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Using Geoinformatics in Construction Management

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Abstract: One common cause of structural failures is inadequate soil analysis resulting in poor foundation design. The effectiveness and economies of time and resources of using the Vertical Electrical Sounding (VES) technique in predicting the soil type and depth of competent soil for construction was compared with a field geotechnical investigation involving soil logging and laboratory analyses on a reclaimed land sold as a virgin land intended for the development of a couple of duplex residential buildings. The plot was located using Geographic Positioning System (GPS). The geotechnical analysis showed that the site has very low load bearing capacity of a mean value of 2 kN m^{-2} and very poor shear resistance. The geophysical analysis also showed that the depth to competent soil was 17.4-33.5 m. The results were used in proposing the appropriate pile foundation type, which was contrary to the raft foundation proposed by the Architect to the client. The duration of fieldwork for the geophysical survey was just about 20% that of the soil logging. Most importantly, the economic loss in terms of resources and time that would have resulted from using the wrong type of foundation was prevented.

Key words: Geographic Positioning System (GPS), geophysical analysis, geotechnical analysis, Vertical Electrical Sounding (VES) technique

INTRODUCTION

The Civil Engineering Building of the Obafemi Awolowo University, Ile-Ife, Nigeria is a double-A Frame massive concrete structure from its substructure to the folded-plate roof. With its gray cement textured finish, it is a beautiful piece of architectural and civil engineering craftsmanship with a big but in its structural stability and integrity. During its design and construction, what appeared to be a minor oversight has become a nightmare that has so far defied solution.

The site investigation included geotechnical analysis, which showed there was an outcrop of granite deep below the ground; hence it was assumed that the rock was competent enough to support the structure. Geophysical analysis of the site was not done and this turned out to be a big misjudgment by the Consulting Engineering firm and the University's Physical Planning and Development Unit (PPDU). This is because during the construction of the three-storied structure, that has two levels of basement beneath it, the basement rock was cut into the fractured column and deep beneath the usual water table at peak of rainy season. The Contractors grouted the fractured rock as best as possible then but it amounted to a surface dressing.

During rainy seasons since completion and commissioning in 1989, the basement that was designed to accommodate the coffee room and two laboratories become flooded. [One was almost tempted to suggest converting the basements into underground swimming pool or aquarium]. Projected cost of grouting and raising the basement floor level recently proposed by the PPDU is more than the cost of building a unit of 10-bedroom hostel blocks for students' accommodation.

This is just one of numerous examples of being 'kobo wise and Naira foolish' that emphasizes the need for a geophysical analysis of a site at an engineering investigative stage in building construction and groundwater evaluation for borehole drilling[1-5]. Geophysics, as well known, is the application of the principle of physics to the study of the earth.

Geophysical methods are based on distinct physical properties of rocks. Magnetic method measures variations in susceptibility while the gravity method measures variations in rock density. The electrical methods measure changes in the conductivity of rocks while the seismic method is based on acoustic impedance contrast. The radiometric method measures variations in rock radioactivity[6-8]. The direct current resistivity method is particularly very useful as a rapid means of rock

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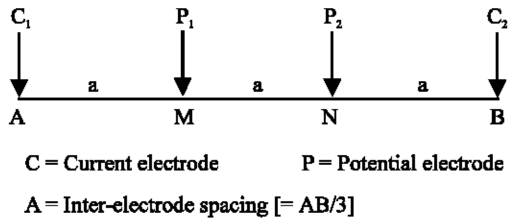

Fig. 1: The Wenner electrode configuration

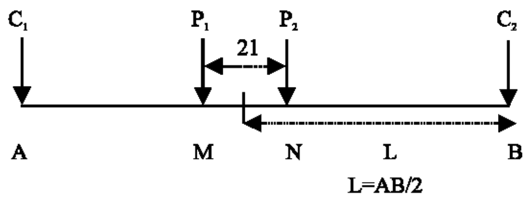

Fig. 2: The Schlumberger electrode configuration

identification and site selection in foundation design and construction. The Electromagnetic Method (EM) is useful as a reconnaissance tool in groundwater exploration for bore-hole drilling and installation, but it is however not as reliable as the resistivity method in terms of its sounding capability and depth of penetration[8-10].

The electrical resistivity of a formation is directly related to the nature, quantity, quality and distribution of the formation water. The resistivity surveying technique involves the passage of current into the ground by means of two electrodes (current electrodes) while the potential drop is measured between a second pair of electrodes (potential electrodes). The two most frequently used electrode configurations in groundwater (GW) studies are the Wenner and Schlumberger Arrays.

The Wenner array has four electrodes positioned such that the potential electrodes in the middle are such that the spacing between two adjacent electrodes is one-third, whereas in the Schlumberger array the spacing between the potential electrodes must not exceed 40% (ie 2/5) of half the distance of the spacing (AB) of the current electrodes (Fig. 1 and 2).

For the Schlumberger VES array, the apparent resistivity (ρ_a) is obtained from the equation:

$$\rho_a = \pi RL^2 /2l \quad (1)$$

where, ρ_a is the apparent resistivity (ohm-m)
R is the ground resistance (ohm)
L (= AB/2) is half the current-current electrode spacing ()m
l is half the potential-potential electrode spacing (m) and
π is a constant (22/7)

The distance MN is kept constant while AB is expanded resulting in a rapidly decreasing potential difference across MN that ultimately exceeds the measuring capabilities of the instrument. The Vertical Electrical Sounding (VES) technique could be used to investigate the subsoil of a site in terms of the water table, the soil characteristics, the extent, depth and spread of each type of soil and determination of the quality and depth of the competent soil type in civil engineering works.

These could be very valuable in water table and depth determination, horizontal spread and depth of such water body in the ground and foundation design.

The resistivity method also has relevance in groundwater investigation, engineering site investigation, Environmental Impact Assessment (EIA) (Pollution monitoring) studies, mineral exploration, geothermal exploration, geological mapping and corrosion study.

This study compares the savings in time and indirectly of fund in the use of VES as a geophysical tool relative to geotechnical investigation in foundation design.

MATERIALS AND METHODS

The site used for this study is located along Olaide Adeyeye Avenue in the coastal plain of Gbagada area of Lagos. A *Thuraya* field Geographic Positioning System (GPS) meter was used in locating the coordinates of the site. The land speculators had landfilled the site to present to the client a firm soil type, with scanty vegetation growing on it but with parts still marshy even during the dry season (in December). The Architect had designed the two-unit duplex proposing pad foundation in one part and raft foundation at where appeared to be a marshy ground. Professionally the Architect was correct to have specified that the foundations should be designed subject to the approval of the Project Engineer or Structural Engineer.

The client decided to seek professional advice for an appropriate foundation design for the proposed structure from the first author. A reconnaissance survey of the site was made in December 2000 (at about the peak of dry season) especially of the adjacent landed properties. Signs of differential settlement of the fence walls and main building of the property a few metres across the site and a totally sunken decked building not far from the failed structure and the site informed the advise for a thorough site investigation. The client was advised to clear the site for the engineering soil investigation before a structural analysis of the architectural design could be made.

Both geotechnical and geophysical analysis were decided upon. The Schlumberger VES array method using the ABEM SAS 300C Digital Terrameter Resistivity meter was proposed for the geophysical investigation for its rapid output and accuracy. For the geotechnical investigation four-1.20x1.20 m wells were sunk to 1.8-3.20 m in randomized locations on the site for soil logging of the sites. Both disturbed and undisturbed soil samples were collected from each pit for sieve analysis and soil characterization according to standard soil sampling methods[11].

The two teams commenced work about the same time. While augering may have been suitable, the pit logging method commonly used by Contractors handling non-governmental projects was chosen. This was also to enable a higher characterization of the soil type and water table in the spots investigated. The soil samples were analyzed in the Geotechnical Engineering Laboratory, Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife (OAU) while the geophysical data were analyzed at the Department of Geology, OAU. The dry density, moisture content, sieve analysis and compaction tests including triaxial analyses of the soil samples were determined using standard methods[11]. The geotechnical analyses took ten days to complete. The geophysical data were also analyzed using the Geosoft WinSev 5.1 software within few hours.

RESULTS AND DISCUSSION

The survey site is underlain by (Quaternary) alluvium littoral and Lagoonal deposits that lies around coordinates 3°24' E and 6°27' N as read on the GPS facility (Fig. 3). The advantages of GPS facilities such as a Workstation in field site surveying have resulted in savings from the traditional use of theodolites and levels.

The deposits consist of sands with intercalations of peaty matter and clays. The deposits are underlain by the Benin Formation directly. The geomorphology of the site showed a relatively flat terrain with topography near sea level within the coastal plain and lowland area of the southwestern Nigeria.

The VES curves are of the KH, QH and KQH types (Fig. 4). The quantitative interpretation of the VES curves involving partial curve matching and computer iteration technique assumes that the earth is made up of horizontal layers with differing resistivities. Any significant deviation (ie dip angle >10°) from this planar assumption in the stratigraphy will slightly distort the VES curve and introduce error in the VES interpretation results. Other sources of error are lateral inhomogeneity, suppression and equivalence.

Table 1: The geologic layers of the surveyed site

Level	Soil description	Layer resistivity (ohm-m)	Layer thickness, m (average, m)
1st layer	Topsoil composed of clay, sandy clay and silty sand	28-219	0.5-0.9
2nd layer	Soil composed of clay and sandy clay	45-145	1.3-4.6
3rd layer	Soil composed of clay and peat	7-47	13.9-29.9 (24.0)
4th layer	Soil composed of Sand	243-3762	17.4-32.5 (27.3)

Table 2: Depths to bedrock at the VES stations in the study area

VES station No.	Depth to competent bedrock (m)
1	27.8
2	33.5
3	33.0
4	17.3
5	23.1
6	31.6
7	31.5
8	26.4
9	30.2
10	28.4
11	17.4

VES computer modeling is usually aided by availability of borehole lithologic logs from an environment of interest. Apart from serving as good control, the logs help in lithologic identification. No such log was available in the present study except those determined from the test pits to a maximum depth of 3.20 m. Notwithstanding, in a simple geologic setup with horizontal or near horizontal stratification (ie dip angle <10°) VES determined depths to geologic interface could be accurate to within 0-10% at shallow depth levels not exceeding 50 m.

The depth sounding interpretation results are presented as geoelectric sections in Fig. 5. The sections showed horizontal to near horizontal stratification of the subsurface geologic layers. There was no indication of any major structural features such as faults. If a geophysical analysis had been done on the Civil Engineering building cited, perhaps it would have delineated the basement fractures and guide in the foundation design or call for a modification of the design.

The geologic layerings are as shown in Table 1 while the depths to bedrock at the VES stations are as shown in Table 2. The sand layer constitutes the competent bedrock in the survey site. Depths to the sand layer vary from 17.4-33.5 m. In view of the significantly thick incompetent clay overlying the competent sand bedrock, a pile foundation was recommended for the surveyed site. The pile depth proposed should not exceed 35-40 m. The sand layer constitutes the aquifer unit. It is porous and permeable with high groundwater yielding capacity.

The geotechnical analysis showed that the investigated site was a reclaimed marshy ground with humic clay soil overlain with decaying vegetation to a

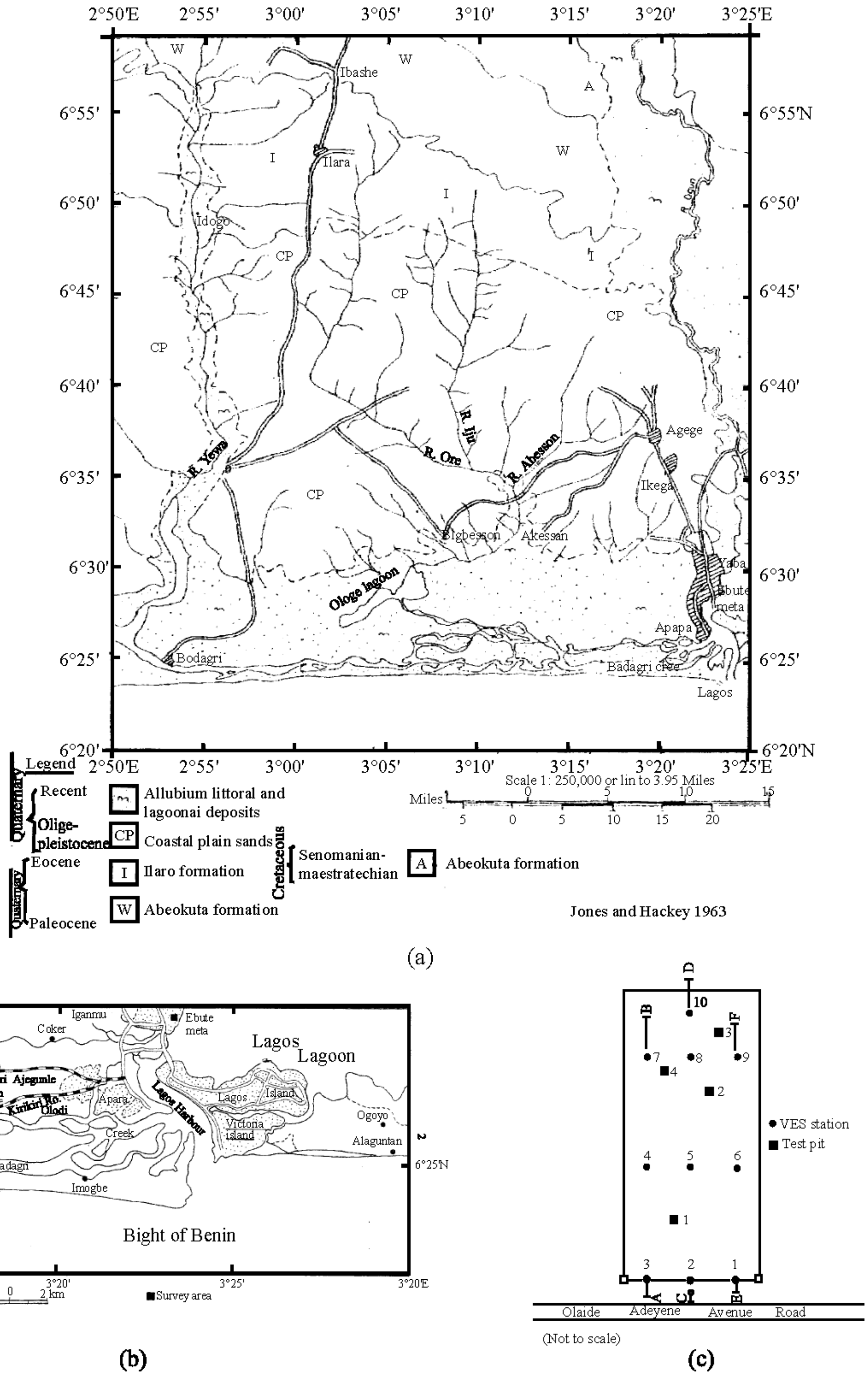

Fig. 3(a): The generalized geological map of Lagos state
(b): Map of Lagos state showing the survey area
(c): Site plan showing the VES and test pit location

Table 3: Results of geotechnical analysis of soil samples collected from the study area

Location	Shearing strength (kN m^{-2})	Load bearing capacity (kN m^{-2})	Sieve analysis, % retained on sieve size (mm)
Pit 1	2.56	3.33	3.6 : 7.8% 2.36 : 1.5% 1.18 : 3.9% 0.85 : 7.9% 0.425 :12.3% 0.300 : 23.9% <0.300 : 42.7%
Pit 2	1.35	2.0	3.6 : 4.5% 2.37 : 1.9% 1.18 : 5.0% 0.85 : 3.6% 0.426 :9.7% 0.300 : 20.1% <0.300 : 55.2%
Pit 3	1.24	2.1	3.6 : 4.8% 2.38 : 2.9% 1.18 : 0.0% 0.85 : 7.2% 0.427 :11.6% 0.300 : 17.4% <0.300 : 56.1%
Pit 4	0.95	1.33	3.6 : 4.0% 2.39 : 4.5% 1.18 : 1.9% 0.85 : 8.8% 0.428 :12.2% 0.300 : 24.3% <0.300 : 44.3%

depth of 1.75-2.1 m. The bearing capacity of the soil showed that even at a depth of 3.20 m the capacity of the soil to support a structure was limited to an average of 2.0kN/m^2 and a shearing strength between 0.85-2.56 kN/m^2 (Table 3). These values are much more below the minimum soil bearing capacity of at least 60.0-120.0 kN/m^2 for a raft foundation and/or structure. The bulk of the soil types are within the clay/silt range in grain size (Table 3). The soil analysis curve showed that the samples are of a poorly graded soil type not competent as foundation material. The water table in January 2001 (dry season) when the site was investigated was within 500 mm from the ground surface. Most of the soil types were decayed organic plants and water had to be baled out of the pits during the digging and soil sampling. The depth of 1.50 m suggested for a raft foundation by the architect was exceeded to 3.20 m in some of the pits before a 'reasonable' type of soil sample was found and the analysis showed that it was organic soil that was not competent as foundation material to support even a bungalow or the proposed duplex structure. Under that type of situation, it would have been necessary to continue the pit logging, by using standard augers. That would take more days and more cost. Rafting and substructure materials cost at that depth would also not be economical.

The risk for assumptions in structural design of foundations is higher and has been one of the reasons responsible for many cases of collapsed structures or dilapidated buildings as commonly experienced in Lagos State and other places in Nigeria. Other reasons for collapsed structures include reliance on the design by unqualified and /or unregistered professionals (engineers and architects) for the design and construction of such structures, use of substandard materials, poor or lack of supervision by competent personnel, etc. in an effort to reduce cost.

The answer that the geotechnical analysis could not provide or which further logging beyond what was done could have eventually provided was obtained from the geophysical analysis results. There was also correlation between the characterization of the soil type on the site to

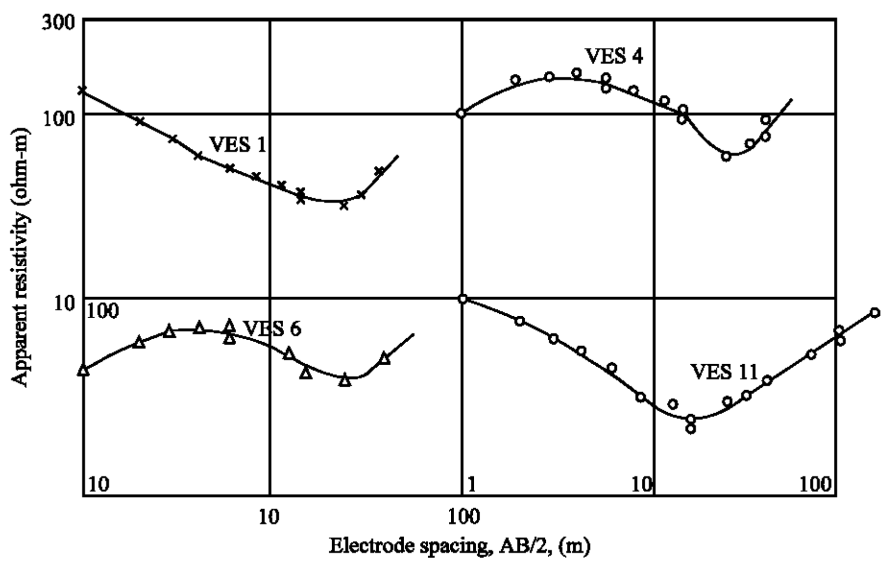

Fig. 4: Typical sounding curves at VES stations 1,4, 6 and 11

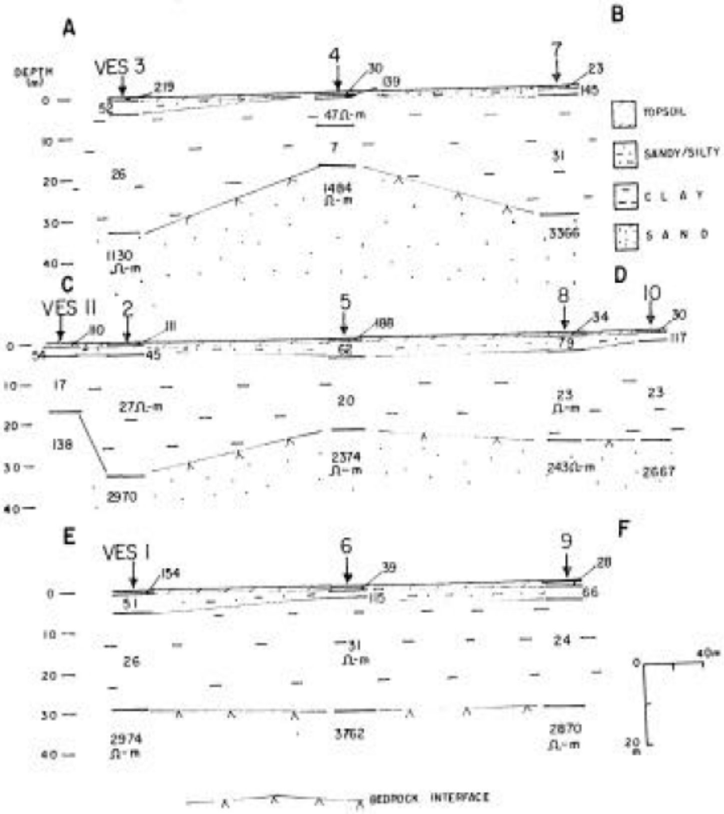

Fig. 5: Geoelectric sections beneath traverses A-B, C-D and E-F

the level determined through geotechnical analysis and the geophysical analysis as shown in the geoelectric sections beneath the traverses A-B, C-D and E-F (Fig. 5). The clay/silty clay soils with high level of organic debris from decaying vegetation reported in the geophysical analysis were similar to the findings in the geotechnical field investigation.

The geophysical team completed the fieldwork on the site within three hours and the computer iteration and analysis within 24 h. The soil sampling of the geotechnical team took more than eight hours or three times the duration for the geophysical field work and the laboratory analysis of the disturbed and undisturbed samples took well over two weeks.

Based on the results of the geophysical analyses and the recommendations on the type and depth of foundation suitable for the site, the client was briefed and a projection of the number of piles required for the site and the appropriate depth at each location was provided. After considering the cost, the client decided to use the site as a poultry farm rather than constructing a duplex that would have been built on a raft or pad foundation and sooner or later result in another collapsed structure. Judging by the savings from projected cost of labour and construction, the geophysical survey had served a very useful purpose equivalent to what a feasibility study could have provided in a proposed project.

CONCLUSIONS

The study has provided justification of the usefulness and economy, albeit qualitatively, of a geophysical survey to engineering design of foundations or other soil investigations in terms of time and fund for major structural and infrastructural projects.

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