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Application of 2D electrical resistivity imaging and cone penetration test (CPT) to assess the harzadous effect of near surface water on foundations in Lagos Nigeria

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Abstract. Adequate information on the condition of the subsurface is very important for site evaluation for engineering purposes. In this study two dimensional (2D) geoelectrical resistivity survey and cone penetration tests were conducted to study the hazardous effect of excess near surface water on the foundation of building in a reclaimed land located at Victoria Island area of Lagos State. The results of the inverted 2D geoelectrical resistivity data revealed three distinct geoelectrical layers characterized by low to moderate electrical resistivity of 2.23 and 129 Ωm and 9.46 to 636 Ωm respectively. The topsoil is characterized by wet sandy soil, which is underlain by sandy clay and banded at the below by a geologic formation of low resistivity which is suspected to be clay. The clay material may be responsible for the excess water retention observed in the area. The CPT method on the other hand revealed a geological formation of low resistance to penetration between 2-3 kg/cm^2 from the topsoil to a depth of 7 m, which may be the effect of excess water in the near surface. This study revealed that the foundation of building may not be founded directly on the soil in any reclaimed land as this may result in collapse as a result of upward migration of water to the near surface.

1. Introduction

Lack of appropriate studies of the subsurface is one of the factors contributing to the frequent building collapse in our society of late. Therefore, adequate studies of the subsurface [1] will assist building developers on the right choice of building materials, type of foundation and the design that matches a particular geological setting [2][3]. Several approaches have been used for the success of foundation investigations among which are the conventional and modern geophysical and geotechnical methods, particularly electrical resistivity technique and cone penetration test [4][5]. This combination has become presently very reliable and popular techniques to investigate the subsurface underground features for different applications, such as environmental, groundwater potential study, engineering and geotechnical, investigation [6][7][8].

The electrical resistivity method is non invasive, cost effective and fast to conduct, it also measures the lateral and vertical variation of resistivity with depth, the acquired resistivity data is used to produce an inverted 2D image of the surveyed area[9]. The cone penetration test on the other hand measures the resistance of the subsurface to cone penetration, which is used to determine the strength or the bearing capacity of the subsurface [10][8][11]. This method is capable of a single point investigation but it is essential to ground-truth the result obtained from other geophysical methods. Although, the method is invasive but it is not destructive, it is a very fast geotechnical method and very economical [12][13][14][15]. In the present study, 2D resistivity method using Wenner array electrode configuration and cone penetration test were conducted in order to determine the effect of excess near surface water to engineering construction.

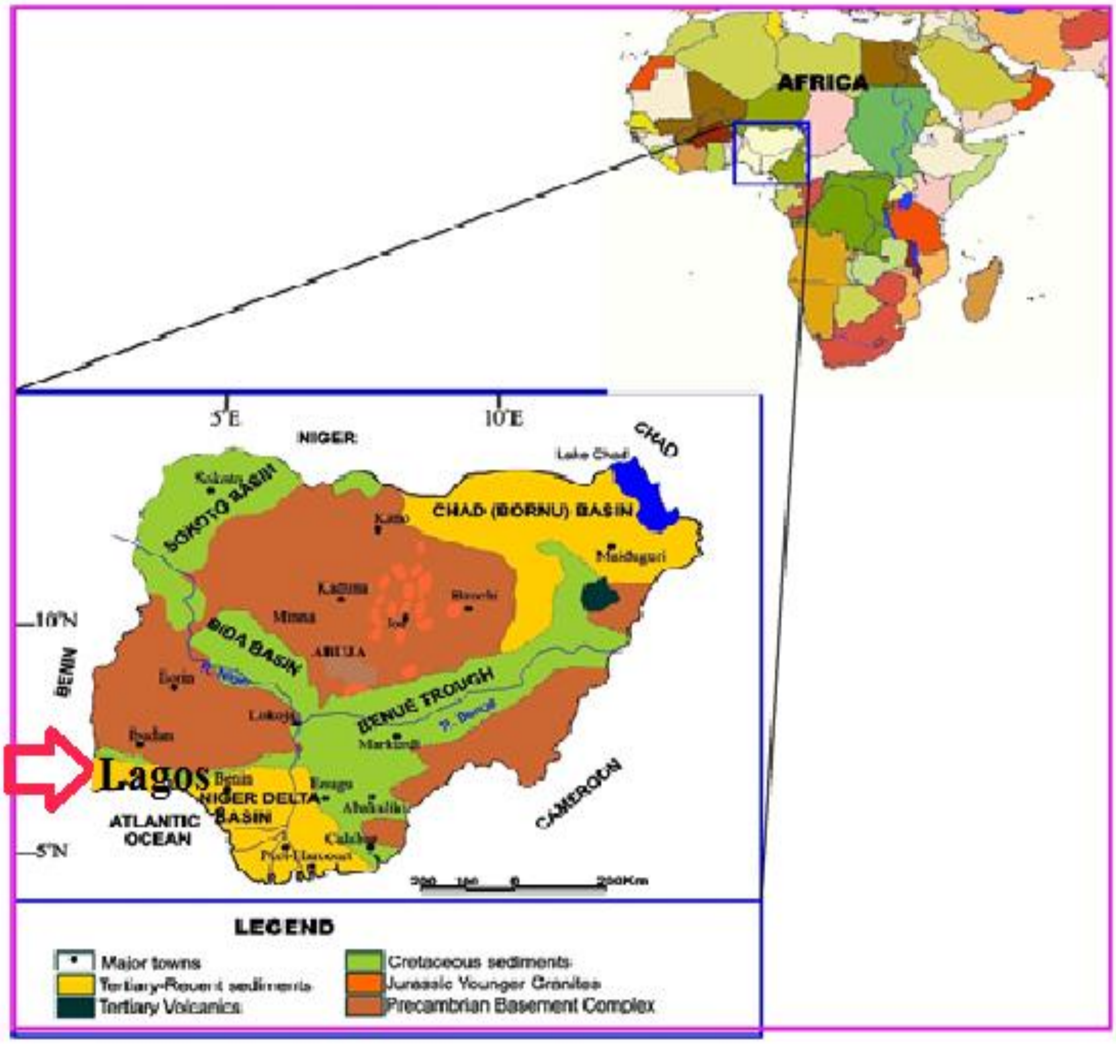

Figure 1. Location map of the studied area

2. Field description

2.1. Geological setting

The study area is located at Eti-Osa local government in the southeastern part of Lagos State (Figure 1). It lies between latitudes $6^0\ 30^1\ 37^{11}$ and $6^0\ 30^1\ 18^{11}$ N and longitude $3^0\ 36^1\ 3^{11}$ and $3^0\ 35^1\ 34^{11}$ E in South West Nigeria. This area is in the zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. It is situated in the Nigeria sector of the Benin-basin and near the eastern margin of the basin. The geological formation of the study area is composed of sediments that are typical of the marine environments, which is an intercalation of sand and clay (Figure 2). These sediments also grade into one another and vary widely in both lateral extent and thickness [16][17]. The choice of this study area is because the area is reclaimed from water bodies and it is always logged with water.

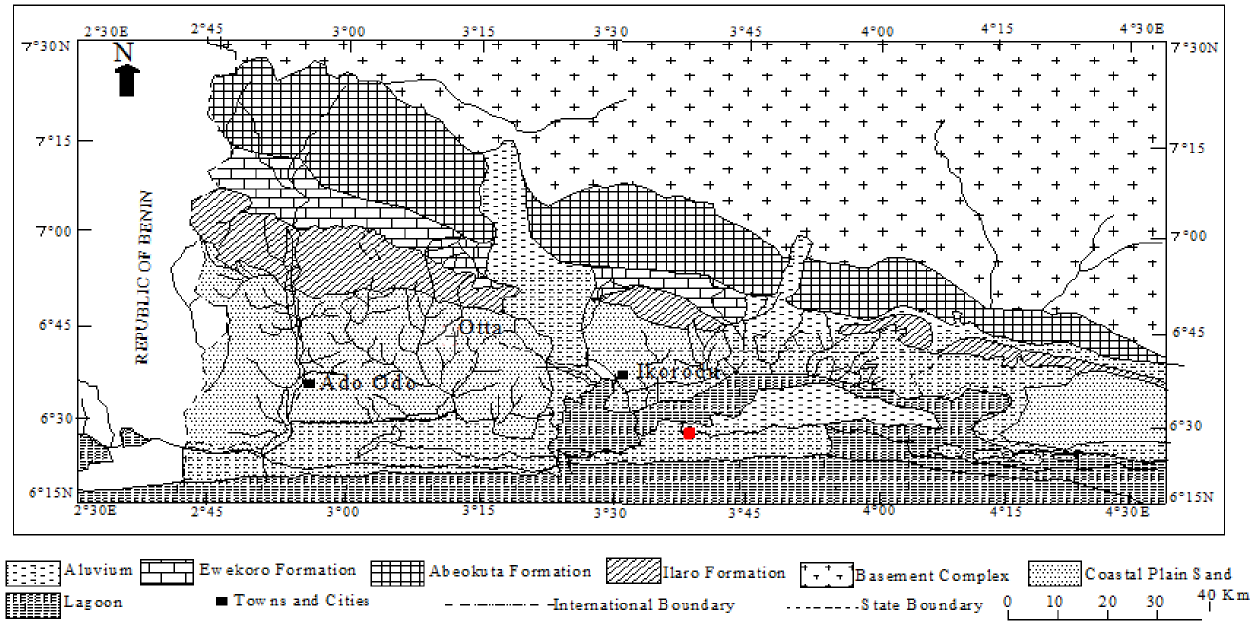

Figure 2. Simplified geological map of the study area, with the study area marked in red

3. Data acquisition and processing

2D electrical resistivity survey was conducted in the study area using an ABEM Terrameter (SAS 1000/4000) [18]. Four 2D profiles were surveyed with profile length ranging between 85 and 250 m as a result of accessibility, 5m electrode spacing was used. The 2D data was processed using RES2DINV software. The RES2DINV inversion code uses nonlinear optimization technique that automatically determines the inverse model of the 2D resistivity distribution of the subsurface [12]. The RES2DINV code subdivides the subsurface into a number of rectangular blocks on the basis of the distribution and volume of the data measured, which also depends on the electrode spacing, positions of electrodes and the data level [13]. The inversion was subjected to least-squares inversion technique with standard least-squares constraint, which reduces the square of the difference between the observed and the computed apparent resistivity. The cone penetration test was conducted with the use of a 2.5 ton Shell and Auger equipment. Two cone tests were conducted at two different locations in the study area. In this method a cylindrical penetrometer with a conical tip was driven into the ground at a constant rate. During penetration, the forces acting on the cone tip and on the shaft behind the tip are measured. For this study a standard Dutch cone (60° apex angle and base area of 10 cm^2) was used. The investigation of each location was concluded when the anchors that held the CPT rig firmly to the ground began to pull out of the ground. The cone resistance data obtained by this technique was plotted against the depth.

4. Results and discussion

Electrical resistivity profiling is used to acquire information on the lateral and vertical variation of resistivity with depth. The results of the inverted 2D electrical resistivity data showed three distinct geoelectrical layers which were delineated in the study area (Figure 3).

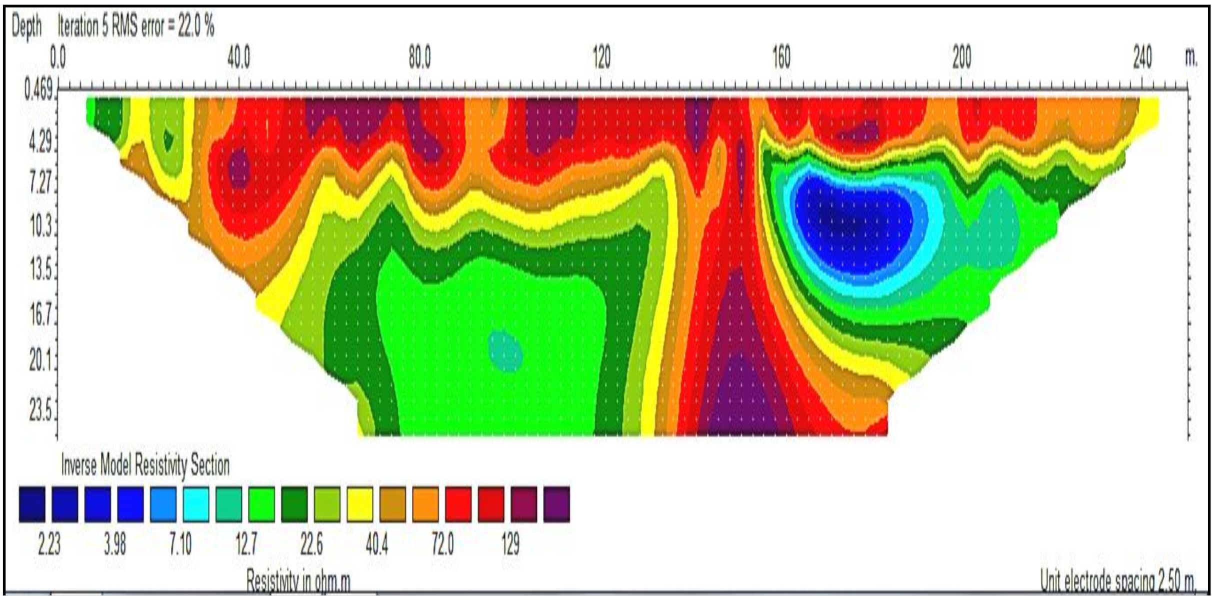

Figure 3. 2D inverse resistivity model conducted in the study area

The lithology of the delineated layers was dependent on all other available information from boreholes, hand-dug wells, known geology and previous studies. The first geoelectric layer represents the top soil with thickness varies from 0.5 to 7 m and has high resistivity value of about 150 Ω*m* corresponding to wet sand. The second geoelectric layer has a moderate resistivity values that ranged between 30 and 70 Ω*m* with an average thickness of 6 m representing sand clay. The third geoelectric layer depicted very low resistivity values that ranged between 2 and 10 Ω*m* with an average thickness of about 8 m corresponding to clay layer in the study site. Within the depth of investigation for foundation at the study area, the 2D electrical resistivity image revealed variations in electrical resistivity with clay layer of appreciate thickness in the subsurface. Also, there is a channel for upward migration of water from the subsurface noticed in the 2D image. Clay materials have poor porosity and this explains why the study area is always logged with water, which may be very harzadous to the foundation of the building. The result of the cone penetration test revealed the material from the topsoil to a depth of about 7 m to be of low resistance of about 2-3 kg/cm^2 (Figure 4). The geologic formation with this type of resistance value may be regarded as a weak geomaterial and of low bearing capacity. The low bearing capacity observed in the first region of the subsurface may be as a result of the influx of water into the geomaterial which is retained by the presence of clay material in the subsurface.

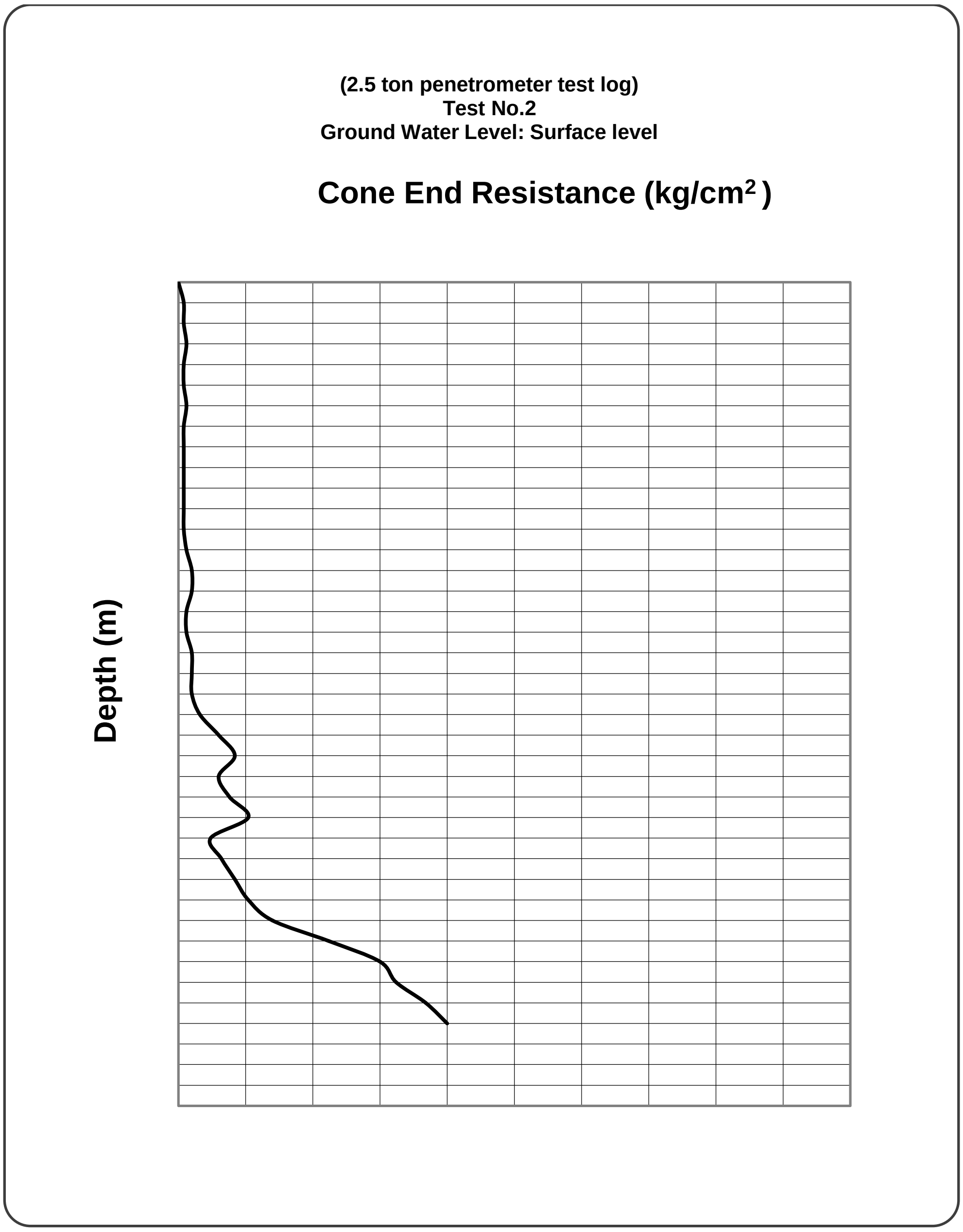

Figure 4. Result of cone penetration test conducted in the study area.

5. Conclusions

From the geologic information, interpretation of resistivity data and cone penetration test results conducted in the study area, it can be concluded that there are three distinct geoelectric layers, which are (from top to bottom); wet sand (150 ohm.m), sandy clay (30 to 70 ohm.m) and clay layer (2-10 ohm.m). Within the depth of investigation for foundation, there are no faults and cavities but a channel that allows for upward migration of water to the near surface. The geomaterial from the topsoil to a depth of about 7 m is composed of soft geologic formation, which may be the influence of water retained in the body of the soil. Some sort of soil improvement or pile foundation is recommended in order to mitigate the direct impact of the foundation on the soil.

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