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# GEOPHYSICAL STUDY OF ROAD FAILURES USING VERTICAL ELECTRICAL SOUNDING OF SOME ROADS IN ENUGU, ENUGU STATE, NIGERIA

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**ABSTRACT:** Road failures in Nigeria have been attributed to so many factors such as lack of proper geophysical investigation prior to road construction and a proper understanding of the weathered layer characteristics. The thickness of the road layer was determined using Vertical Electrical Sounding (VES) or Vertical Electrical Drilling (VED) data collected from ten (10) VES stations along the Enugu-Onitsha Expressway, Thinker's Corner Enugu, and Port Harcourt Enugu expressways. The survey was conducted with the ABEM SAS 1000 Terrameter with half current electrode spacing of 50m, and the data was processed with computer software to obtain modeled curves and the thickness of the layers. The study's findings revealed that the first layer's thickness ranged between 0.6 m and 2.3 m with an average thickness of 1.6m along the ten VES locations, and the apparent resistivity of the first layer ranged between 46.2 Ωm and 1265.7 Ωm with an average resistivity value of 302 Ωm along the ten VES locations. These showed low resistivity of the first layer, indicating clay/shale and low bearing capacity. It is therefore recommended that if soil and clay are the main top materials that usually contain water, they must be removed and replaced with more competent materials.

**Keywords***: Vertical Electrical Sounding, Weathered layer, Geophysical investigation, Clay, Apparent resistivity, road failure and bearing capacity.*

## 1.0 INTRODUCTION

Kar and Berenjian (2013) define the weathered layer as the shallow subsurface layer composed of unconsolidated materials such as soil, sand, and gravel. The thickness of the topsoil is important in road design. Several factors influence the competency (or strength) of any geological material, including mineralogy, particle contact character, and weathering agent (Blyth and De Freitas, 1984).

In most parts of Nigeria, the rate of road failure is alarming, these has over the years became a big challenge to the country's economic development and has affected the lives of the masses negatively. These failures have been attributed to a variety of factors, including a lack of adequate knowledge of the road subsurface geology. This is due to a lack of geophysical investigation of the proposed area prior to construction, though failures are not limited to any particular geologic setting. Failures in crystalline, basement, complex rocks, and sedimentary formations have been documented. Road pavement failure is defined as a break in a road network caused by cracks, potholes, bulges, or depression. Visible cracks, potholes, and depressions, which are commonly associated with road failure, can disrupt a smooth ride to one's destination (Rahaman, 1984; Aigbedion, 2007).

However, it has been discovered that bad sections of roads, many of which are the result of poor construction on incompetent subgrade and sub-base materials, cause more harm than good. They have been responsible for numerous fatal accidents, vehicle wear and tear, and the loss of valuable time during traffic jams (Osinowo, 2011). A lack of an adequate geophysical survey prior to start-up is also a contributing factor to failure. Such preliminary investigations have the potential to reveal structures such as unconsolidated soil formations with varying resistivity and conductivity (Praveen and Ankit, 2010). Low electrical resistivity indicates a good electrical conduction path arising from reduced aeration, increased electrolyte saturation or high concentrations of dissolved salts in soils (Abdel Aal et al., 2004).

The electrical resistivity method is the most common technique used for the determination such and is cheap and reliable (Susan, 2004, Dafalla and Al Fouzan, 2012). It provides a non-destructive geophysical method of determining soil water flow from the surface to effective depth.

Several researches have been carried using vertical electrical sounding (VES) and on the causes of road failure in Nigeria. Joshua et al. (2018), in their study on the causes of road failure along Kutigi Street in Minna using the Wenner array method, discovered that the road failure was caused by the presence of clay and sandy clay materials, which have the tendency to absorb water, and suggested excavating these materials to a depth of 4 to 6 meters and replacing them with more competent material. Okamkpa et al. (2018) conducted groundwater exploration research in parts of Enugu East Local Government Area of Enugu State using Vertical Electrical Sounding (VES) and observed relatively low resistivity, which was deduced to be clay/shale with subordinate sandy lamina.

1.1. Geology of the Study Area

The Enugu Shale is one the rock formations that were deposited in the Anambra Basin, after the Santonian tectonism. The Anambra Basin according to Nwajide (1990) and, is a major depocenter (alongside the Afikpo Basin) within the southern Benue Trough, that was created as a result of the tectonism (uplift) in the late Cretaceous as a depression to the west of the uplift, Benkhelil (1987). The stratigraphic setting in the Anambra Basin, thought to belong the third cycle sedimentation within the Benue Trough, Nwajide (1990), is made up of two Group of Formations.

The oldest group is the Nkporo Group (late Campanian in age), as reported by Nwajide, (1990) and Ikegwuonu et al (2021). It comprises of the Nkporo Shale, Owelli Sandstone and the Enugu Shale**,** Reyment (1965), etc. The Nkporo Group is overlain by the Coal Measure Group (early Maastrichtian to early Danian in age). The oldest formation in this group is the Mamu Formation (Lower Coal Measure), and overlain by the False Bedded, Ajalli Sandstone, which in turn is overlain by the Nsukka Formation (Upper Coal Measure).

1.2. Description of Study Area

The study areas are as shown in figure 1 these include, Enugu-Onitsha expressway with three VES stations (VES 1 at longitude N6º 27’ 19.35’’ latitude E$7^0$ 25’ 44.04’’, VES 2 longitude N6º 28’ 11.13’’ latitude E$7^0$ 28’ 32.05’’, and VES 3 at longitude N6º 28’ 12.62’’ latitude E$7^0$ 28’ 41.08’’ ), four VES stations at Alor road, Thinker’s Corner Enugu (VES 4 at longitude N6º 28’ 29.47’’ latitude E$7^0$ 31’ 15.46’’, VES 5 at longitude N6º 28’ 29.24’’ latitude E$7^0$ 31’ 18.81’’, VES 6 at logitude N6º 28’ 20.30’’ latitude E$7^0$ 31’ 22.77’’, and VES 7 at longitude N6º 28’ 16.75’’ latitude E$7^0$ 31’ 30.16’’), and Three VES stations at Port Harcourt expressway, Enugu (VES 8 Enugu at longitude N6º 26’ 37.20’’ latitude E$7^0$ 32’ 20.65’’, VES 9 at longitude N6º 25’ 42.94’’ latitude E$7^0$ 32’ 17.44’’ and VES 10 at longitude N6º 24’ 22.63’’ latitude E$7^0$ 31’ 31.31’’. These roads are of commercial importance. The Enugu-Onitsha expressway is one of the access roads between Enugu state and Anambra state, while Alor Road, Thinker’s Corner, is one of the access roads to Godfrey Okoye University and the Port Harcourt expressway, linking Enugu state and River state.

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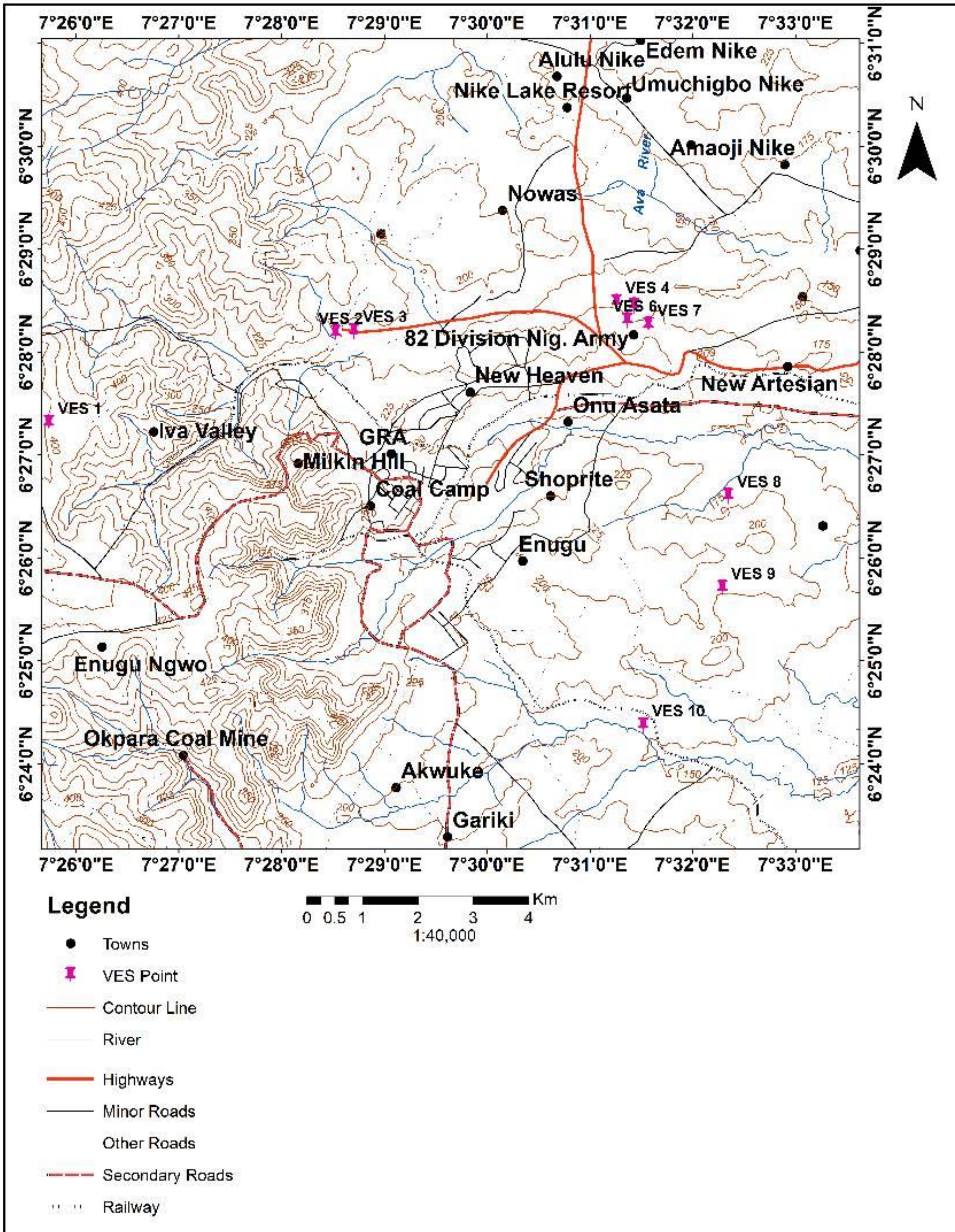

Figure 1: Topographic map showing VES points

## 2.0. METHODOLOGY

In this study, vertical electrical sounding (VES) with a Schlumberger array was used. VES is a non-destructive and convenient method of determining the depth to the rock head for foundation purposes, as well as providing information on subsurface material saturation (Philip Kearey, Michael Brooks, and Ian Hill, 2022). The Schlumberger array was used, and the half current electrode spacing (AB/2) in meters was varied from 1m to 50m. The VES data was quantitatively interpreted for each location to obtain the resistivity and thickness of the soil. Each location's computer-modified curve was also obtained.

### 2.1. Field Procedure

The Schlumberger array was used to carry out the survey. The basic field equipment used for this study includes four metal electrodes; cables for current and potential electrodes (four); hammers; measuring tapes; and the ABEM Terrameter SAS 1000, which displays apparent resistivity values digitally as computed from Ohm’s law

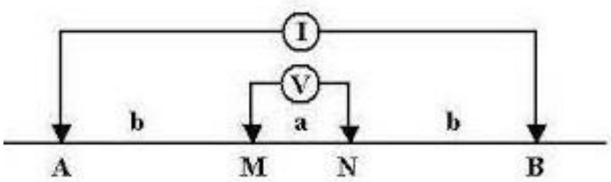


Figure 2: Schlumberger array configuration (Morrison and Gasperikov, 2012)

Ten VES points were used for the study. These points were located along the Enugu-Onitsha Expressway, Port Harcourt road, and Thinkers Corner (Alor Street), which connects to Godfrey Okoye University. The four electrodes were spread as shown in figure 1 where AB is the distance between the current electrodes and MN is the distance between the potential electrodes and they were connected to the terrameter with the wire rack. To change the depth range of the measurements, the current electrodes were displaced outward together. During field work, the ABEM Terrameter SAS 1000 (Self Averaging System) records voltage and current automatically, stacks the results, computes resistance in real time, and digitally displays it (Dobrin and King, 1976; Alile et al., 2011). The Terrameter was set up in such a way that it displays apparent resistivity.

## 3.0. RESULTS

This research was carried out to investigate the causes of road failure in some roads in Enugu metropolis, some of the roads investigated include Enugu-Onitsha Expressway, Port-Harcourt road and Alor road Thinker’ corner. Vertical electrical sounding was carried in ten (10) locations using current electrode separation (AB/2) of 50m. the data were obtained and analyzed. Computer modified curves were obtained for each profile. The results from the VES are shown in fig. 3 to 12. The study area is underlain by four or five layers of varying lithologies. The curve type are mostly Q except for VES 1 and VES 10 which are A and QA respectively.

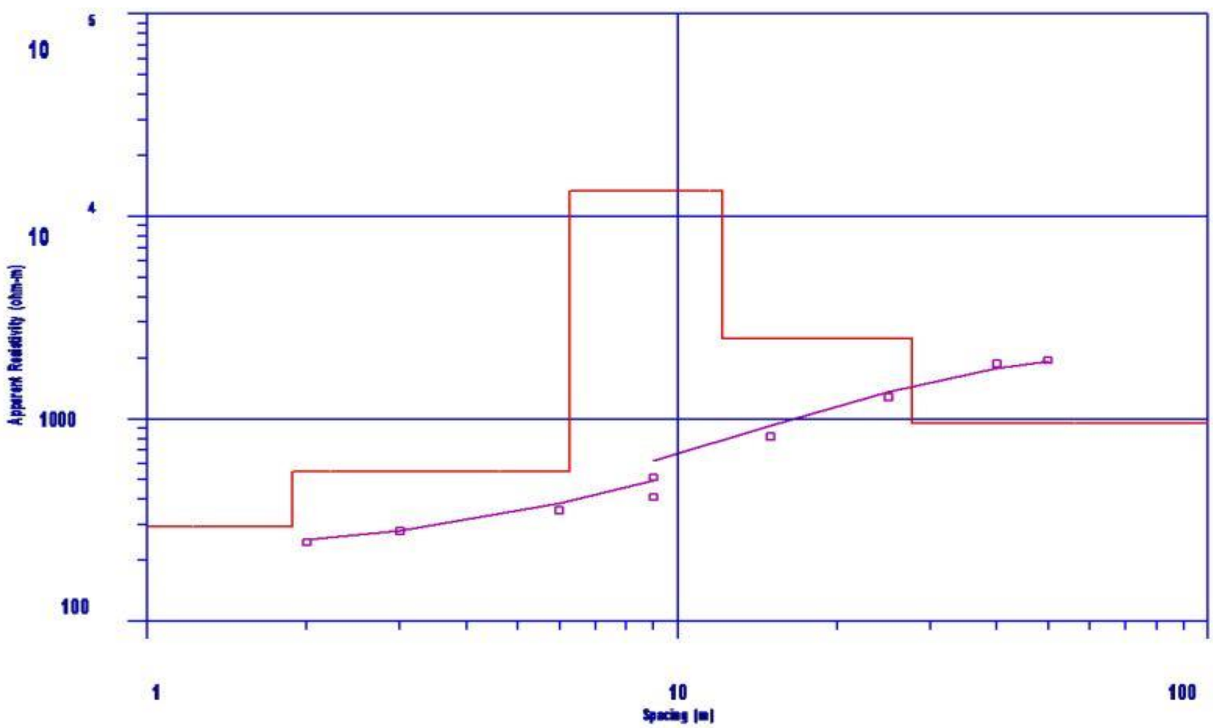


**Figure 3: VES 1 curve (Enugu-Onitsha)**

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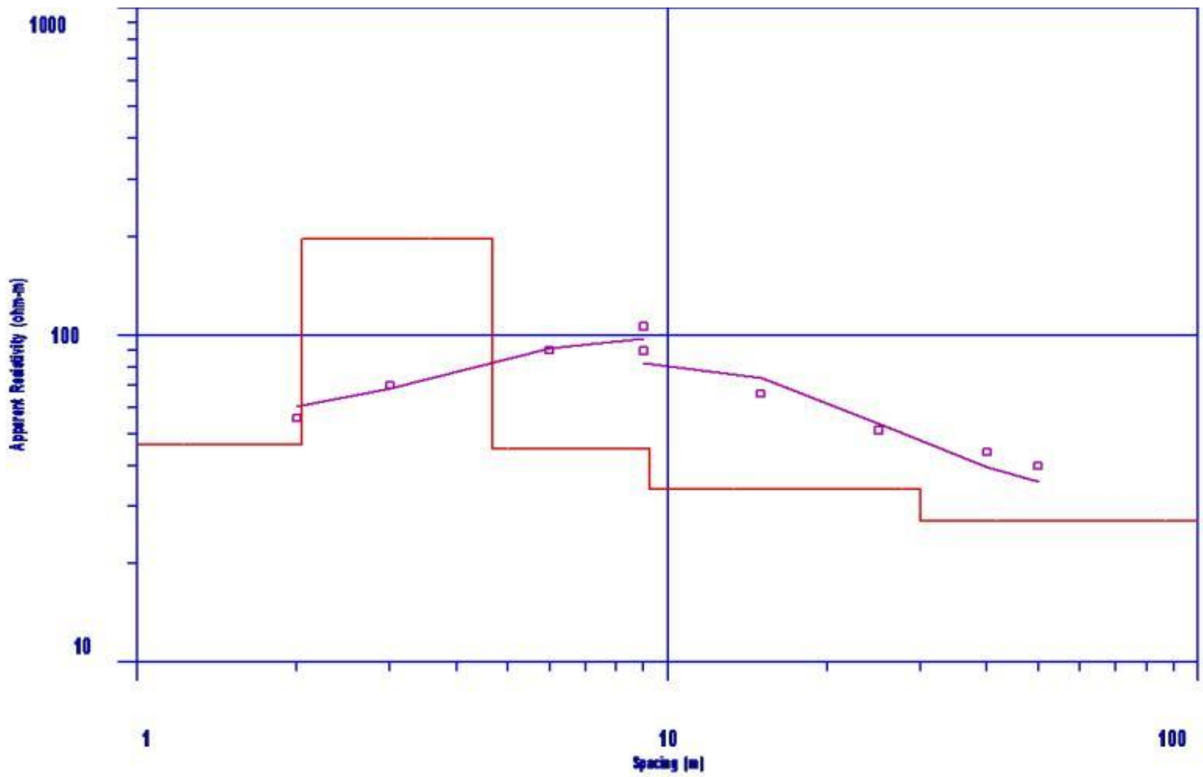


**Figure 4: VES 2 curve (Enugu-Onitsha expressway)**

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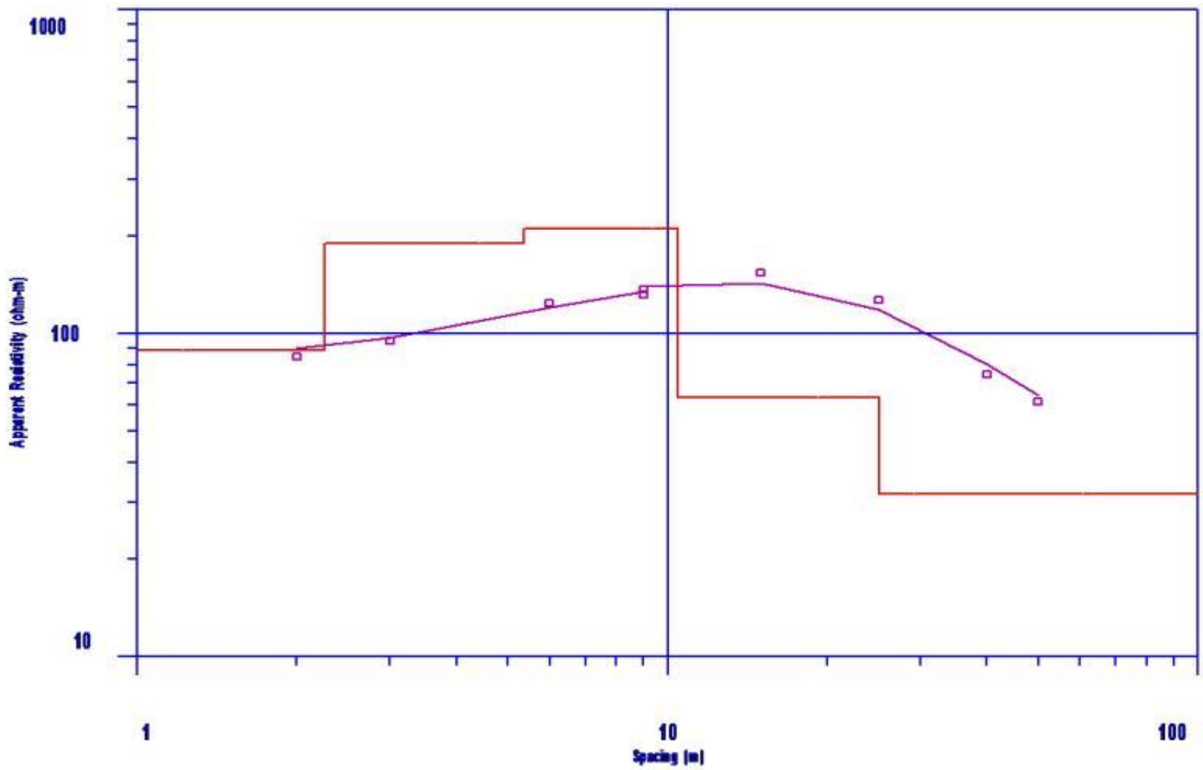


**Figure 5: VES 3 curve (Enugu-Onitsha expressway)**

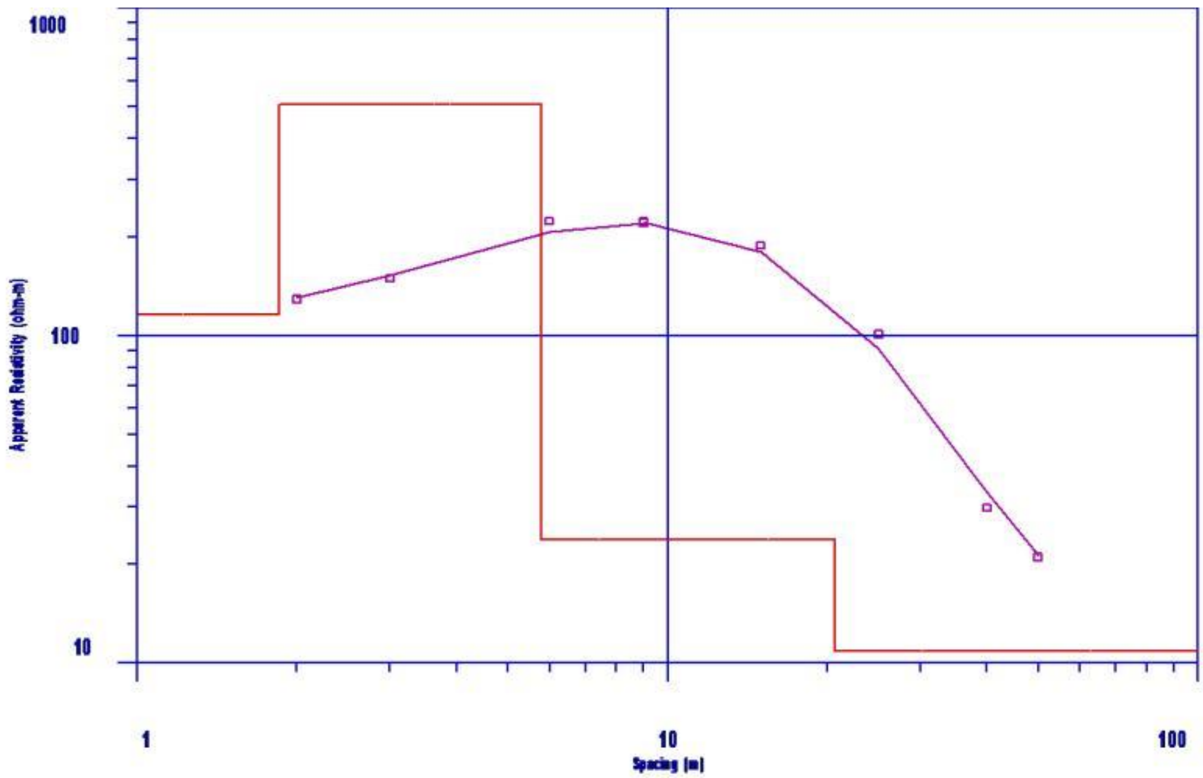


**Figure 6: VES 4 curve**

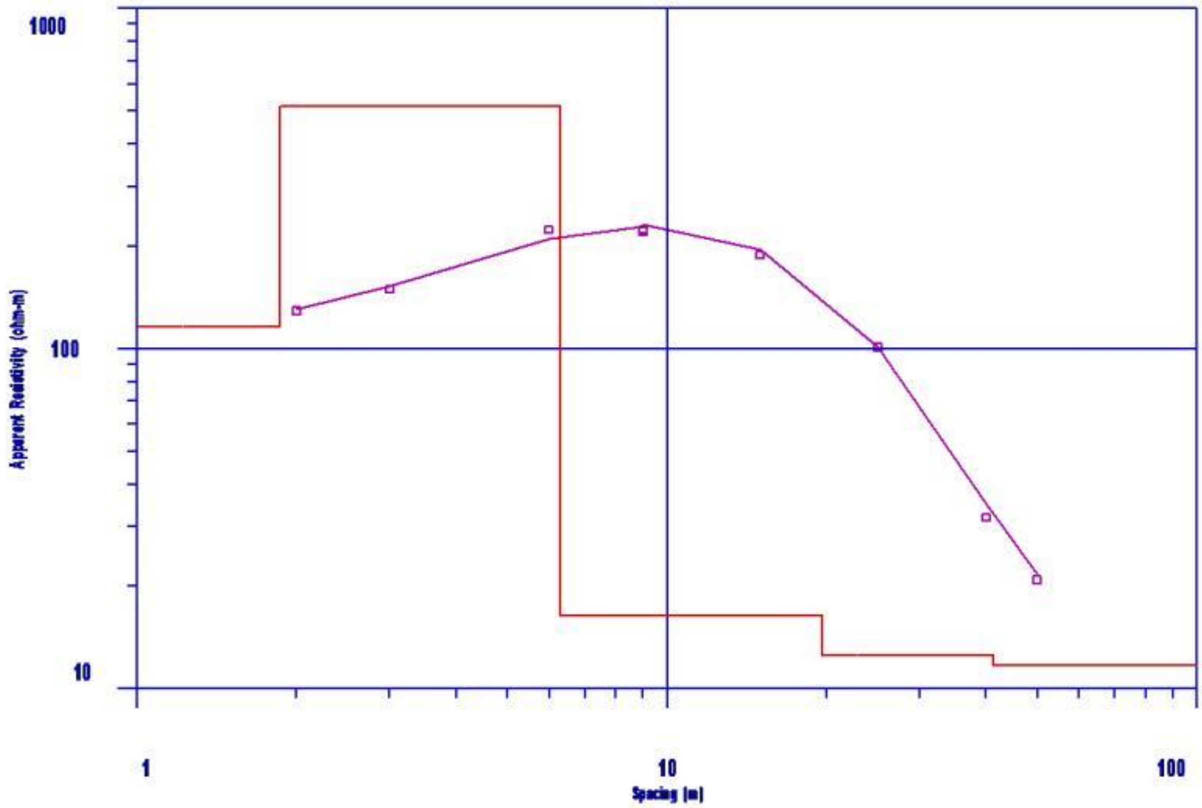


**Figure 7: VES 5 curve**

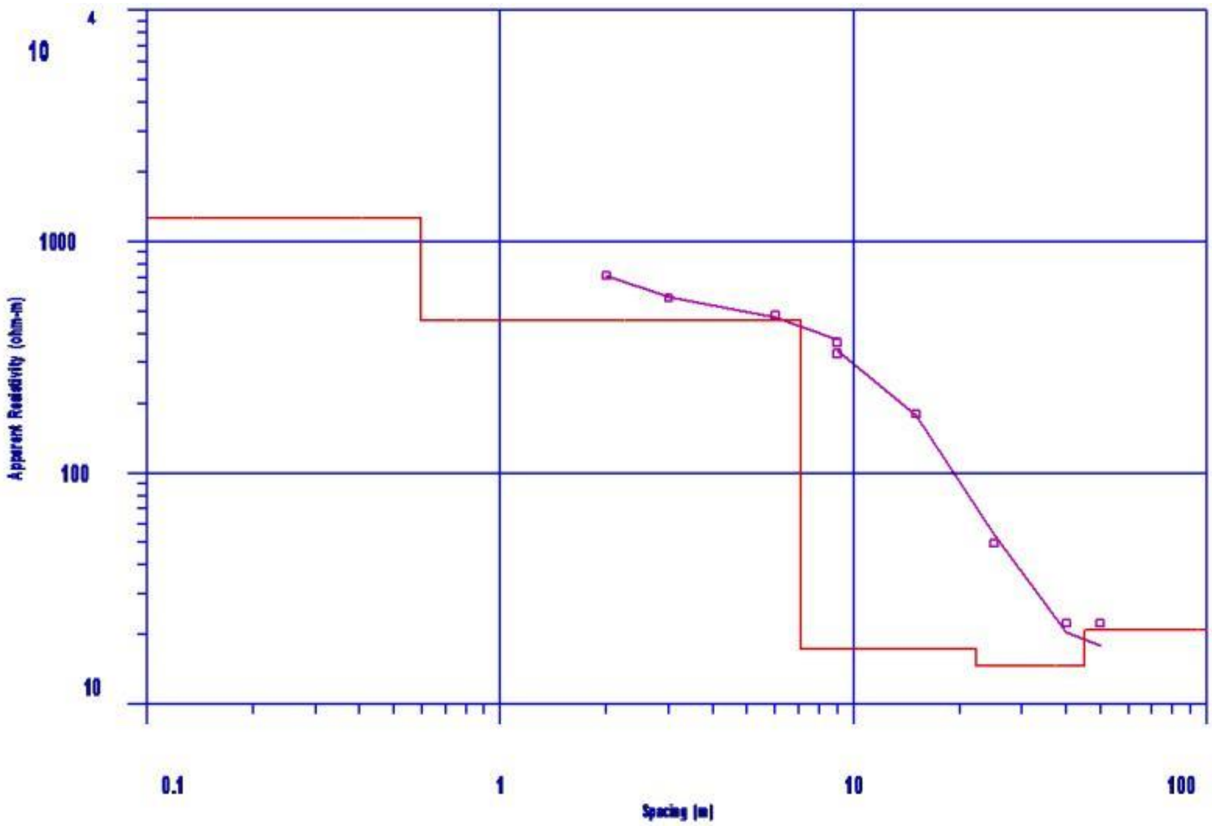


**Figure 8: VES 6 curve**

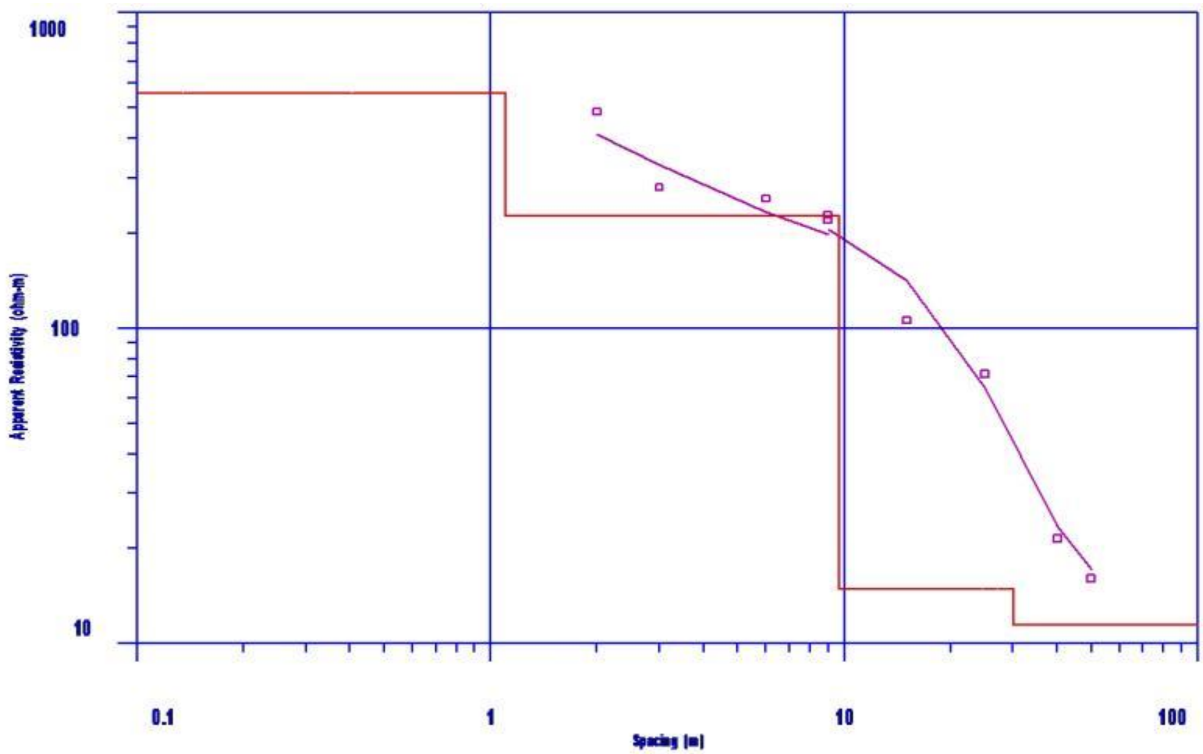


**Figure 9: VES 7 curve**

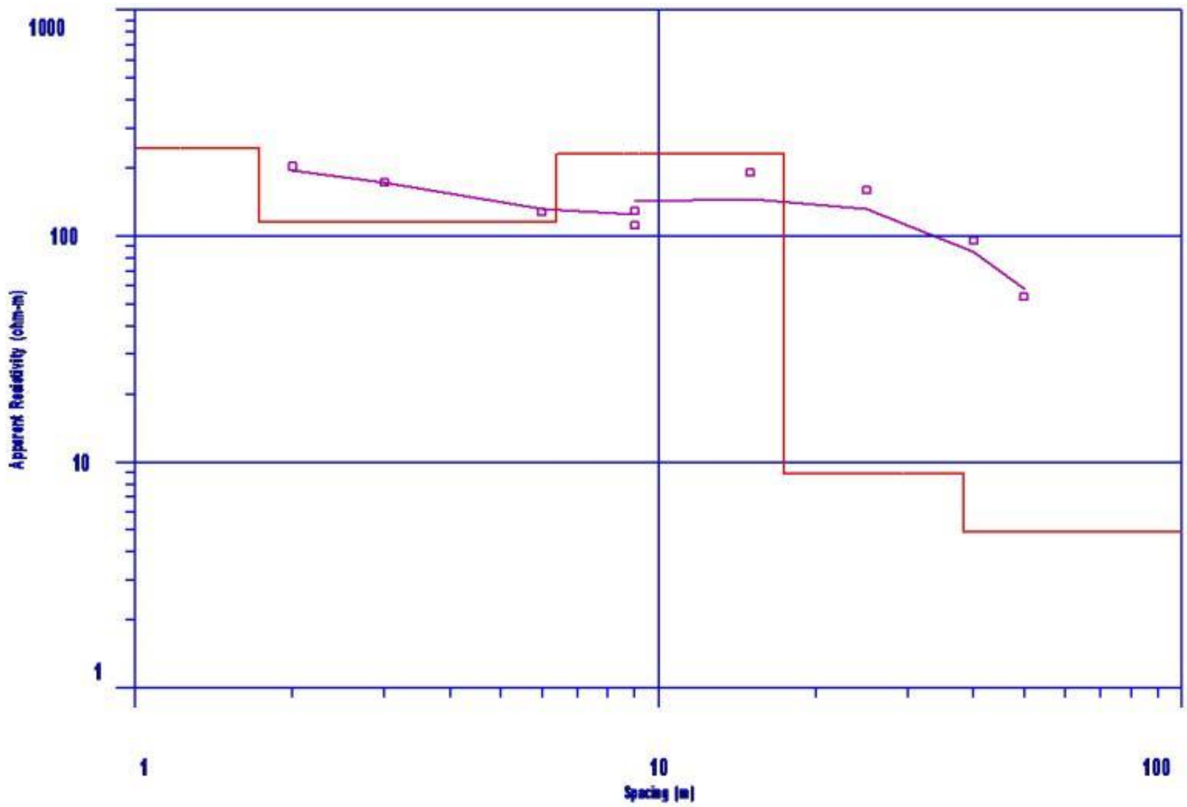


**Figure 10: VES 8 curve**

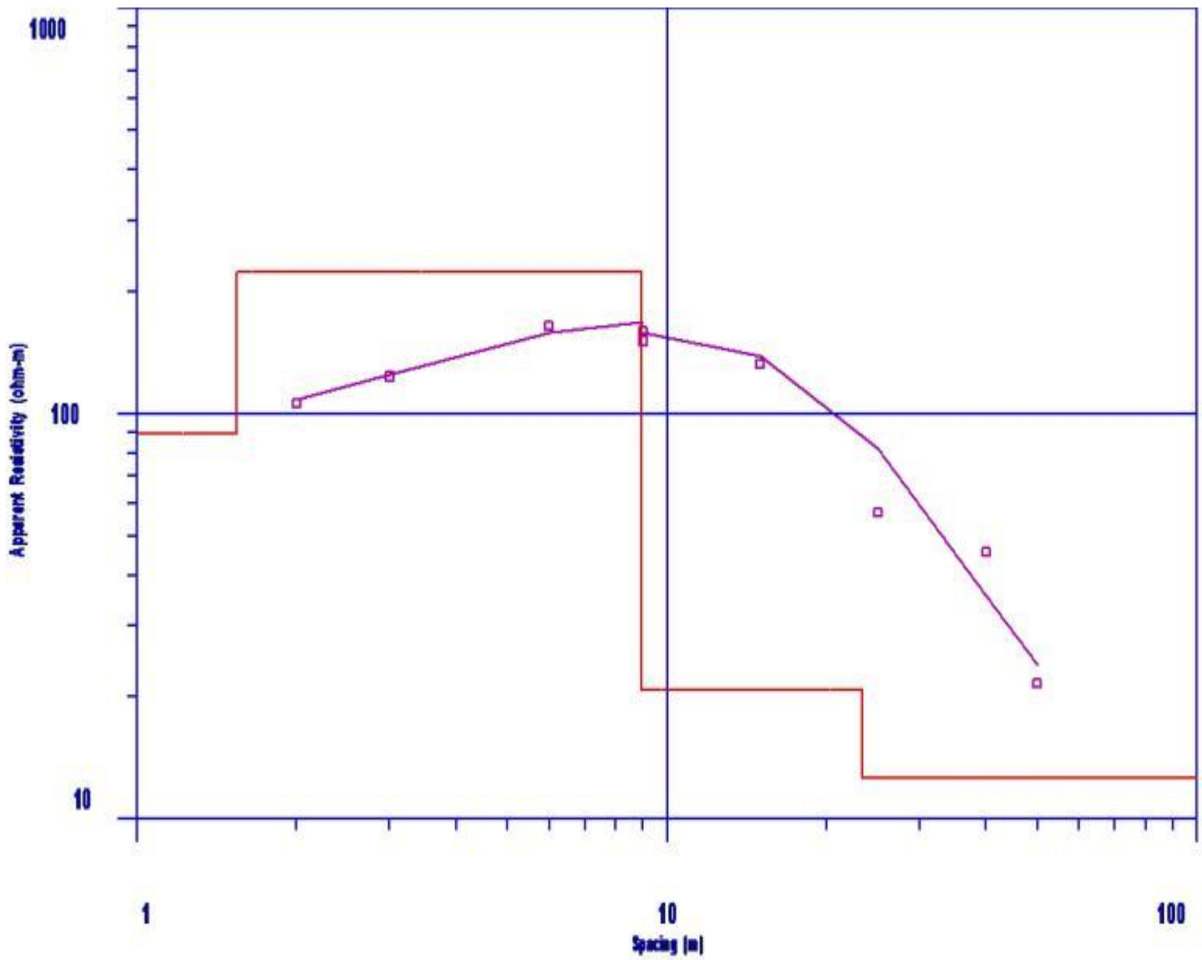


**Figure 11: VES 9 curve**

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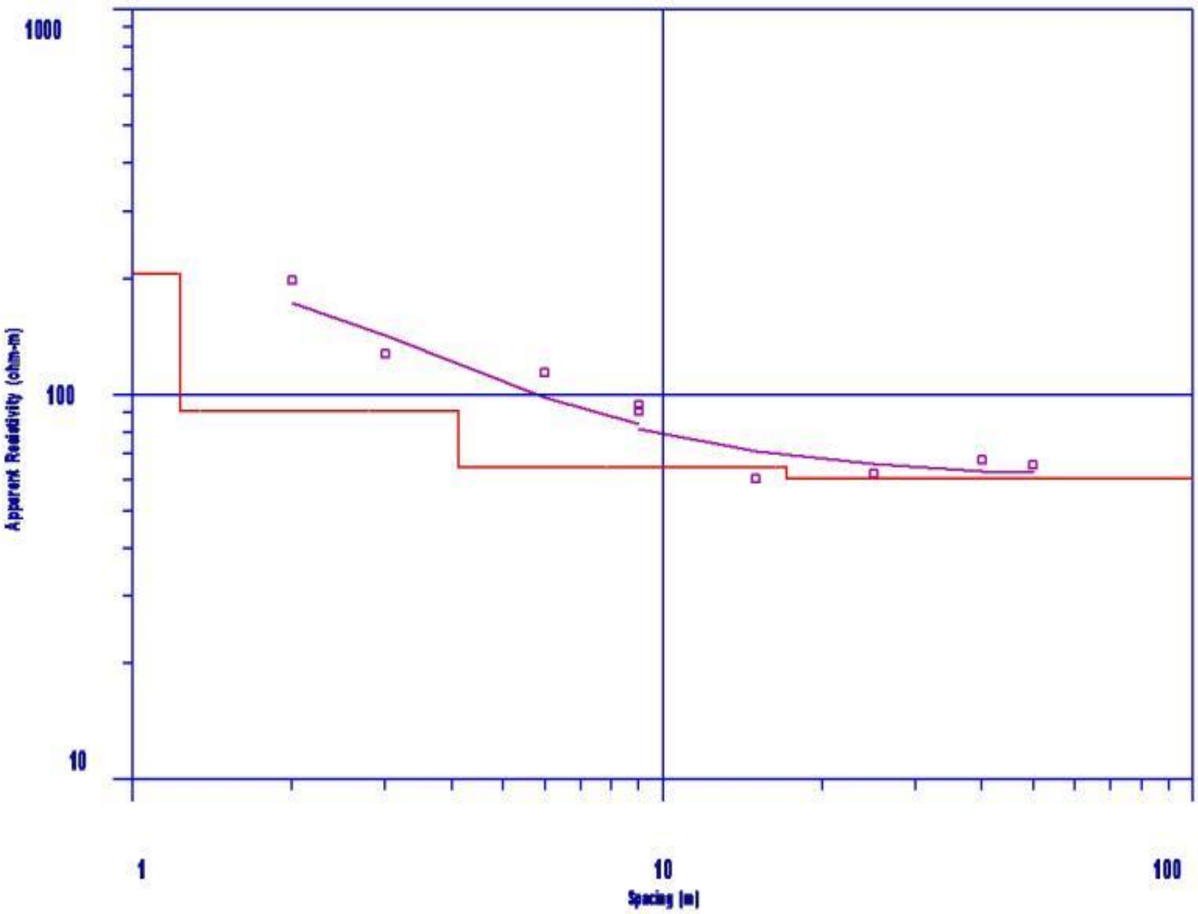


**Figure 12: VES 10 curve**

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**Table 1: Summary of Geoelectric parameter**

| Station | Layer | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve Type | Probable lithology |
|---|---|---|---|---|---|---|
| **VES 1** | 1 | 295.0 | 1.9 | 1.9 | A | Topsoil |
| | 2 | 549.1 | 4.4 | 6.3 | | Clayey Sand |
| | 3 | 13286.2 | 5.9 | 12.1 | | Sand |
| | 4 | 2476.3 | 15.6 | 27.7 | | Sand |
| | 5 | 951.0 | | | | Basement |
| **VES 2** | 1 | 46.2 | 2.0 | 2.0 | Q | Topsoil |
| | 2 | 196.2 | 2.6 | 4.7 | | Sandy Clay |
| | 3 | 44.9 | 4.6 | 9.3 | | Clay |
| | 4 | 33.8 | 20.8 | 30.0 | | Clay |
| | 5 | 26.9 | | | | Basement |
| **VES 3** | 1 | 88.6 | 2.3 | 2.3 | Q | Topsoil |
| | 2 | 189.6 | 3.1 | 5.4 | | Sandy Clay |
| | 3 | 210.5 | 5.1 | 10.5 | | Sandy Clay |
| | 4 | 63.1 | 14.6 | 25.1 | | Clay |
| | 5 | 31.9 | | | | Basement |
| **VES 4** | 1 | 115.5 | 1.9 | 1.9 | Q | Topsoil |
| | 2 | 507.9 | 3.9 | 5.8 | | Clayey Sand |
| | 3 | 23.7 | 14.9 | 20.7 | | Clay |
| | 4 | 10.9 | | | | Basement |
| **VES 5** | 1 | 115.9 | 1.9 | 1.9 | Q | Topsoil |
| | 2 | 514.1 | 4.4 | 6.3 | | Clayey Sand |
| | 3 | 16.4 | 13.4 | 19.7 | | Clay |
| | 4 | 12.5 | 13.4 | 19.7 | | Clay |
| | 5 | 11.7 | | | | Basement |
| **VES 6** | 1 | 1265.7 | 0.6 | 0.6 | Q | Topsoil |
| | 2 | 456.6 | 6.5 | 7.1 | | Clayey Sand |
| | 3 | 17.4 | 15.1 | 22.2 | | Clay |
| | 4 | 14.6 | 23.0 | 45.2 | | Clay |
| | 5 | 21.0 | | | | Basement |

| | | | | | | |
|---|---|---|---|---|---|---|
| **VES 7** | 1 | 553.2 | 1.1 | 1.1 | Q | Topsoil |
| | 2 | 226.1 | 8.6 | 9.7 | | Sandy Clay |
| | 3 | 14.9 | **20.4** | **30.1** | | Clay |
| | 4 | **11.5** | | | | Basement |
| **VES 8** | 1 | 245.0 | 1.7 | 1.7 | Q | Topsoil |
| | 2 | 115.5 | 4.7 | 6.4 | | Sandy Clay |
| | 3 | 231.1 | 11.0 | 17.3 | | Sandy Clay |
| | 4 | 8.9 | 21.0 | 38.3 | | Clay |
| | 5 | 4.9 | | | | Basement |
| **VES 9** | 1 | 89.3 | **1.5** | **1.5** | Q | Topsoil |
| | 2 | 223.5 | **7.4** | **9.0** | | Sandy Clay |
| | 3 | **20.9** | **14.4** | **23.4** | | Clay |
| | 4 | **12.6** | | | | Basement |
| **VES 10** | 1 | **205.6** | **1.2** | **1.2** | QA | Top layer |
| | 2 | **90.5** | **2.9** | **4.1** | | Clay |
| | 3 | **64.9** | **13.0** | **17.1** | | Clay |
| | 4 | **60.5** | | | | Basement |

**Table 2: Summary Layer Thickness and Resistivity**

| VES | LAYER THICKNESS (M) | | | | LAYER RESISTIVITY (ΩM) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | h1 | h2 | h3 | h4 | ρ1 | ρ2 | ρ3 | ρ4 | ρ5 |
| **1** | 1.9 | 4.4 | 5.9 | 15.6 | 295 | 549.1 | 13286.2 | 2476.3 | 951 |
| **2** | 2 | 2.6 | 4.6 | 20.8 | 46.2 | 196.2 | 44.9 | 33.8 | 26.9 |
| **3** | 2.3 | 3.1 | 5.1 | 14.6 | 88.6 | 189.6 | 210.5 | 63.1 | 31.9 |
| **4** | 1.9 | 3.9 | 14.9 | | 115.5 | 514.1 | 16.4 | 12.5 | 11.7 |
| **5** | 1.9 | 4.4 | 13.4 | 13.4 | 115.9 | 514.1 | 16.4 | 12.5 | 11.7 |
| **6** | 0.6 | 6.5 | 15.1 | 23 | 1265.7 | 456.6 | 17.4 | 14.6 | 21 |
| **7** | 1.1 | 8.6 | 20.4 | | 553.2 | 226.1 | 14.9 | 11.5 | |
| **8** | 1.7 | 4.7 | 11 | 21 | 245 | 115.5 | 231.1 | 8.9 | 4.9 |
| **9** | 1.5 | 7.4 | 14.4 | | 89.3 | 223.5 | 20.9 | 12.6 | |
| **10** | 1.2 | 2.9 | 13 | | 205.6 | 90.5 | 64.9 | 60.5 | |

## 1. DISCUSSION

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The resistivity of the topsoil ranged from 46.2 Ωm to 1265.7Ωm while the layer thickness ranged from 0.6m to 2.3m the topsoil resistivity obtained for VES 1,2,3,4,5,7,8,9 and 10 ranged from 46.2Ωm to 553.2Ωm which is within that of clayey sand lithologies class (Idornigie and Olorunfemi, 2000) while VES 6 has topsoil resistivity of 1265.7 Ωm. The second layer resistivity ranged from 90.5 Ωm to 549.1 Ωm which is in the category of clayey sand lithology while the layer thickness ranged from 2.6m to 8.6m. The third layer resistivity values lie between 14.9 Ωm and 13286.2 Ωm while the layer thickness ranged 4.9m to 20.4m. The fourth layer resistivity values ranged from 8.9 Ωm to 2476.3 Ωm with layer thickness between 14.6m to 23m, while the fifth layer resistivity values ranged from 4.9 Ωm to 951 Ωm.

Five layers was obtained at VES 1, 2, 3, 5, 6, 8,9 and four layers at VES 4, 7 and 10. VES 1 has the top layer resistivity value of 295 Ωm with layer thickness of 1.9m.VES 3 has top layer resistivity values are obtained to be 88.6 Ωm. this resistivity fall in the range of clay soil. The thickness of this layer is 2.3m. The second layer of resistivity 189.6Ωm falls in the range Sandy Clay. At VES 4 the top layer resistivity value is obtained to be 115.5 Ωm. this resistivity fall in the range of sandy clay (Table 1). The thickness of this layer is 1.9m at the elevation of 145.7m. The second layer of resistivity 141.8 Ωm falls in the range Clay. At VES 5, five layers was obtained in which the top layer's resistivity was obtained to be 115.9 Ωm. this resistivity fall in the range of sandy clay (Table 1). The thickness of this layer is 1.9m at the elevation of 141.9m. The second layer of resistivity 137.7 Ωm falls in the range Clayey sand.

VES 6 has the top layer resistivity value to be 1265.7 Ωm. this resistivity fall in the range of sandy clay (Table 1). The thickness of this layer is 0.6m. The second layer of resistivity 456.6 Ωm falls in the range Clayey sand. VES 7 has the top layer resistivity value to be 553.2 Ωm, this resistivity fall in the range of clayey sand (Table 1). The thickness of this layer is 1.1m. The second layer of resistivity 226.1 Ωm falls in the range of sandy clay. For VES 8 the top layer resistivity was obtained to be 245.0 Ωm. this resistivity fall in the range of sandy clay (Table 1). The thickness of this layer is 1.7m at the elevation of 157.3m. The second layer of resistivity 115.5 Ωm falls in the range of sandy clay. No functional drainage system was observed at this location.

for VES 9 the top layer resistivity was obtained to be 89.3 Ωm, this resistivity falls in the range of clay (Table 1). The thickness of this layer is 1.5m. The second layer of resistivity 223.5 Ωm falls in the range of sandy clay.

VES 10 the top layer resistivity was obtained to be 205.6 Ωm. This resistivity falls in the range of sandy clay (Table 1). The thickness of this layer is 1.2m. The second layer of resistivity 90.5 Ωm falls in the range of clay.

A general trend of low resistivity was observed at the ten VES stations. This low resistivity was as a result of the presence of clay of high moisture content. Clay of high moisture content has a low bearing capacity. As a result of this capacity any engineering structure built on them is bound to fail. This can be attributed to the failure of the roads observed. Another problem observed was the lack of proper drainage system. The lack of the gutter to drain away excess water on the surface of the roads also increases the moisture content of the clay underneath the asphalt. This causes the Asphalt to cave in, causing the cracks and the potholes on the road surfaces observed.

## 2. CONCLUSION AND RECOMMENDATION

It was concluded in this study that the road failures observed in the profile areas are as a result of the presence of clay in the top soil and inability of the engineers to excavate to the appropriate depth and also lack of drainage system is a contributing factor.

This study recommends as follows:

Construction engineers should endeavor to carry out proper geophysical investigations before continuing construction works. The engineers should endeavor to excavate at least 2m of the top soil and fill them with a more competent material e.g. laterite (red soil). Proper drainage system should be constructed on both sides of the roads in order to drain excess water on the road surface of the roads to prevent absorption of more water by the underneath soil and most importantly, If the soil and the clay are main top material which usually contain water, they must be removed or excavated in order to ensure good bedrock or foundation.

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