulting and jointing, showing a general trend of North – South with subsidiaries along NW – SE, E –W and NE – SW orientations. The depth of weathering depends to a large extent on the nature of the rocks, climate, topography and structural elements such as faults and joints [10, 11, 12].

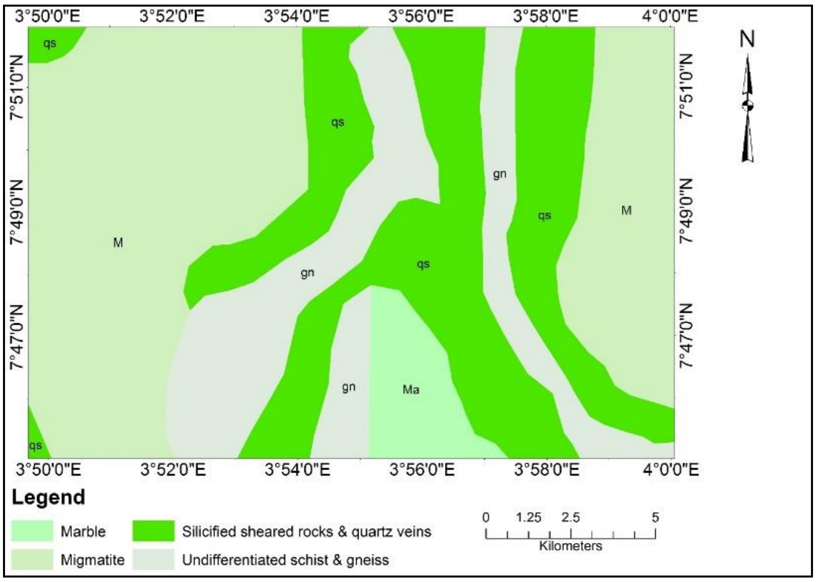

Figure 2: Geological map of Ilora.
Source: Authors, (2022).

III. MATERIALS AND METHODS

The investigation consisted of geotechnical fieldwork followed by geoelectric surveying essentially run to provide for an appraisal of the drilling results and eventual foundation recommendations. The geotechnical fieldwork comprising of two (2 Nos.) shell and auger boring was carried out using the light cable percussion rig of the Pilcon Wayfarer type. Sampling and *in suit* tests were carried out where necessary during the boring operations. Standard Penetration Test (SPT) was carried out at intervals to determine penetration resistance. The tests involve obtaining the number of blows (N-values) producing the last 300mm of penetration, in connection with an overall 450 mm penetration test, by a 63.4 kg hammer having a free fall through 760 mm. The penetration resistance is an indication of the density of cohesionless soils and of the strength of cohesive soils. SPT is thus an in – place dynamic shear test. The allowable bearing pressure based on the ‘N’ value has been estimated for the borehole locations [13, 14].

The geophysical investigation was carried out using vertical electrical sounding (VES) technique with the Schlumberger array. Half current electrode spacing (AB/2) has been varied from 1 to 100m. The instrument used for resistance measurement was the ABEM Tetrameter SAS 300B with ABEM 2000 Booster. VES stations were located along the traverse such that at least one of the stations was very close to an exploratory borehole. Seven VES stations were occupied to generate the geoelectric sequence of the study area, delineate zones of weakness and evaluate the structural competence of the sub-soil/bedrock [3, 15, 16]. The apparent resistivity values obtained from the vertical electrical sounding were plotted against electrode spacing on a bi-log paper. Visual inspection of these curves gave qualitative interpretation of the subsurface resistivity variations. Quantitatively the sounding curves were interpreted by partial curve matching technique using a 2-layer master curve and the corresponding auxiliary curves. Geoelectric parameters from this manual interpretation were improved upon through the use of computer iteration technique using the computer algorithm RESIST Version 1.0 [17]. These results were then presented as geoelectric sections [3, 15, 18]. In this study the exploratory boreholes provided controls to avoid interpretation ambiguity.

IV. RESULTS AND DISCUSSIONS

The results of the drilling exercise showed a considerable variation in the subsoil conditions at the two points investigated. Bedrock was encountered at 4.0 m depth at BH 1 and 6.95 m depth at BH 2. The soil stratifications with the corresponding lithological sections are presented in Figure 3. The results of the SPT, the estimated allowable pressure and the proposed foundation recommendation based on the 2 Nos. exploratory boreholes drilled at the site are presented in Table 1. The SPT gave >800 kN/m^2 as allowable pressure at BH 1 and BH 2 respectively.

The geoelectric investigation is presented as a geoelectric section with the BH lithological section in place (Figure 4).

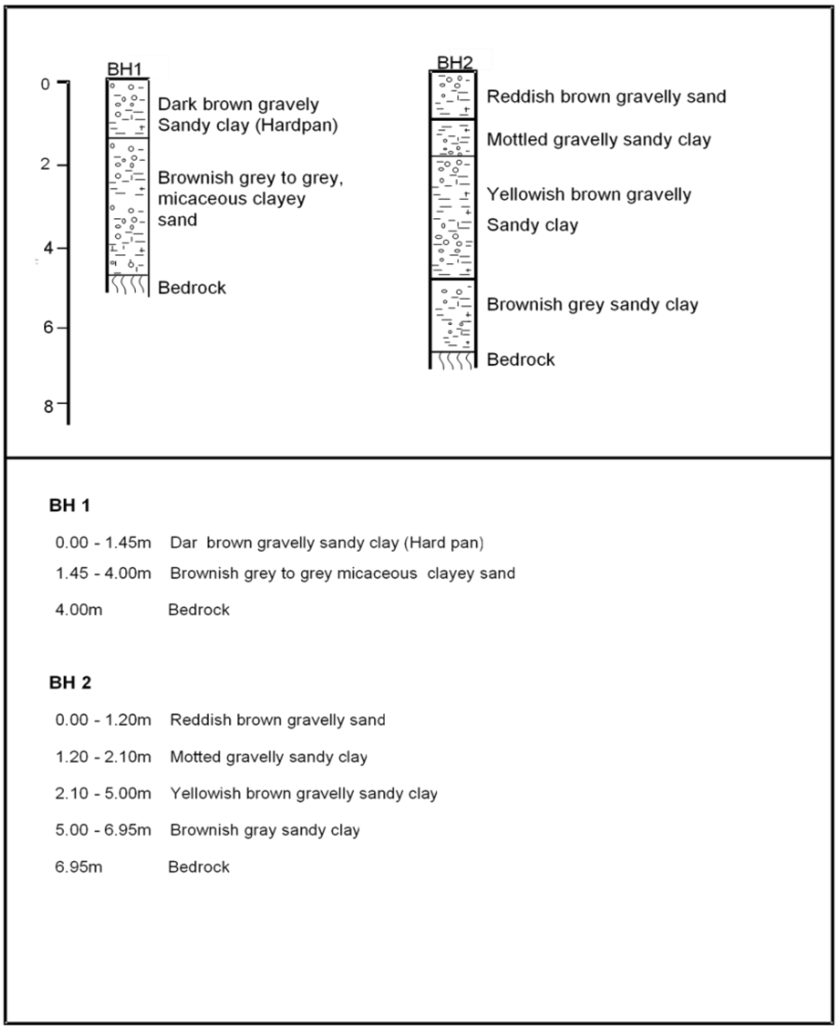

Figure 3: Lithological Section of the Bridge Site.
Source: Authors, (2022).

Table 1: SPT Results and Foundation Recommendation (based on 2Nos. Exploratory boreholes drilled at the site).

Bh	Depth (m)	Value of "N"	Pressure (kN/m^2)	Proposed Foundation Depth and Type
BH 1	0.45	40	530	Spread foundation at depth 4.0m below existing ground level (elev. +282.26). Proposed road level +284.20
	1.95	28	440	
	3.45	21	330	
	4.00	50	>800	
BH 2	0.4	12	230	Spread foundation at depth 6.0m below existing ground level (elev. +280.26). Proposed road level +284.20
	1.95	27	480	
	3.45	12	250	
	5.25	23	300	
	6.95	50	>800	

Source: Authors, (2022).

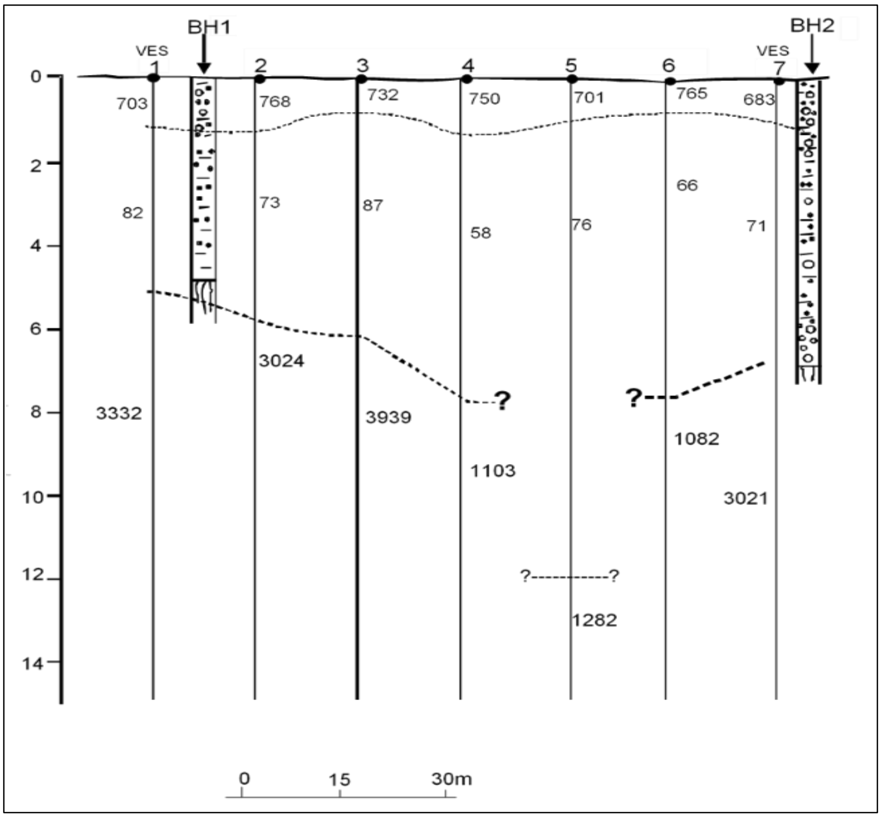

Figure 4: Correlation between Geoelectric Section and Lithological Section.

Source: Authors, (2022).

Three subsurface geologic layers were delineated (the topsoil, lateritic/clay substratum and partly weathered/fractured basement/fresh basement with resistivity ranging from 623 – 768 ohm-m, 58 – 87 ohm-m and 1082 – 3939 ohm-m, respectively). The thickness under VES 5 could be attributed to local fracturing of the bedrock. The third layer constitutes the bedrock with varying degree of freshness indicated by resistivity values ranging from 1082 to 3939 Ωm. The faulting/fracturing under VES 5 could be a consequence of a minor tectonic event emanating from the major faulting between Ilora and Oyo [10, 11, 15].

Despite the good correlations shown in Figure 3 (BH 1 / VES 1; BH 2 / VES 7) the localized structural defects (fracturing/faulting) occurring between VES 4 and VES 6 could not be deciphered from the borehole data. This is consistent with the fact that results from conventional geotechnical investigation methods are discrete. The marked variability and unpredictability of the nature of crystalline basement rocks suggests that precision is essential as the prolonged *in situ* weathering under tropical conditions has produced a lithologic sequence of unconsolidated material whose thickness and lateral extent vary extensively. The geology of the subsurface thus needs to be investigated in considerable details [12, 15, 16].

The thickness of the clayey horizon overlying the faulted bedrock is also significant. Substrata characterized by low resistivity (~ 1000 ohm-m) within the bedrock and low average resistivity (<100 ohm-m) within the overburden are considered geotechnically incompetent to bear significant engineering structures (Figure 5). Loading the near surface soil will result in consolidation settlement of the clayey layer overlying the bedrock [3, 18]. The existence of such tectonic features is inimical to the performance of the project if not addressed in the selection and design of the foundation. An effective site characterization is required in order to detect zones with poor geotechnical materials [2, 13, 19].

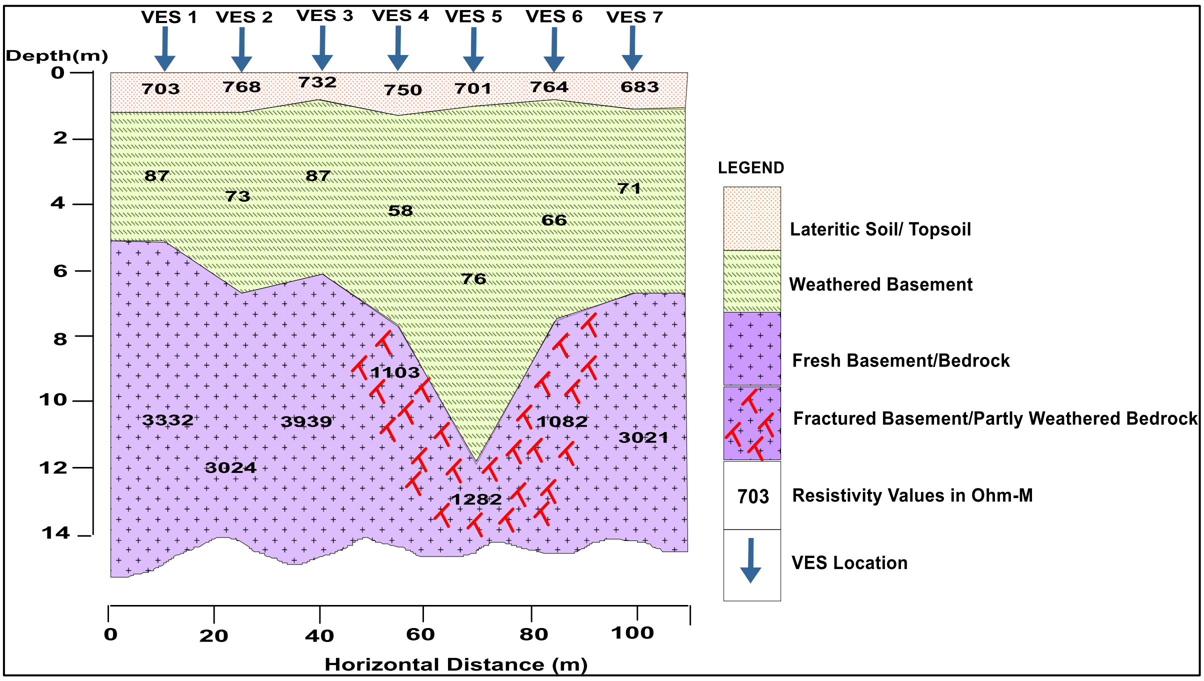

Figure 5: 2-D Geoelectric Section along the traverse.
Source: Authors, (2022).

The proposal of placing a spread foundation at a depth of 4.0m below the existing ground level at BH 1 (Elevation +282.26) and similarly at depth of 6.0 m at BH 2 (Elevation +280.26) informed by the results of the 2Nos. exploratory boreholes (Table 1) would have been considered adequate but for the risk of founding the piers and abutments within the problematic region around VES 5 spanning about 45.0 m of the 100 m right of way. The presence of these localized features would have adverse effects on the stability of the interchange if the spread foundation is adopted.

Although the bedrock with allowable bearing pressure of >800 kN/m^2 and resistivity of >3000 Ωm indicates a substratum of appreciable geotechnical competence, the uniformity of sound and competent unit cannot be assumed for the span (of about 45.0 m) through the degradation evidenced by the localized features. The region delineated as geotechnically incompetent requires engineering workings to be determined by the proposed load in order to improve the bearing capacity of the geomaterial. The application of jet grouting technique, as a soil stabilization method would enhance the competence of the affected region. Jet grouted piles become a suitable choice under these conditions [20, 21, 22].

V. CONCLUSIONS

The study revealed that geophysical exploration methods should be run to complement boring exercise for optimal results. Appropriate geophysical investigations should precede the application of traditional geotechnical investigation methods in order to guide the positioning of exploratory test points for optimum information on subsoil investigation. A simple spread foundation would be inadequate for the interchange despite the coherent results of the carefully executed drilling exercise due to the localized faulted region with the clayey saprolite of significant thickness delineated by the geoelectric survey. The 2Nos. borings at a separation of about 90.0m could not detect the problematic region. These results agree with the submission that exploratory boreholes provide information only at discrete locations while geophysical studies provide a relatively rapid and cost – effective means of deriving aerially distributed information on subsurface geology.

To accommodate the varying depths to competent bedrock and the localized features indicative of lesser geotechnical integrity, friction bearing piles or jet grouted piles should be adopted for the foundation works of the structure. An integration of geophysics and conventional geotechnical investigation methods will enhance the efficiency and reliability of subsoil investigation thereby promoting stability of built structures.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele, Akinwamide and Ogunyebi.
Methodology: Oyedele and Akinwamide.
Investigation: Oyedele and Ogunyebi.
Discussion of results: Oyedele, Akinwamide and Ogunyebi.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Akinwamide and Ogunyebi.
Resources: Oyedele and Ogunyebi.
Supervision: Oyedele and Akinwamide.
Approval of the final text: Oyedele, Akinwamide and Ogunyebi.

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