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Geophysical Investigation and Protective Capacity of Frequently Failed Road Sections of Selected Roads in Delta State, Nigeria

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ABSTRACT
Geophysical survey has been successfully carried out along failed road sections situated in Delta State, Nigeria to delineate the causes of failure along portions of the road. These were executed by using forty Vertical Electrical Sounding (VES) from Schlumberger array along road sections using SAS 1000 ABEM Terrameter. The recorded field data were processed via Winresist software. Resistivity values ranging from 22 to 1026 Ωm at 15 m depth from surface were traced along Amukpe, Ekpan-Ovu, Aghalokpe, Okpara to Otumara. At Eku, Igun, Oria, Erho, and Abraka and Obiaruku, the resistivity figures procured ranged from 11 to 500 Ωm at depth of 5.5 m via the topsoil, 21.5 m from sub-grade and 9.76 to 50 m along few profiles. Umutu, Urhomehe, Abavo, Urhonigbe and Agbor signal resistivity ranging from 59 to 1468 Ωm for stable (lasting) and unstable (unsteady) segments of the road at 15 m depth for some profiles. Low resistivity values (≤197Ωm) were observed in some trenchant regions of the profiles comprising collapsible, expansive, compressible sandy clay materials which have the capability of absorbing water. The results of the geoelectric study revealed that the failure of road portions can be attributed to the presence of incompetent clayey materials used for the filling materials and low standard materials found underneath the built road. The protective capacity echelon ranges from poor-moderate. Competent filling soil should replace the low resistivity soils from 5-7 meters below the surface when rehabilitating the road.

INTRODUCTION

It is required that one carry out an inquiry into the carrying capability of soils containing an index of clay material before building a highway foundation. Investigating the engineering qualities of the underlying foundation material by geomorphologic, geotechnical, geophysical, methods are crucial when building any engineering venture (Ugbe *et al.,* 2022; Akpoyibo *et al.*, 2022). Due to a lack of this, highways have been built in regions where there has already been surface and subsurface geological degradation for a variety of reasons. Despite several rehabilitation initiatives, a number of roadway segments permanently collapse shortly after they are launched. Such rehabilitation has turned into a yearly rite that costs a lot of money for the government at all levels (Akpoyibo *et al.,* 2023). As a consequence, in order to maintain the transportation network usability, rehabilitations and corrective measures are required (Akpoyibo *et al.,* 2022).

Road failure is simply described as the incapability of a road to offer to its users a smooth ride. The users include the wheeled vehicles conveying goods and services or people moving from one terrain to another (Ugbe *et al.,* 2022; Akpoyibo *et al.*, 2025). Roads serve as linkage between cities, villages, towns, states and countries and it enhance trading and transportation of goods globally (Akpoyibo *et al.*, 2022). Road failures is associated with potholes, cracks, ruts, upheavals, ravels, shoves etc paving way for damage to vehicles, time and traffic delays and fostering criminals who take leverage of these failed (flunked) portions to perpetrate (commit) robbery on the failed spots and in some cases causes several fatal crashes (Akpoyibo *et al.*, 2022). Nigeria must create and maintain a road network in order to promote economic development throughout the nation.

Due to inadequate road networks along the study area and as more roads are envisioned (prefigured) in the near future, it is necessary to learn from preceding (past) failures so as to nullify (annul) repeated problems in the future, resulting in languish (waste) of the limited economic resources (Okolie & Akpoyibo, 2012; Ofomola *et al.*, 2017; Akpoyibo *et al.*, 2022). Numerous risky sections of the investigated road performed more destructions than good and are ascribable to deficiency in proper study or the use of incompetent subsurface materials in the construction (sub-grade and sub-base). In many places of Niger Delta, Nigeria, the constant occurrence of road collapse on the delta state road structure is growing concerning. Numerous variables, including subpar building materials, poor design, usage, inadequate drainage network, shallow water level, insufficient soil information, and the ineptitude of these subsurface geologic materials, have been blamed for these failures. Failures can occur in any type of geologic context. The rising (increasing) number of casualties, loss and damageannounced, reported and documented as a result of road failure in failed segments has called for (necessitated) that all precautions, and tactical measures must be employed (taken) to ascertain the safety and securityof man and his valuable property. Road Failures investigation in Niger Delta Oil producing states in Nigeria have been intensely focused on the geotechnical soils properties severally without studying the geophysical aspect in resolving pavement failures (Ugbe *et al.,* 2022*).* Geophysical techniques are helpful for pre-construction feasibility studies through post-construction integrity assessment for civil or construction engineering related tasks like roads, airports, buildings, telecommunications, bridges, etc. (Akpoyibo *et al.,* 2022; Esi et al., 2025; Akpoyibo *et al.*, 2025; Akpoyibo, 2026). The passive nature of the VES system, its ease of instrumentation, its low labor requirements, the terrain, and its low cost all contributed to its selection over other approaches.

In order to avoid the loss of priceless lives and property that invariably accompanies such failures, pre- and post-construction analysis and monitoring of the subsurface of the intended site or road failure parts has become essential. Soil composed of expandable clay swells upon absorbing water. The clay particles bind to the water. The soil expands and compresses when it experiences wet and dry spells. Buildings resting on the clay soil's surface rise and fall with the soil. If this occurred consistently across the buildings, there would be less soil movement harm to the finishes or foundations, which would prevent distress and cracking. In light of the aforementioned, geophysical approach was utilized to assist with the engineering construction exercise by examining the subsurface characteristics in delta state road to know the causes of the incessant road failure in selected and crucial villages and towns in Delta State.

Location and Geology of Study Area

The roads investigated is situated in Delta State, Nigeria located between latitude 005°44' 27.4" to 6° 7' 8" N and longitude 005°54' 43.7" E to 6° 11' 3" E (Figure 1). The road stretched through two senatorial districts namely the Delta Central and Delta North and measuring about 110.63 km in length (Figure 1). The road is very important as it linked Sapele, Amukpe, Aghalokpe, Adagbrassa, Ekpan-Ovu, Okpara-Water Side, Otumara, Igun, Eku, Oria, Erho, Abraka, Umeghe, Obiaruku, Umutu, Urhonigbe, Urhomehe, Abavo, Agbor communities to the major highway running through two state headquarters of Benin for Edo State and Asaba for Delta State. It is also a means to the biggest market in Sub-Sahara Africa, the Onitsha market located in Anambra State. The market is an economic nest to the people of the area. The Sapele-Agbor road is also a means to the oil rich city of Warri known for petroleum industry in Nigeria.The sections consist of both sides of the road with residential structures, bridges, and trees. The elevation of the studied area is between 5 and 156 meters above mean sea level. During the rainfall (wet) season, certain sections of the road flood, while amid the dry months, they remained dry.Both the rainy and dry seasons are described for the regions. The sunny or dry season extends from November to March, whereas the wet or rainy season spans from April to October. The primary source of groundwater recharge in the study areas is the copious amounts of rainfall (Akpoyibo *et al.*, 2025). The Orogodo River is a small river that flows through the cities of Abavo and Agbor before emptying into the River Ethiope. The Atlantic Ocean is linked to the study regions by the River Ethiope, which originates in Umuaja and flows through the cities of Umutu, Obiaruku, Abraka, Eku, Igun, Okpara Waterside, Aghalokpe, and Amukpe, which are located along the Sapele-Agbor road. These rivers provide the household water needs of the numerous communities mentioned above. In the several communities within the examined locations, subsistence farming is also carried out (Akpoyibo *et al.*, 2023; Molua *et al.*, 2024; Vwavware et al., 2024a; 2024b). As compared to the rather flat, undulating, and featureless Sombreiro - Warri Deltaic level, the study area exhibits distinctive features sloping toward the sea (Akpoyibo *et al.*, 2023). Low-lying areas in relation to the surrounding topography and riverbanks are occupied by freshwater wetlands. In the study regions, the vegetation is primarily rain forest. The three main stratigraphic units (Esi & Akpoyibo, 2024; Oghenevovwero *et al.*, 2025; Ogholaja *et al.*, 2025) can be used to categorize the research region (Figure. 1). The rock source for hydrocarbons is thought to be the Akata Formation, which has clear signs of marine shale. Sands and shales of different compositions make up the Agbada Formation. The early Benin Formation in the present-day Niger Delta contains a prolific aquifer, and numerous water supply boreholes are open to the public practically everywhere but a variety of silts, sandy clay, fine to coarsely granulated sands, and clay-identifying bands cover the layers in the Sombreiro-Deltaic plain (Anomohanran *et al.,* 2023).The area is associated with non uniformity of the clay formations thicknessesand has been reasons for road failure (Anomohanran *et al.,* 2023; Akpoyibo &Vwavware, 2024).

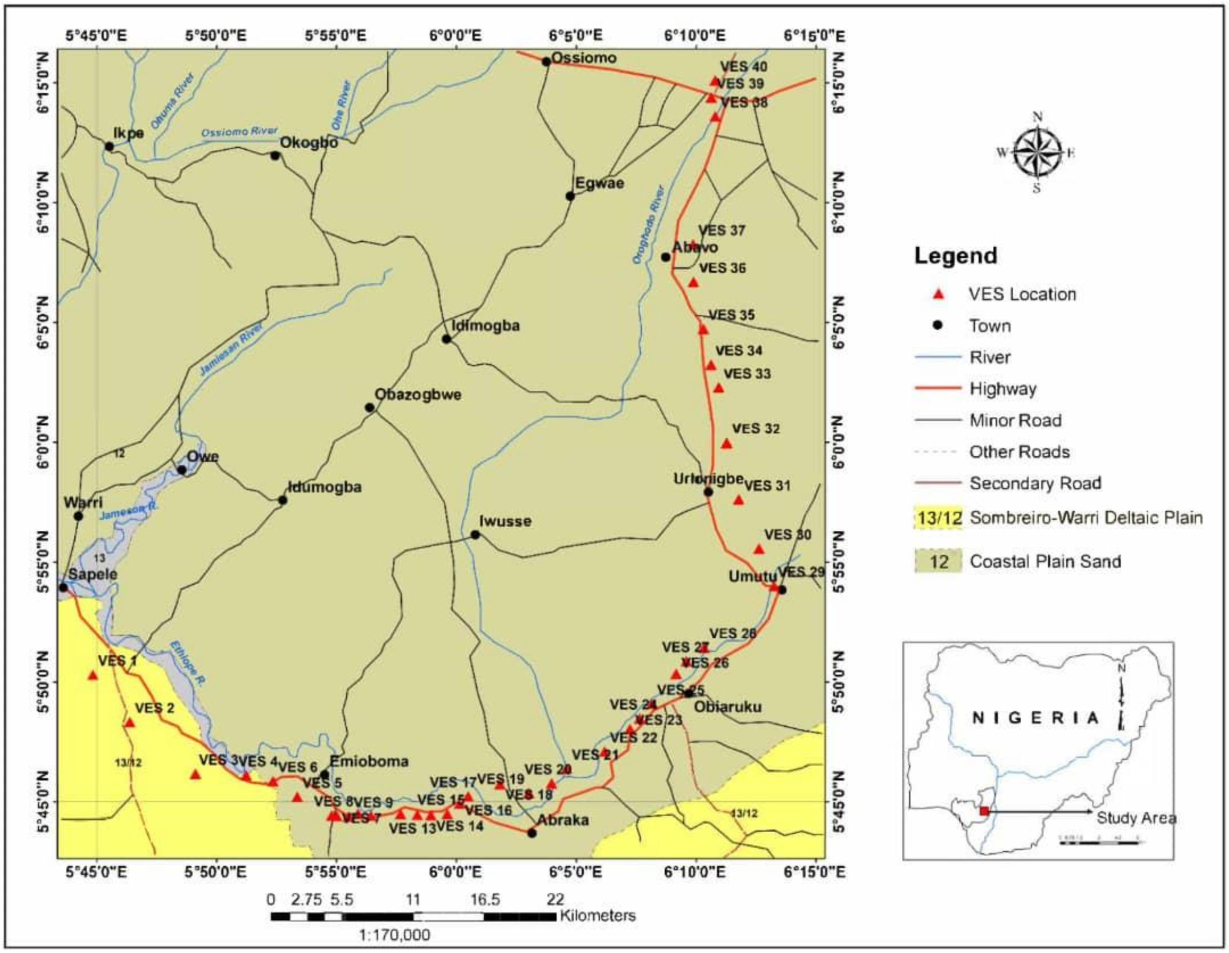

Figure 1: Road map of the study area

MATERIALS AND METHODS

Geophysical Material and Analysis

It used the Schlumberger pattern array and VES. We collected and recorded sounds (signals) from ten different locations. Figure 2-41 shows the VES stations. The necessary data was gathered using the ABEM SAS 1000 transportable Terrameter, which has an integrated booster for deeper and larger depth. To achieve shallow sounding, the maximum electrode spacing (separation) ranged from 200 to 250 meters. 40 vertical electrical soundings (VES) were conducted from the Amukpe-Eku-Agbor road, with 26 VES heard on the road's failed sections (FS) and 14 on its stable segments (SS), with 2-3 VES sounded on the same community of the areas under study. The actual resistivity and thickness of each layer were determined using quantitative computational processing and the Win Resist Software, which was developed in response to Vander Velpen's (2004) resist Version 1.0 study and what was found (results) from the electrical resistivity investigation (Table 1). The total, or broad longitudinal portion (section) conductance (S), likewise referred to as the Dar Zarrouk parameter, was created by applying these basic variables (resistivity ρi and thickness hi) (Esi & Akpoyibo, 2023; Esi *et al.*, 2023; Egheneji *et al.*, 2023; Akpoyibo *et al.*, 2025; Ogheneovovwero *et al.*, 2025). The unit conductance of the total estimated longitudinal portion is

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad (1)$$

Accordingly, the complete longitudinal split (section) conductance measurements (values) in the equation that follows were used to determine the overload protection capability (Akpoyibo *et al.*, 2025). The protective capacity was assessed using Akpoyibo (2025) enhanced longitudinal conductance (mhos)/protective capacity categories. The evaluations are listed as follows: >10 = Outstanding/distinction; 5 to 10 = Very/Really Good; 0.7 to 4.9 = Good; 0.2 to 0.69 = Moderate/Average; 0.1 to 0.19 = Weak/Low; and <0.1 = Poor/Horrible.

RESULTS AND DISCUSSION

Borehole Records

Well or borehole logging is the process of making an in-depth and accurate record (documentation) of the geologic sections via borehole Geophysical logs require devices lowered (dropped) into the well (water) hole to make physical observations while geological logs use a viewable examination of samples raised to the surface and are based on visible measures. Well logging is conducted in boreholes for geotechnical studies, geodesic research, groundwater, oil (crude) and gas, mineral, environmental and geothermal exploration (Akpoyibo *et al.*, 2022; Anomohanran *et al.,* 2023; Chukwunwike *et al.*, 2024; Ikegu *et al.*, 2024). The geological log delineate the subsurface composition into laterite, clay and sandy clay at depth of 5 m at different locations of the study area while at depth of 10 m, the subsurface arrangement is inferred as fine sand and change to sandy clay in Otumara. At depth of 20 m, the soil compositions are interpreted as fine sand, medium and coarse sand for various VES points. The geologic log results reveal that at depth of 30 m, the subsurface varied from fine to coarse sand and while at vertical distance of 39 m, the soil grain component is within the range of coarse sand. The data obtained from the well logging records (drilled borehole) were used to evaluate (determine) the characteristics and give information about the subsurface formations at different depths which serve as a basis and assistance in the lithological classifications of VES data in the research or study area.

Evaluations of Vertical Electrical Sounding

The results of this research work for the Schlumberger arrays were displayed as sounding curves and geoelectric imaged sections. The procured VES results were carefully correlated with the lithologic logs constructed to obtain the geoelectric parameter and lithologic description of the study area VES as shown in Table 1. The electrical resistivity curves obtained are made up of four layers KH, AA, QH, HA, HK, AK, KQ, QQ, QH type curves shown in the Figure 2-41 and also Table 1. Eight geoelectric divisions (sections) were sketched utilizing the first and foremost order ranking geoelectric parameters with the assistance of SURFER 8 (2002) modeling software as unveiled in (Figure 47-54).

Table 1: Geoelectric parameter and lithologic description of investigated areas (VES)

Locations / Road Condition	VES	Layers	Resistivity	Thickness	Depth	Lithology	Curves
Amukpe	VES	1	140.8	1.9	1.9	Topsoil	KH
FS	1	2	210.7	7.3	9.2	Laterite	
		3	104.2	12.3	21.5	Sandy clay	
		4	493.9	--	--	Fine sand	
Amukpe	VES	1	190.6	0.7	0.7	Topsoil	AA
SS	2	2	231.5	12.1	12.8	Laterite	
		3	1059.0	8.7	21.4	Medium sand	
		4	5983.6	--	--	Coarse sand	
Adagbrassa	VES	1	95.4	2.1	2.1	Topsoil	KH
FS	3	2	236.9	8.7	10.8	Laterite	
		3	68.0	11.1	21.9	Clay	
		4	2074.4	--	--	Coarse sand	
Aghalokpe	VES	1	458.1	2.1	2.1	Topsoil	KH
SS	4	2	1321.5	3.9	6.0	Laterite	
		3	76.2	9.6	15.6	Clay	
		4	104.8	--	---	Sandy clay	
Aghalokpe	VES	1	886.4	0.9	0.9	Topsoil	QH
FS	5	2	391.9	10.1	10.9	Laterite	
		3	94.7	14.7	25.6	Clay	
		4	1490.6	--	--	Fine-medium sand	
Ekpan-Ovu	VES	1	204.7	1.2	1.2	Topsoil	HA
FS	6	2	99.6	10.6	11.7	Clay	
		3	154.6	9.3	21.0	Sandy clay	
		4	488.9	--	--	Fine sand	

Locations / Road Condition	VES	Layers	Resistivity	Thickness	Depth	Lithology	Curves
Okpara Water/	VES	1	717.1	0.5	0.5	Topsoil	HK
side	7	2	461.3	4.2	4.7	Laterite	
SS		3	1725.7	8.5	13.2	Medium Sand	
		4	2167.7	--	--	Coarse Sand	
Okpara Water/	VES	1	192.3	0.9	0.9	Topsoil	HK
side	8	2	93.5	1.5	2.4	Clay	
FS		3	4072.7	11.7	14.2	Coarse Sand	
		4	438.5	--	--	Fine Sand	
Okpara Water/	VES	1	108.0	0.8	0.8	Topsoil	HA
side	9	2	67.1	2.0	2.8	Clay	
FS		3	195.1	13.0	15.8	Fine Sand	
		4	7757.9	--	--	Coarse Sand	
Otumara	VES	1	166.8	0.6	0.6	Topsoil	AK
SS	10	2	1980.5	3.5	4.1	Laterite	
		3	2780.9	18.8	22.9	Coarse Sand	
		4	588.3	--	--	Fine Sand	
Otumara	VES	1	42.0	0.5	0.5	Topsoil	KQ
FS	11	2	3674.4	6.6	7.1	Laterite	
		3	1180.9	5.7	12.8	Medium Sand	
		4	33.8	--	--	Clay	
Igun	VES	1	136.5	1.0	1.0	Topsoil	AK
SS	12	2	455.2	2.9	3.9	Laterite	
		3	2237.6	15.8	19.6	Coarse Sand	
		4	926.5	--	--	Medium Sand	
Igun	VES	1	946.9	1.4	1.4	Topsoil	QH
SS	13	2	524.4	4.7	6.0	Laterite	
		3	65.7	13.6	19.6	Clay	
		4	2899.2	--	--	Coarse Sand	
Igun	VES	1	95.8	0.9	0.9	Topsoil	AA
FS	14	2	193.7	8.7	9.7	Laterite	
		3	454.4	14.0	23.6	Fine Sand	
		4	791.0	--	--	Medium Sand	
Eku	VES	1	254.2	0.7	0.7	Topsoil	KH
SS	15	2	3138.1	3.6	4.2	Laterite	
		3	75.5	12.9	17.1	Clay	
		4	968.5	--	--	Medium Sand	
EKU	VES	1	192.8	0.6	0.6	Topsoil	AK
FS	16	2	887.4	12.3	12.9	Fine Sand	
		3	1670.6	7.7	20.6	Medium Sand	
		4	832.0	--	--	Medium Sand	
EKU	VES	1	262.3	0.7	0.7	Topsoil	KH
FS	17	2	639.8	6.0	6.7	Laterite	
		3	80.3	16.0	22.7	Clay	
		4	2474.0	--	--	Coarse Sand	
Oria	VES	1	1273.1	2.8	2.8	Topsoil	HA
FS	18	2	60.9	5.3	8.1	Clay	
		3	497.3	7.3	15.4	Fine Sand	
		4	6852.3	--	--	Coarse Sand	
Oria	VES	1	877.0	1.0	1.0	Topsoil	KH
SS	19	2	1064.5	11.8	12.8	Laterite	
		3	64.4	21.4	34.2	Clay	
		4	1078.2	--	--	Medium Sand	

Locations / Road Condition	VES	Layers	Resistivity	Thickness	Depth	Lithology	Curves
Erho	VES	1	914.1	1.0	1.0	Topsoil	QQ
FS	20	2	599.5	12.4	13.4	Laterite	
		3	563.8	13.2	26.6	Fine sand	
		4	338.7	--	--	Fine sand	
Erho	VES	1	1134.5	1.2	1.2	Topsoil	HK
FS	21	2	461.0	9.5	10.6	Laterite	
		3	600.1	10.4	21.0	Fine sand	
		4	430.6	--	--	Fine sand	
Abraka	VES	1	805.7	1.4	1.4	Topsoil	QQ
FS	22	2	559.5	6.7	8.1	Laterite	
		3	293.7	11.0	19.1	Fine sand	
		4	202.6	--	--	Fine sand	
Abraka	VES	1	1047.1	1.0	1.0	Topsoil	QQ
FS	23	2	742.9	12.1	13.1	Laterite	
		3	507.4	10.1	23.3	Fine sand	
		4	443.5	--	--	Fine sand	
Umeghe	VES	1	896.5	1.0	1.0	Topsoil	QQ
SS	24	2	765.7	9.5	10.5	Laterite	
		3	551.0	10.2	20.7	Fine sand	
		4	434.8	--	--	Fine sand	
Umeghe	VES	1	520.5	2.7	2.7	Topsoil	QH
FS	25	2	278.2	12.5	15.3	Laterite	
		3	77.2	15.6	30.9	Clay	
		4	128.1	--	--	Sandy clay	
Obiaruku	VES	1	137.8	0.9	0.9	Topsoil	AK
FS	26	2	663.9	3.7	4.6	Laterite	
		3	4522.7	16.8	21.4	Coarse sand	
		4	501.9	--	--	Fine sand	
Obiaruku	VES	1	1117.4	2.3	2.3	Topsoil	HK
FS	27	2	77.2	4.8	7.0	Clay	
		3	738.9	13.2	20.3	Medium sand	
		4	14.8	--	--	Clay	
Obiaruku	VES	1	963.1	1.5	1.5	Topsoil	KH
SS	28	2	768.7	8.4	9.9	Laterite	
		3	208.2	14.0	23.9	Fine sand	
		4	734.4	--	--	Medium Sand	
Umutu	VES	1	116.8	2.3	2.3	Topsoil	KH
SS	29	2	324.5	6.4	8.6	Laterite	
		3	218.6	13.2	21.8	Fine sand	
		4	393.1	--	--	Fine sand	
Umutu	VES	1	103.2	1.2	1.2	Toposoil	HA
FS	30	2	80.6	5.3	6.5	Clay	
		3	144.8	19.1	25.6	Sandy clay Medium	
		4	941.1	--	--	Sand	
Urhonigbe	VES						KH
SS	31	1	380.0	1.2	1.2	Topsoil	
		2	741.6	6.7	7.9	Laterite	
		3	69.1	13.6	21.6	Clay	
		4	2228.7	--	--	Coarse Sand	
Urhonigbe	VES	1	96.4	1.3	1.3	Topsoil	KH
FS	32	2	213.0	6.8	8.1	Laterite	
		3	88.8	9.7	17.7	Clay	
		4	3098.5	--	--	Coarse Sand	

Locations / Road Condition	VES	Layers	Resistivity	Thickness	Depth	Lithology	Curves
Urhonigbe FS	VES 33	1	117.6	1.2	1.2	Topsoil	KH
		2	266.1	7.4	8.6	Laterite	
		3	205.4	11.3	19.9	Fine Sand	
		4	6772.1	--	--	Coarse Sand	
Urhomehe FS	VES 34	1	397	1.5	1.5	Topsoil	AA
		2	600.7	5.0	6.5	Laterite	
		3	634.5	15.5	22.0	Fine Sand	
		4	737.9	--	--	Medium Sand	
Urhomehe FS	VES 35	1	297.7	1.0	1.0	Topsoil	AA
		2	610.4	10.1	11.1	Laterite	
		3	631.6	12.7	23.8	Fine Sand	
		4	1554.7	--	--	Fine–medium Sand	
Abavo SS	VES 36	1	350.4	1.8	1.8	Topsoil	AK
		2	868.6	3.6	5.4	Laterite	
		3	1904.7	8.0	13.4	Fine-medium Sand	
		4	630.2	--	--	Fine Sand	
Abavo FS	VES 37	1	1161.1	2.1	2.1	Topsoil	QH
		2	616.2	8.6	10.8	Laterite	
		3	70.9	14.2	25.0	Clay	
		4	2335.5	--	--	Coarse sand	
Agbor FS	VES 38	1	207.4	2.1	2.1	Topsoil	HK
		2	57.2	4.4	6.6	Clay	
		3	848.8	12.6	19.1	Medium sand	
		4	681.1	--	--	Fine Sand	
Agbor SS	VES 39	1	140.2	1.4	1.4	Topsoil	KH
		2	320.8	8.3	9.7	Laterite	
		3	62.4	14.5	24.2	Clay	
		4	2685.5	--	--	Coarse sand	
Agbor FS	VES 40	1	376.6	1.5	1.5	Topsoil	HA
		2	167.5	8.8	10.3	Laterite	
		3	344.3	8.8	19.1	Fine sand	
		4	2671.9	--	--	Medium–Coarse Sand	

FS= Failed Section SS=Stable Section

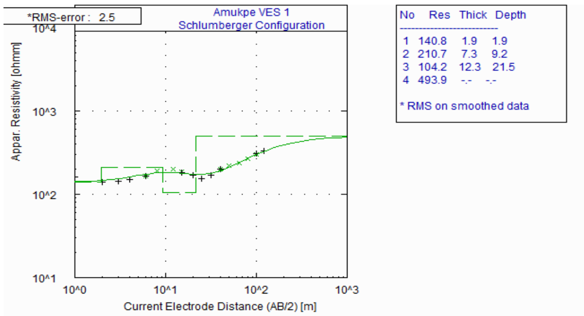

Figure 2: Typical Sounding Curve for VES 1 in Amukpe

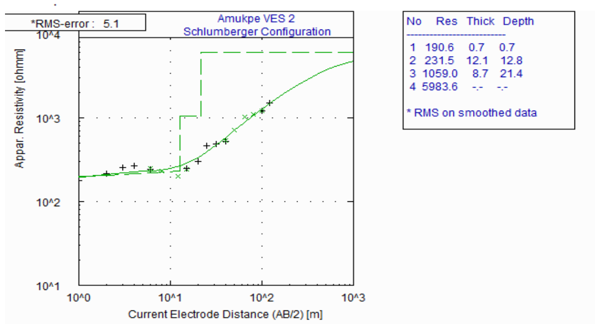

Figure 3: Typical Sounding Curve for VES 2 in Amukpe

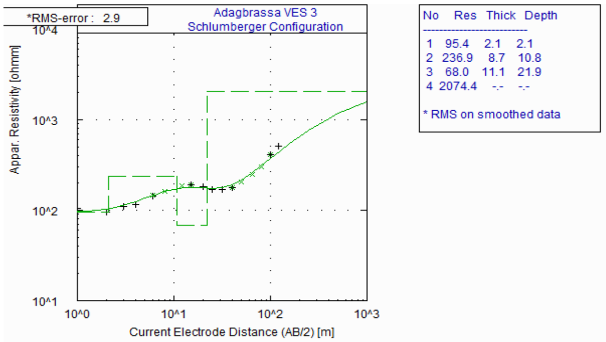

Figure 4: Typical Sounding Curve for VES 3 in Adagbrassa

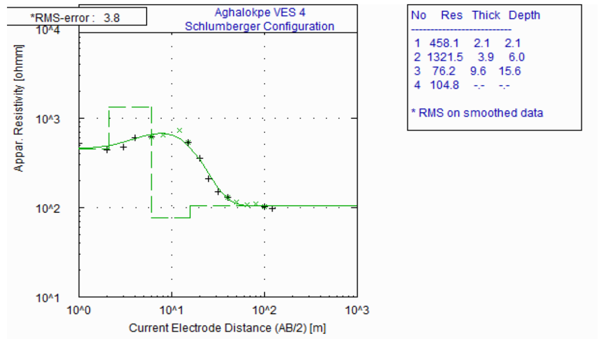

Figure 5: Typical Sounding Curve for VES 4 in Aghalokpe

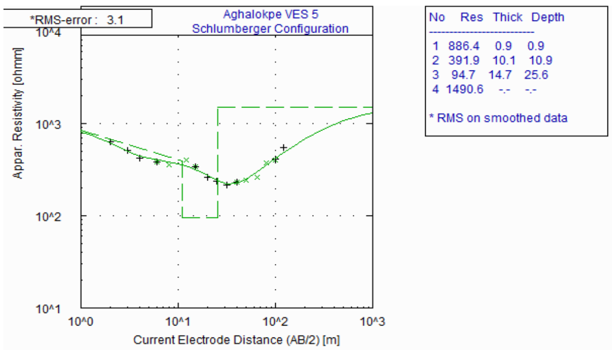

Figure 6: Typical Sounding Curve for VES 5 in Aghalokpe

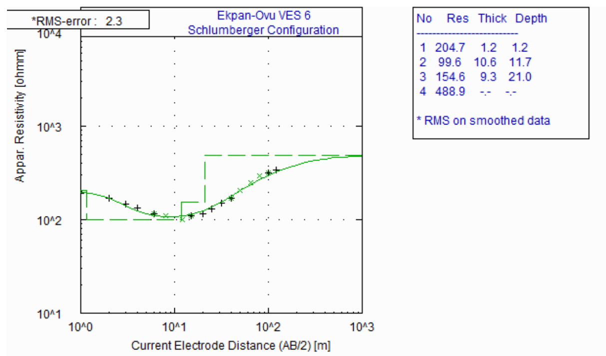

Figure 7: Typical Sounding Curve for VES 6 in Ekpan-Ovu

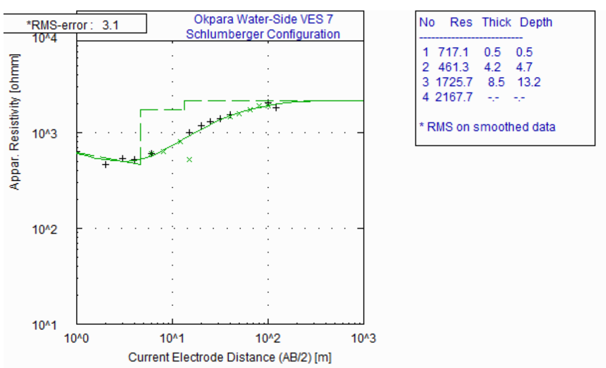

Figure 8: Typical Sounding Curve for VES 7 in Okpara Water-side

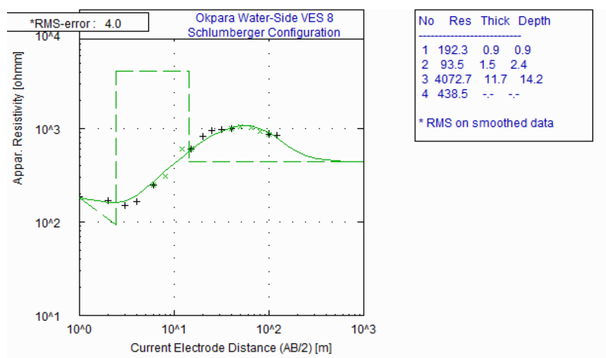

Figure 9: Typical Sounding Curve for VES 8 in Okpara Water-Side

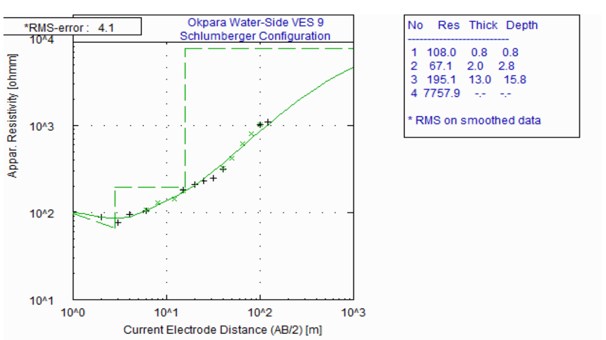

Figure 10: Typical Sounding Curve for VES 9 in Okpara Water-side

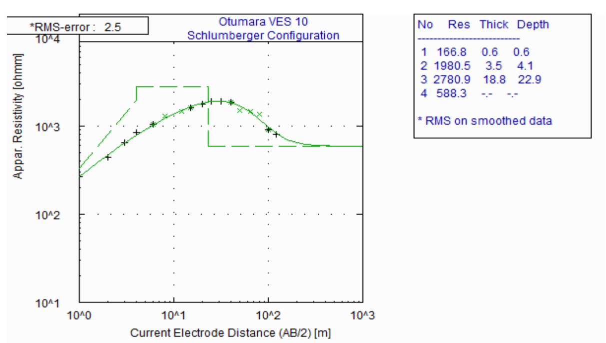

Figure 11: Typical Sounding Curve for VES 10 in Otumara

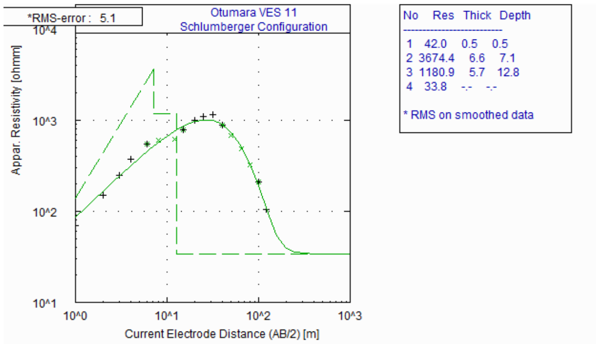

Figure 12: Typical Sounding Curve for VES 11 in Otumara

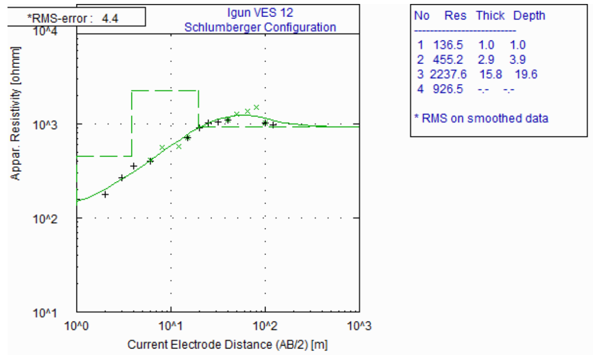

Figure 13: Typical Sounding Curve for VES 12 in Igun

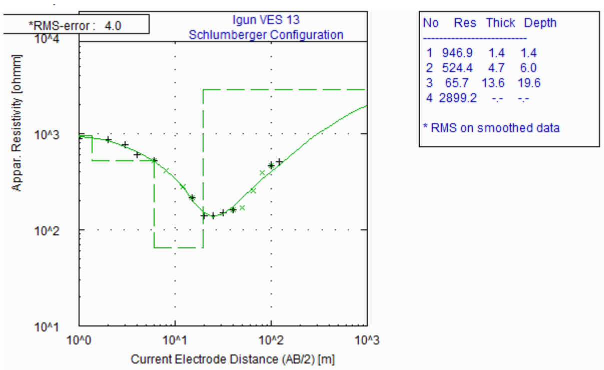

Figure 14: Typical Sounding Curve for VES 13 in Igun

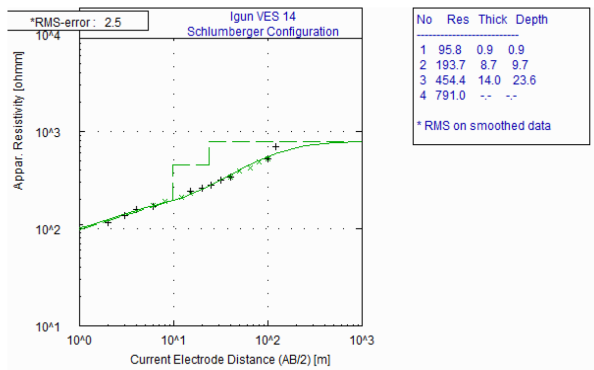

Figure 15: Typical Sounding Curve for VES 14 in Igun

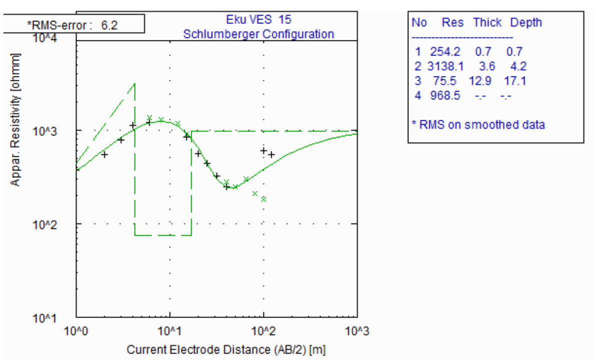

Figure 16: Typical Sounding Curve for VES 15 in Eku

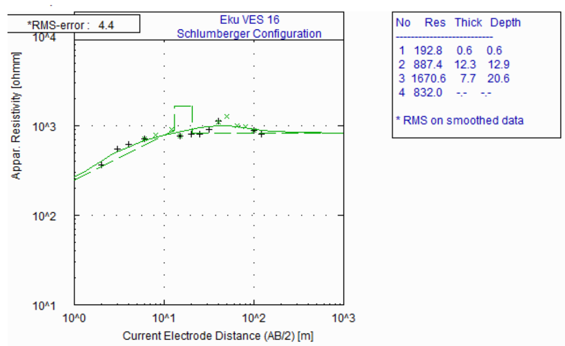

Figure 17: Typical Sounding Curve for VES 16 in Eku

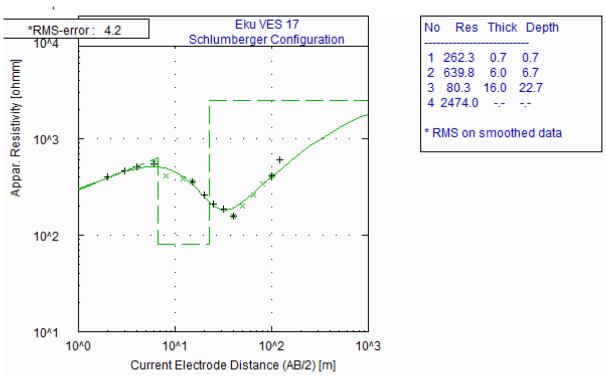

Figure 18: Typical Sounding Curve for VES 17 in Eku

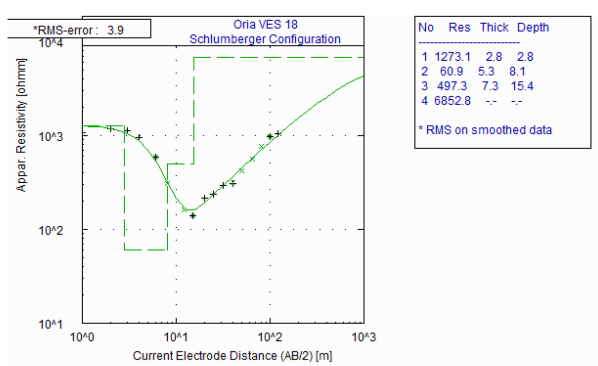

Figure 19: Typical Sounding Curve for VES 18 in Oria

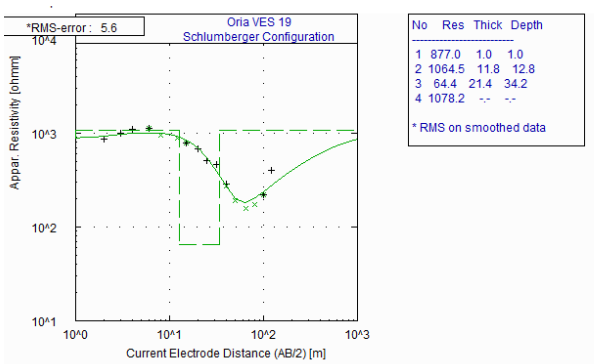

Figure 20: Typical Sounding Curve for VES 19 in Oria

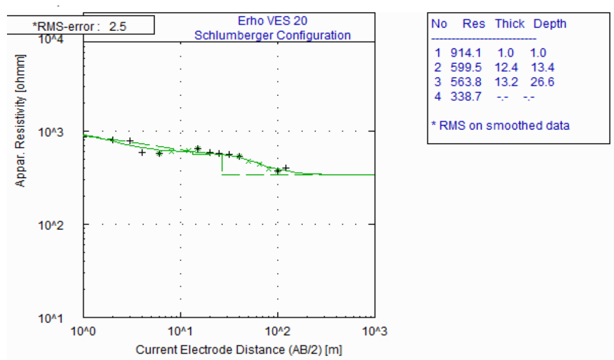

Figure 21: Typical Sounding Curve for VES 20 in Erho

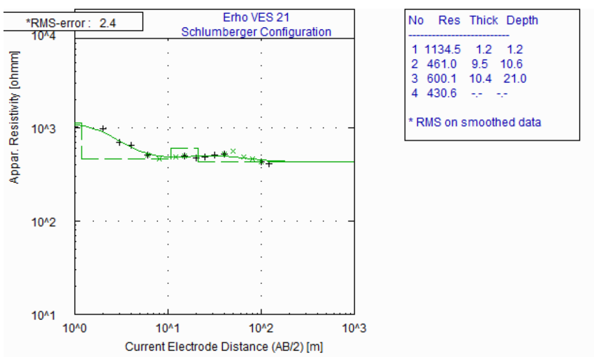

Figure 22: Typical Sounding Curve for VES 21 in Erho

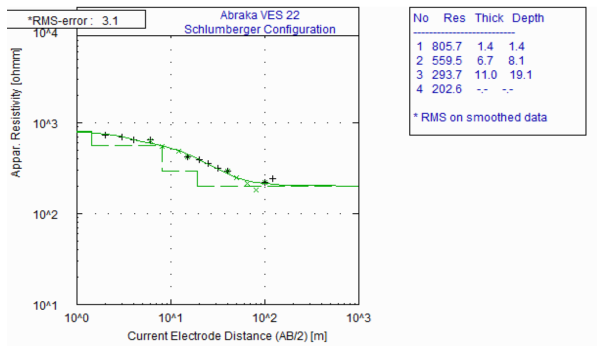

Figure 23: Typical Sounding Curve for VES 22 in Abraka

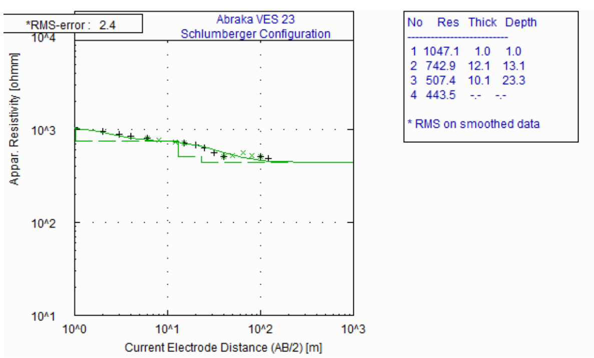

Figure 24: Typical Sounding Curve for VES 23 in Abraka

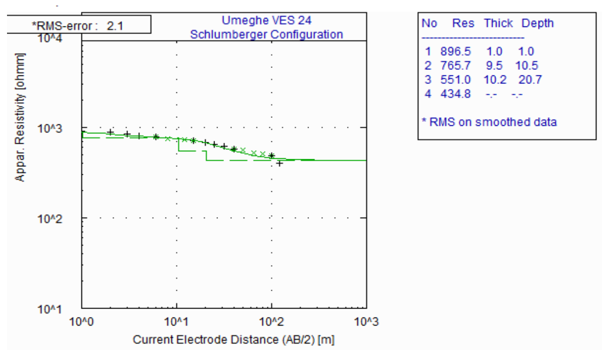

Figure 25: Typical Sounding Curve for VES 24 in Umeghe

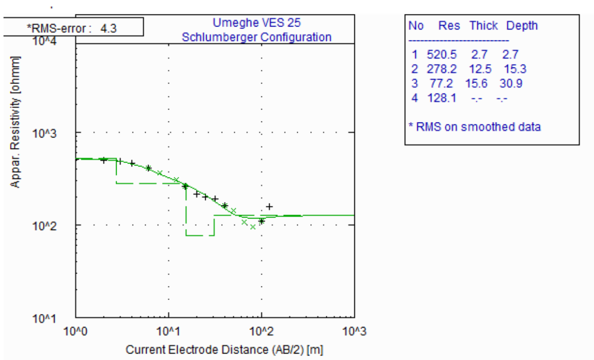

Figure 26: Typical Sounding Curve for VES 25 in Umeghe

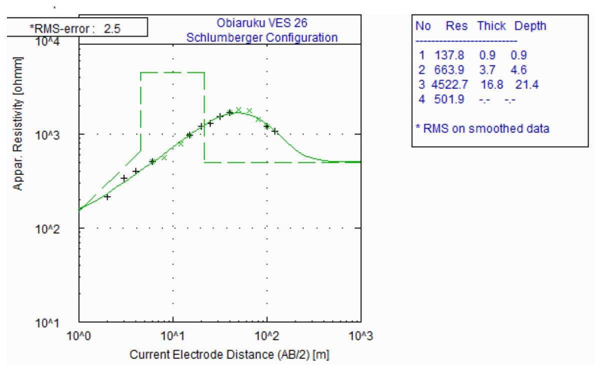

Figure 27: Typical Sounding Curve for VES 26 in Obiaruku

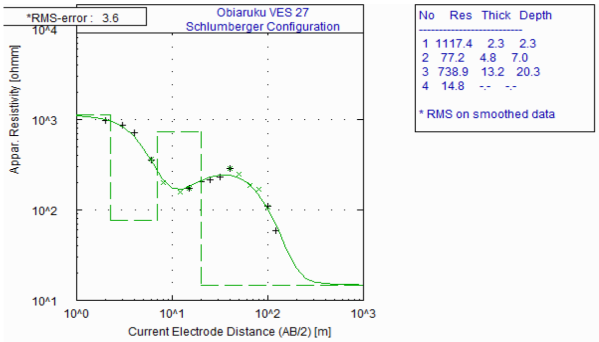

Figure 28: Typical Sounding Curve for VES 27 in Obiaruku

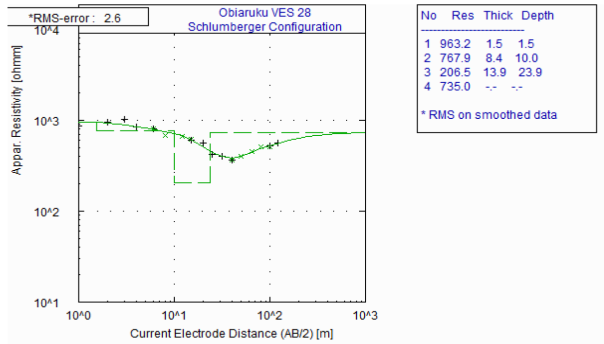

Figure 29: Typical Sounding Curve for VES 28 in Obiaruku

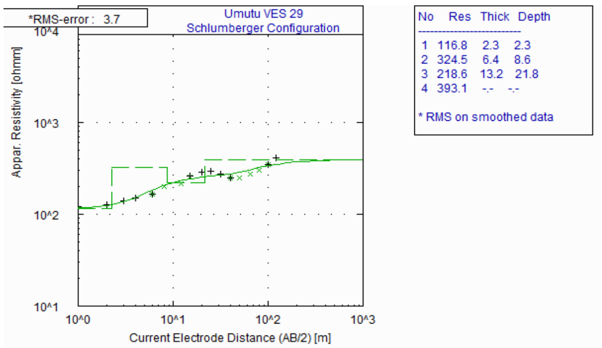

Figure 30: Typical Sounding Curve for VES 29 in Umutu

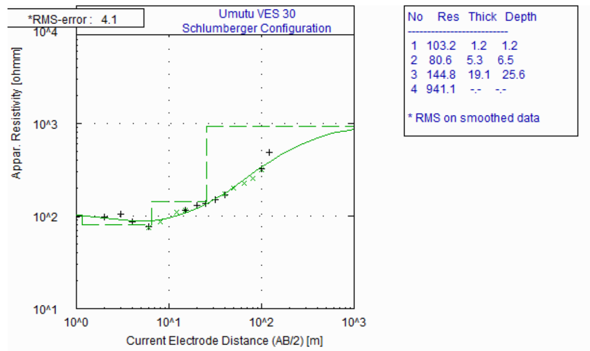

Figure 31: Typical Sounding Curve for VES 30 in Umutu

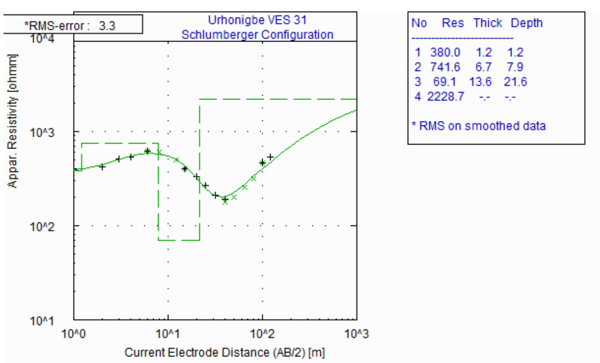

Figure 32: Typical Sounding Curve for VES 31 in Urhonigbe

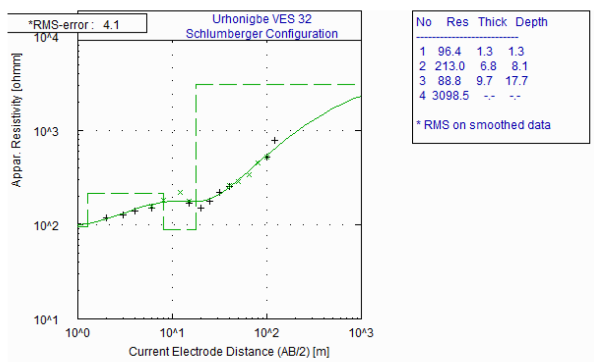

Figure 33: Typical Sounding Curve for VES 32 in Urhonigbe

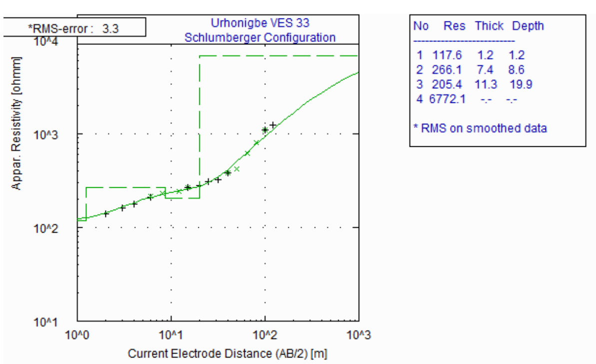

Figure 34: Typical Sounding Curve for VES 33 in Urhonigbe

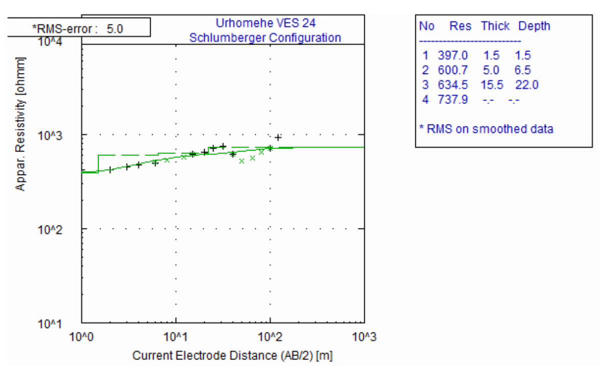

Figure 35: Typical Sounding Curve for VES 34 in Urhomehe

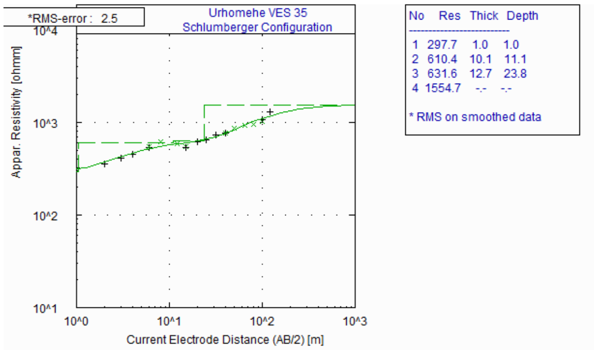

Figure 36: Typical Sounding Curve for VES 35 in Urhomehe

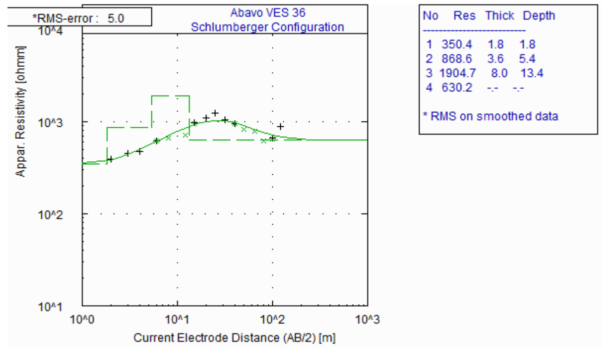

Figure 37: Typical Sounding Curve for VES 36 in Abavo

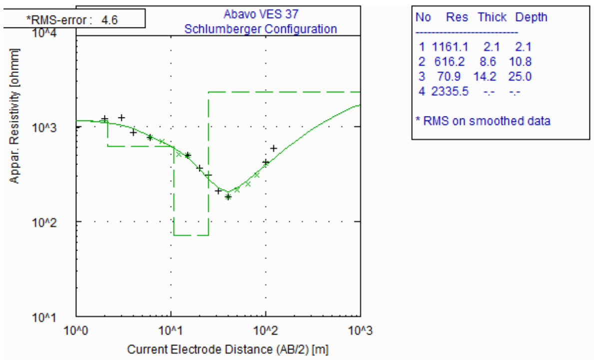

Figure 38: Typical Sounding Curve for VES 37 in Abavo

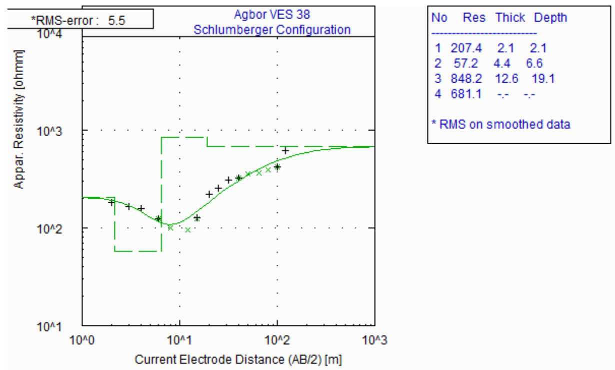

Figure 39: Typical Sounding Curve for VES 38 in Agbor

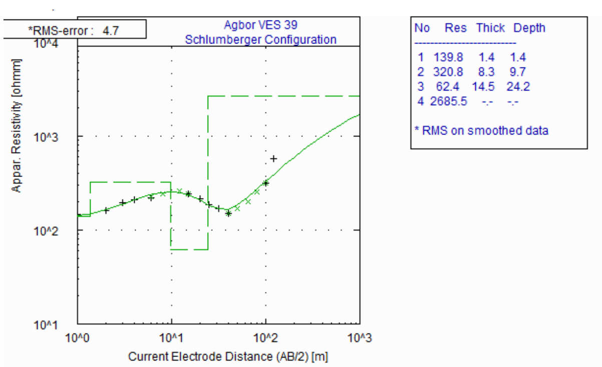

Figure 40: Typical Sounding Curve for VES 39 in Agbor

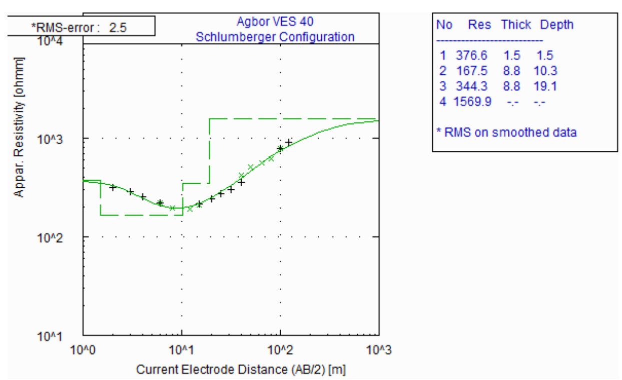

Figure 41: Typical Sounding Curve for VES 40 in Agbor

Table 2: VES interpreted results and longitudinal conductance values

S/N	Layers	Resistivity	Thickness	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Longitudinal Conductivity of Protecting Layers Mhos	Protective Capacity Rating
VES 1	1	140.8	1.9	0.013494		
	2	210.7	7.3	0.034664	0.1662	Weak
	3	104.2	12.3	0.118042		
	4	493.9	---	---		
VES 2	1	190.6	0.7	0.003673		
	2	231.5	12.1	0.052268	0.0642	Poor
	3	1059.0	8.7	0.008215		
	4	5983.6	---	---		
VES 3	1	95.4	2.1	0.022013		
	2	236.9	8.7	0.036724	0.221972	Moderate
	3	68.0	11.1	0.163235		
	4	2074.4	---	---		
VES 4	1	458.1	2.1	0.004584		
	2	1321.5	3.9	0.002951	0.13352	Weak
	3	76.2	9.6	0.125984		
	4	104.8	--	---		
VES 5	1	886.4	0.9	0.001015	0.18201	Weak
	2	391.9	10.1	0.025772		
	3	94.7	14.7	0.155227		
	4	1490.6	--	---		
VES 6	1	204.7	1.2	0.005862		
	2	99.6	10.6	0.106426	0.172443	Weak
	3	154.6	9.3	0.060155		
	4	488.9	--	---		
VES 7	1	717.1	0.5	0.000697		
	2	461.3	4.2	0.009105	0.01473	Poor
	3	1725.7	8.5	0.004926		
	4	2167.7	--	---		
VES 8	1	192.3	0.9	0.004680		
	2	93.5	1.5	0.016043	0.02360	Poor
	3	4072.7	11.7	0.002873		
	4	438.5	--	---		
VES 9	1	108.0	0.8	0.007407		
	2	67.1	2.0	0.029806	0.103846	Weak
	3	195.1	13.0	0.066633		
	4	7757.9	--	---		
VES 10	1	166.8	0.6	0.003597		
	2	1980.5	3.5	0.001767	0.012124	Poor
	3	2780.9	18.8	0.006760		
	4	588.3	--	---		
VES 11	1	42.0	0.5	0.011905		
	2	3674.4	6.6	0.001796	0.018528	Poor
	3	1180.9	5.7	0.004827		
	4	33.8	--	---		
VES 12	1	136.5	1.0	0.007326		
	2	455.2	2.9	0.006371	0.020758	Poor
	3	2237.6	15.8	0.007061		
	4	926.5	--	---		

S/N	Layers	Resistivity	Thickness	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Longitudinal Conductivity of Protecting Layers Mhos	Protective Capacity Rating
VES	1	946.9	1.4	0.001479		
13	2	524.4	4.7	0.008963	0.217444	Moderate
	3	65.7	13.6	0.207002		
	4	2899.2	--	---		
VES	1	95.8	0.9	0.009395		
14	2	193.7	8.7	0.044915	0.08512	Poor
	3	454.4	14.0	0.030810		
	4	791.0	--	---		
VES	1	254.2	0.7	0.000885		
15	2	3138.1	3.6	0.001147	0.172893	Weak
	3	75.5	12.9	0.170861		
	4	968.5	--	---		
VES	1	192.8	0.6	0.003112		
16	2	887.4	12.3	0.013861	0.021582	Poor
	3	1670.6	7.7	0.004609		
	4	832.0	--	---		
VES	1	262.3	0.7	0.002669		
17	2	639.8	6.0	0.009378	0.2113	Moderate
	3	80.3	16.0	0.199253		
	4	2474.0	--	---		
VES	1	1273.1	2.8	0.002199		
18	2	60.9	5.3	0.087028	0.103906	Weak
	3	497.3	7.3	0.014679		
	4	6852.3	--	---		
VES	1	877.0	1.0	0.001140		
19	2	1064.5	11.8	0.011085	0.344523	Moderate
	3	64.4	21.4	0.332298		
	4	1078.2	--	---		
VES	1	914.1	1.0	0.001094		
20	2	599.5	12.4	0.020684	0.045191	Poor
	3	563.8	13.2	0.023413		
	4	338.7	--	---		
VES	1	1134.5	1.2	0.001058		
21	2	461.0	9.5	0.020607	0.038995	Poor
	3	600.1	10.4	0.017330		
	4	430.6	--	---		
VES	1	805.7	1.4	0.001738		
22	2	559.5	6.7	0.011975	0.051166	Poor
	3	293.7	11.0	0.037453		
	4	202.6	--	---		
VES	1	1047.1	1.0	0.000955		
23	2	742.9	12.1	0.016288	0.037148	Poor
	3	507.4	10.1	0.019905		
	4	443.5	--	---		
VES	1	896.5	1.0	0.001116		
24	2	765.7	9.5	0.012407	0.032035	Poor
	3	551.0	10.2	0.018512		
	4	434.8	--	---		
VES	1	520.5	2.7	0.005187		
25	2	278.2	12.5	0.044932	0.252192	Moderate
	3	77.2	15.6	0.202073		
	4	128.1	--	---		

S/N	Layers	Resistivity	Thickness	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Longitudinal Conductivity of Protecting Layers Mhos	Protective Capacity Rating
VES	1	137.8	0.9	0.006531		
26	2	663.9	3.7	0.005573	0.015819	Poor
	3	4522.7	16.8	0.003715		
	4	501.9	--	---		
VES	1	1117.4	2.3	0.002058		
27	2	77.2	4.8	0.062176	0.082098	Poor
	3	738.9	13.2	0.017864		
	4	14.8	--	---		
VES	1	963.1	1.5	0.001558		
28	2	768.7	8.4	0.010928	0.079729	Poor
	3	208.2	14.0	0.067243		
	4	734.4	--	---		
VES	1	116.8	2.3	0.019692		
29	2	324.5	6.4	0.019723	0.099799	Poor
	3	218.6	13.2	0.060384		
	4	393.1	--	---		
VES	1	103.2	1.2	0.011628		
30	2	80.6	5.3	0.065757	0.209291	Moderate
	3	144.8	19.1	0.131906		
	4	941.1	--	---		
VES	1	380.0	1.2	0.003158		
31	2	741.6	6.7	0.009034	0.23743	Moderate
	3	69.1	13.6	0.196816		
	4	2228.7	--	---		
VES	1	96.4	1.3	0.013486		
32	2	213.0	6.8	0.031925	0.154645	Weak
	3	88.8	9.7	0.109234		
	4	3098.5	--	---		
VES	1	117.6	1.2	0.010204		
33	2	266.1	7.4	0.027809	0.093028	Poor
	3	205.4	11.3	0.055015		
	4	6772.1	--	---		
VES	1	397	1.5	0.003778		
34	2	600.7	5.0	0.008324	0.036531	Poor
	3	634.5	15.5	0.024429		
	4	737.9	--	---		
VES	1	297.7	1.0	0.003359		
35	2	610.4	10.1	0.016547	0.040014	Poor
	3	631.6	12.7	0.020108		
	4	1554.7	--	---		
VES	1	350.4	1.8	0.005137		
36	2	868.6	3.6	0.004145	0.013404	Poor
	3	1904.7	8.0	0.004122		
	4	630.2	--	---		
VES	1	1161.1	2.1	0.001809		
37	2	616.2	8.6	0.013956	0.216047	Moderate
	3	70.9	14.2	0.200282		
	4	2335.5	--	---		
VES	1	207.4	2.1	0.010125		
38	2	57.2	4.4	0.076923	0.101903	Weak
	3	848.2	12.6	0.014855		
	4	681.1	--	---		

S/N	Layers	Resistivity	Thickness	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Longitudinal Conductivity of Protecting Layers Mhos	Protective Capacity Rating
VES 39	1	140.2	1.4	0.009986		
	2	320.8	8.3	0.025873	0.268234	Moderate
	3	62.4	14.5	0.232372		
	4	2685.5	--	---		
VES 40	1	376.6	1.5	0.003983		
	2	167.5	8.8	0.052537		
	3	344.3	8.8	0.025559	0.08208	Poor
	4	2671.9	--	---		

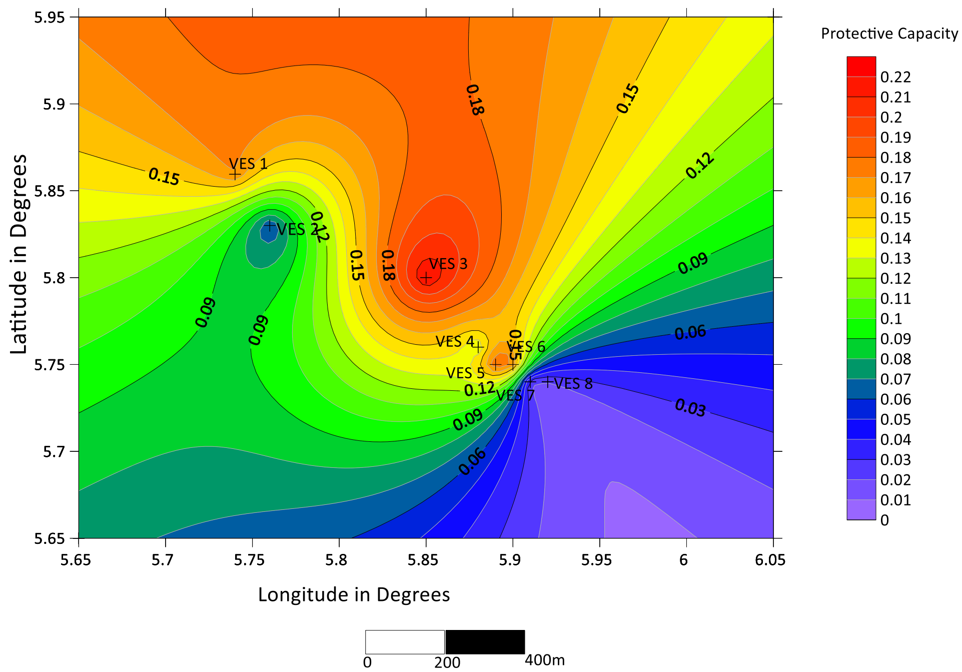

Figure 42: Contour map of the protective capacity for VES 1-8

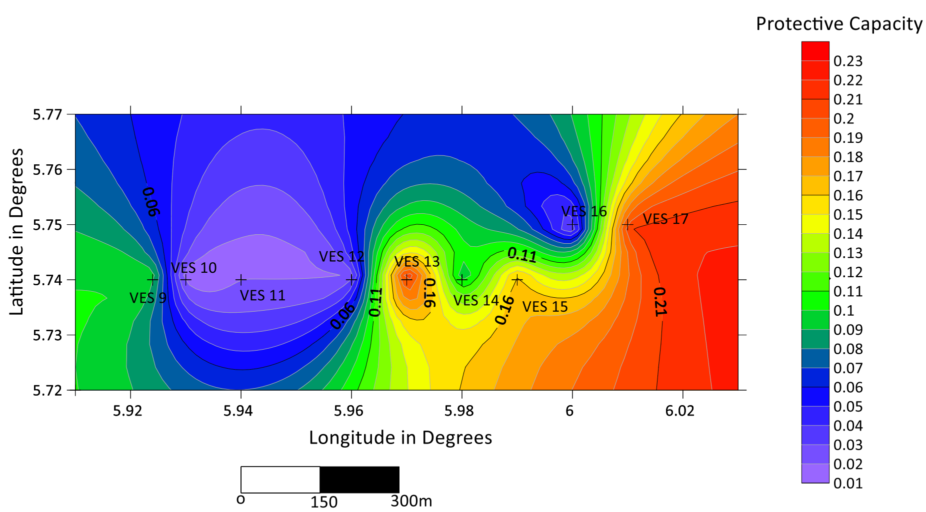

Figure 43: Contour map of the protective capacity for VES 9-17

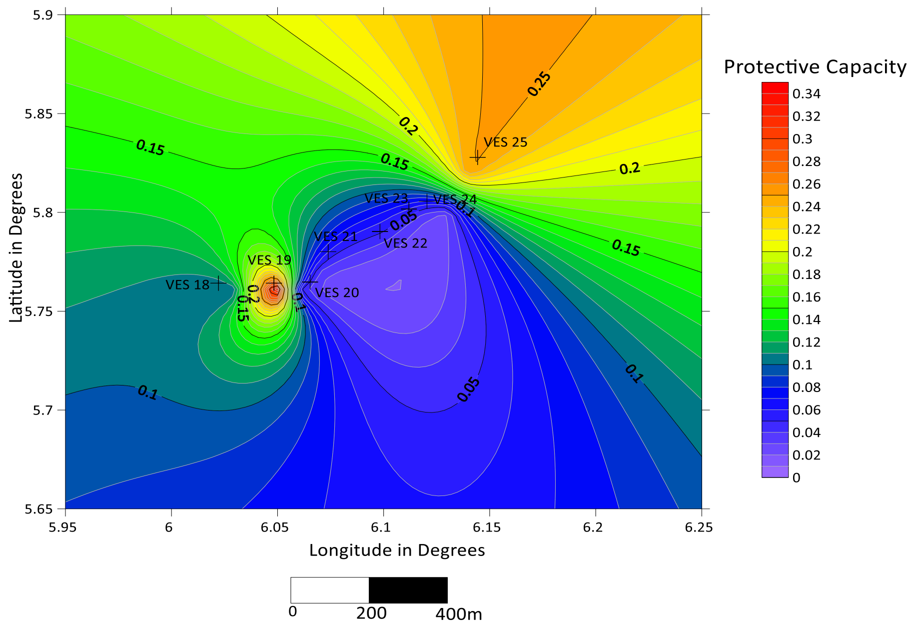

Figure 44: Contour map of the protective capacity for VES 18-25

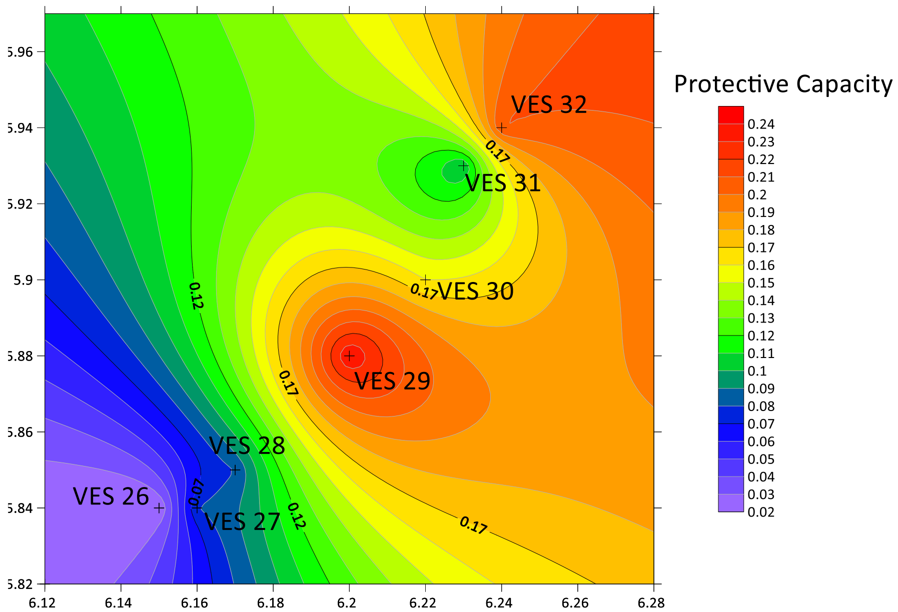

Figure 45: Contour map of the protective capacity for VES 26-32

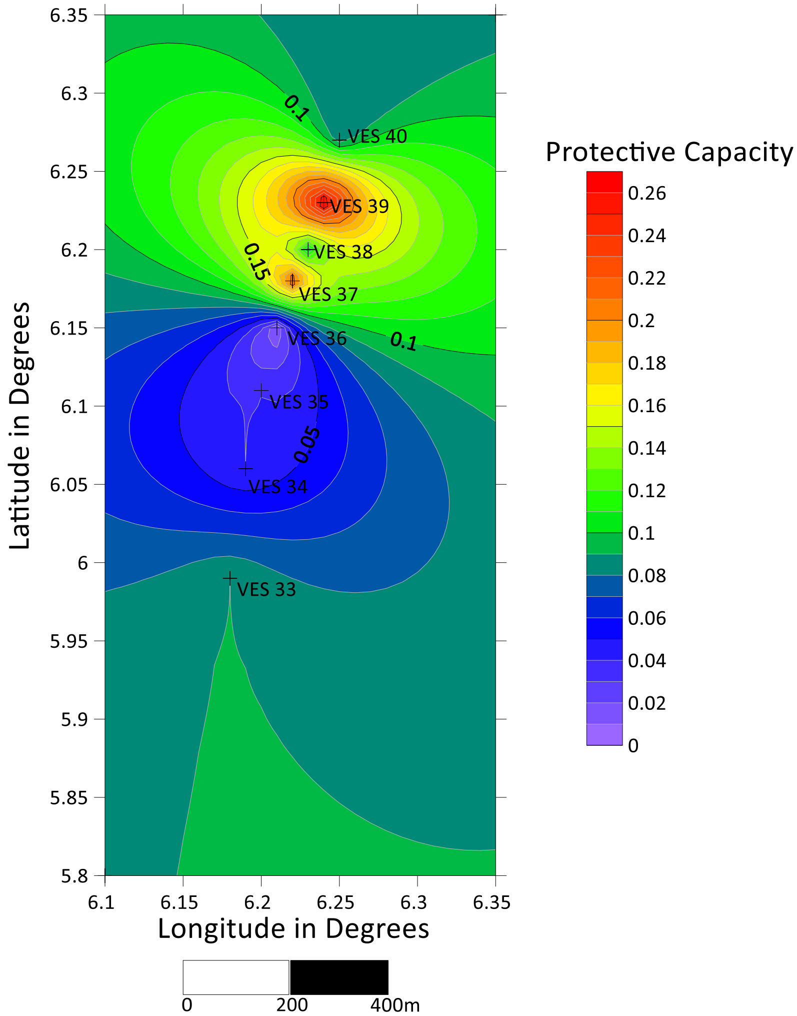

Figure 46: Contour map of the protective capacity for VES 33-40

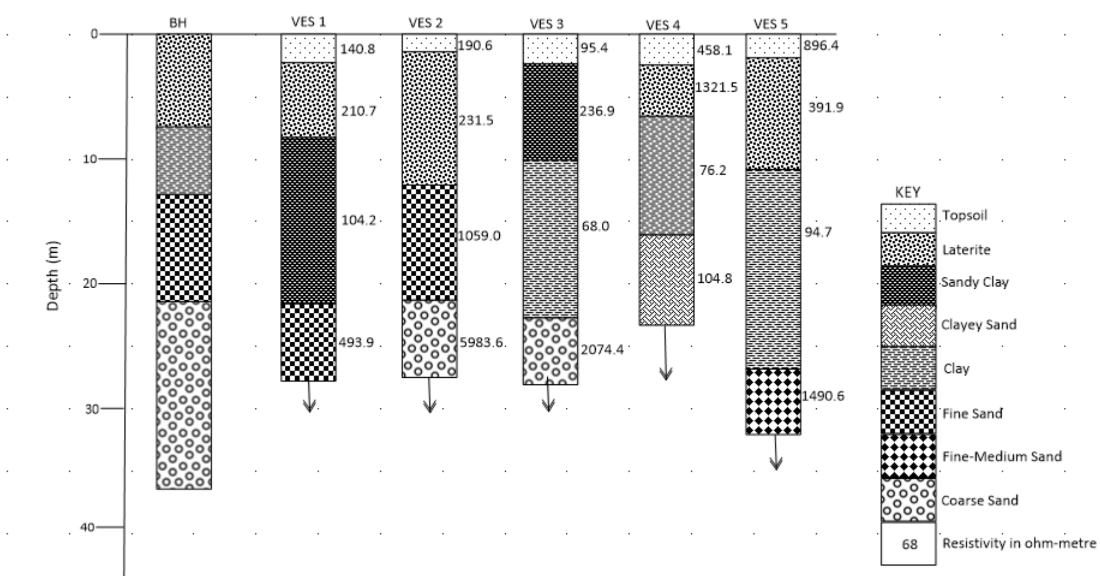

Figure 47: Geoelectric Section for VES 1-5 obtained from Amukpe to Aghalokpe

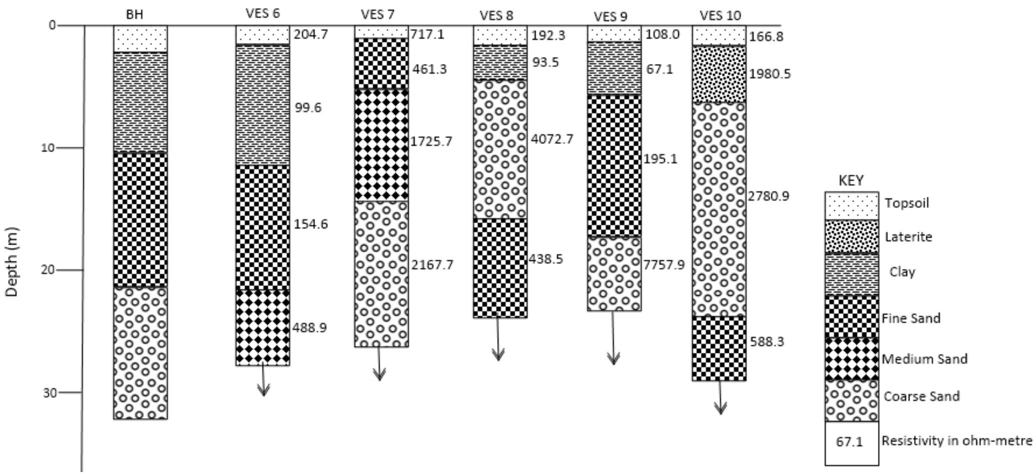

Figure 48: Geoelectric Section for VES 6-10 obtained from Ekpan-Ovu to Otumara

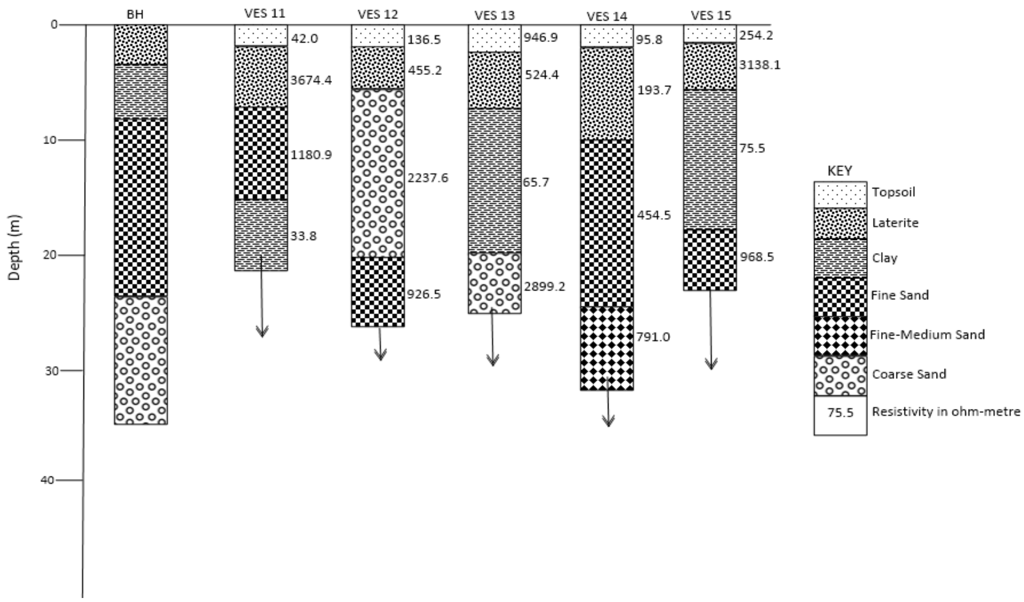

Figure 49: Geoelectric Section for VES 11-15 procured from Otumara to Eku

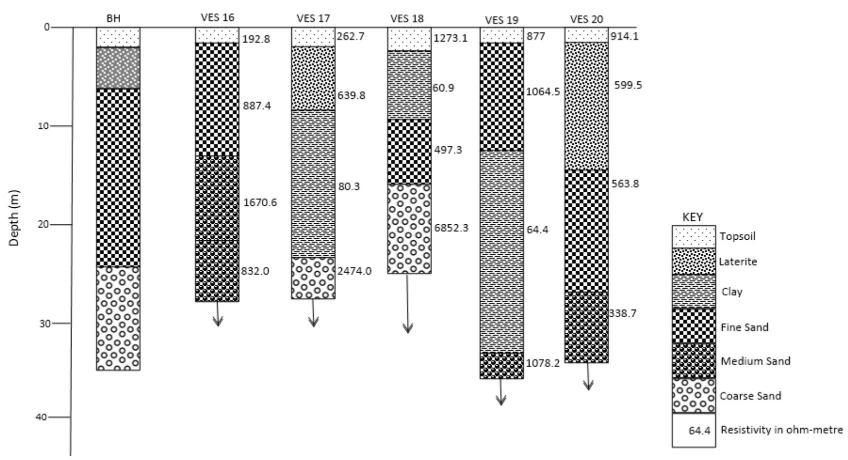

Figure 50: Geoelectric Section for VES 16-20 taken from Eku to Erho

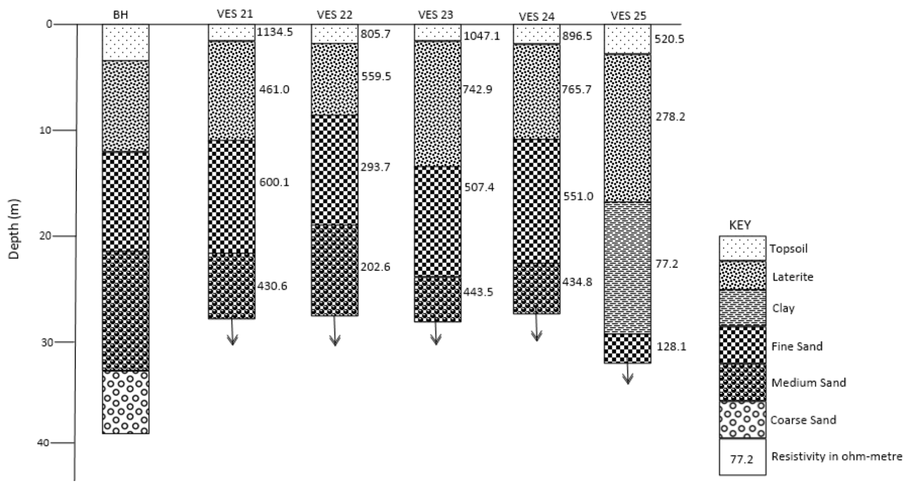

Figure 51: Geoelectric section of VES 21-25 acquired from Erho to Umeghe

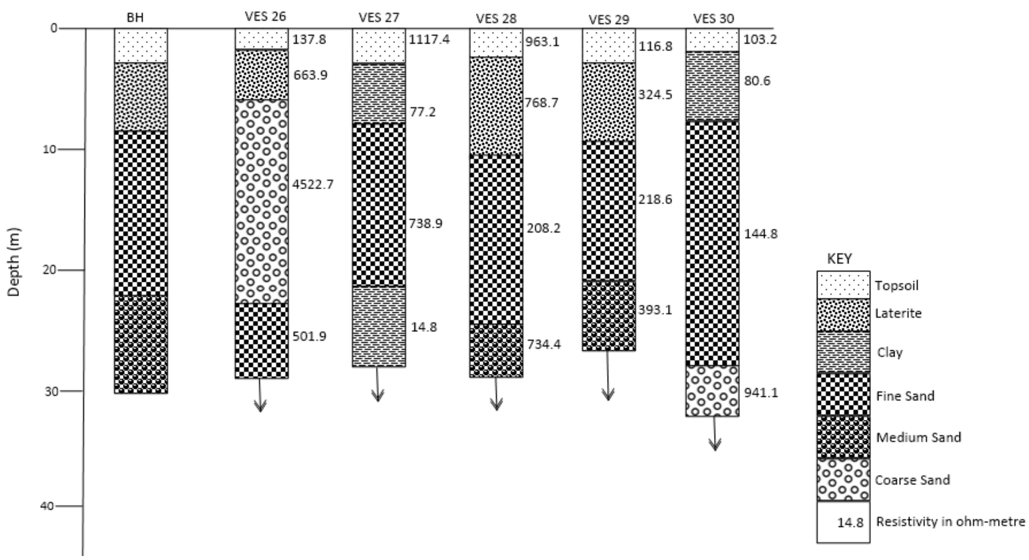

Figure 52: Geoelectric subdivision of VES 26-30 obtained from Obiaruku to Umutu

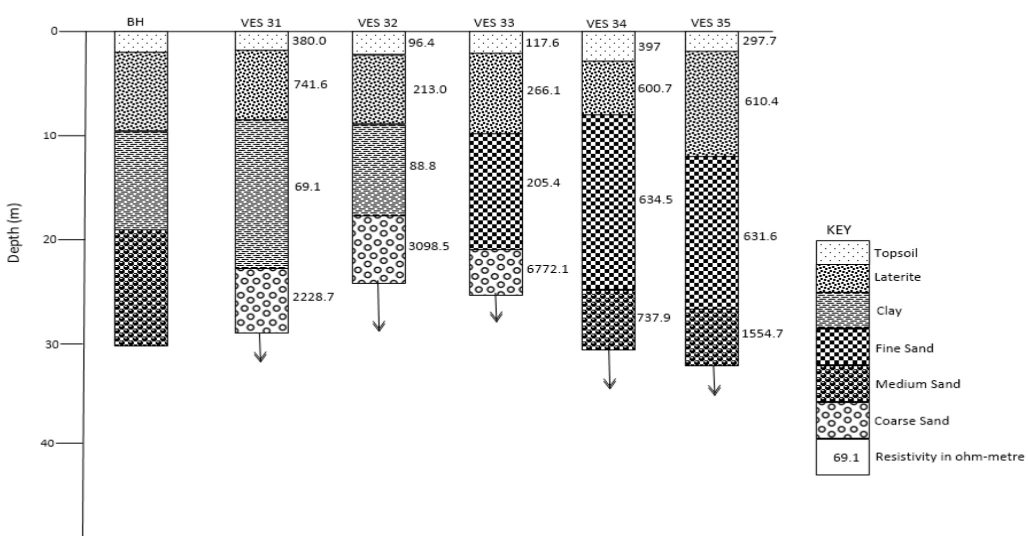

Figure 53: Geoelectric section (portion) of VES 31-35 extracted from Urhonigbe to Urhomehe

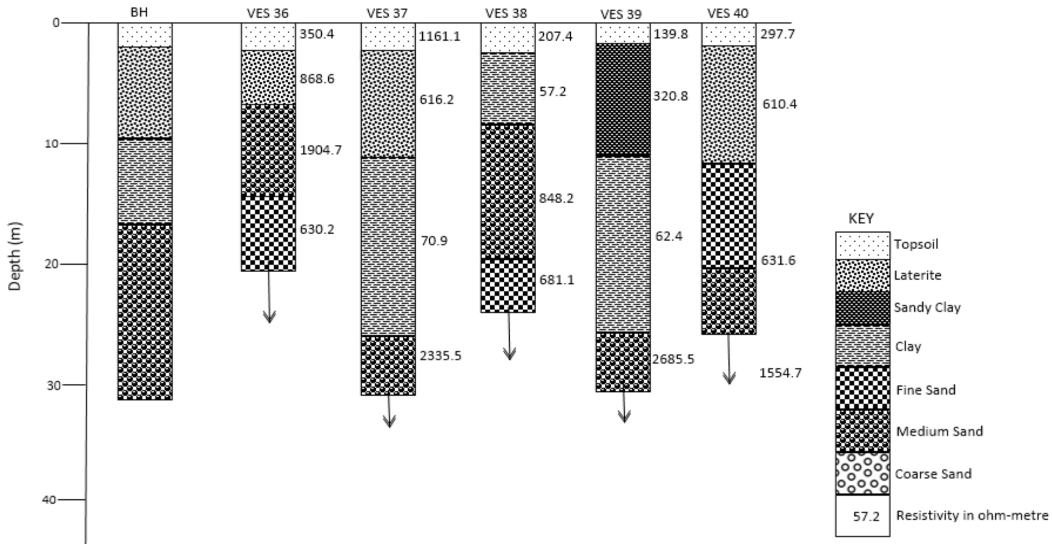

Figure 54: Geoelectric Shape Section of VES 36-40 sourced from Abavo to Agbor

The sounded data from the field were processed first by applying (employing) curve matching method before the usage of computer aided software (WINRESIST). The data acquired from this study is shown as a plot of the apparent (evident) resistivity against half current electrode conductor separation (distance) as revealed in Figure. 2-41. The upshot of the outcome of the 40 VES and those that represented both stable and failed portions are also presented as shown in Table 4.1. The range of resistivity used in the lithological classifications is from 14.8 to 7757.9 Ωm. The forty VES sounded in this study, twenty five (25) VES points were sounded from Amukpe round about to Umeghe-Abraka along sections (portions) of the road with VES 1, 3, 5, 6, 8, 9, 11, 14, 16, 17, 18, 20, 21, 22, 23 and 25 representing the failed portions while VES 2, 4, 7, 10, 12, 13, 15, 19 and 24 denote the stable sections of the road. The first layer constitutes mixture of laterite and clayey sand topsoil done on 16 failed segments and mostly laterite on the 9 stable segments (unfailed sections). The apparent resistivities values vary within 42.0 Ω-m and 1273.1 Ω-m along both failed (flunk) and stable or successful sections (parts) of the road. The thickness varies between 0.4 and 2.9 m. The second layer comprises of laterite, lateritic clay, clay, clayey sand (sand with more of clay), sandy clay (much sand with less of clay) and also with compartment of fine sand. The failed portions depicted as VES 1, 3, 5, 6, 8, 9, 11, 14, 16, 17, 18, 20, 21, 22, 23 and 25 comprises mainly clay while the stable segments designated as VES 2, 4, 7, 10, 12, 13, 15, 19 and 24 consist of laterite, little sandy clay and quantifiable (large) fine sand. The second layer (stratum) has describable resistivity values ranging from 60.9-3674.4 Ω-m and thickness detected between 1.5-12.9 m. The Failed segments of this layer categorize with 60.9-3138.1 Ω-m and 1.5-12.5 m for resistivity and dimensional thickness respectively. The stable segments have resistivity between 193.7-3674.4 Ω-m and thickness observed range from 2.9-12.9 m. Most of the failed portions of the second layers with resistivities (60.9-3138.1 Ω-m) are not greater than (less than) those obtained within the stable segments (193.7 – 3674.4 Ω-m). The third layer show clay and fine sand for failed segment (FS) and fine to coarse sand for stable segments. The failed portions display resistivity values between (64.4-154.6 Ω-m) with thickness limits ranging from 9.3-21.4 m. The resistivity value varies from 104.2-2780.9 Ω-m and thickness 5.7-18.8 m for stable segments. This make known that the recorded resistivity values of the third layer along sections of the failed portions (64.4-154.6 Ω-m) are less than those procured at the stable segments (104.2-2780.9 Ω-m). The failed portions are mainly founded (beneath) on clay formations which can shrink and collapse resulting to road failure. The fourth layer with an indications of clay, presence of clayey sand, fine–coarse sand with infinite thickness have resistivity determine values within the failed segment (33.8- 488.9 Ω-m) less than those obtained at the stable segments (202.6-7757.9 Ω-m). The failed portions are also caused due to poor drainage systems, inadequate maintenance, shallow water table and also application of substandard materials as confirmed from low resistivity values in most of the topsoil lithological formations.

From Table 1, the resistivities of the first to fourth layers from Obiaruku-Agbor sections for 15 VES varied from 96.4 to 1117.4 Ωm, 57.2 to 868.6 Ωm, 62.4 to 4522.7 Ωm, and 14.8 to 6772.1 Ωm, respectively. The top layer thicknesses to the bottom stratum vary from 0.9–2.3 m, 3.6–10.1 m and 8.0–19.1 m respectively. The first layer consists of topsoil sounded on 10 failed portions and 5 stable portions (unfailed sections). The apparent resistivity value varies within 103.2Ω-m and 1161.1Ω-m along both failed and stable portions. The thickness varies between 0.9 and 2.3 m. The second layer comprises of laterite, lateritic clay, clay, clayey sand, sandy clay and fine sand. The failed segments which are denoted by VES 26, 27, 30, 32, 33, 34, 35, 37, 38 and 40 mostly comprises of clay formation while the stable segments represented by VES 28, 29, 31, 36 and 39 composed of laterite, proportion of clay formation and fine texture sand. The second sub-layer has values of resistivity extent spreading from 57.2.9-868.6 Ω-m and thickness between 3.6-10.1 m. The Failed segments of this layer categorize with 57.2-741.6 Ω-m and 3.7-10.1 m for resistivity and thickness respectively while the stable segments have resistivity between 167.5-868.6 Ω-m and thickness noticed range from 3.6-8.4 m. The failed portions of the second layer with resistivity's (57.2-663.9 Ω-m) are not greater than (less than) those obtained within the stable segments (320.8-868.6 Ω-m) which may suggest the instability in the road sections. The third layer show clay and sand formations for failed segments (FS) and sand formations only (fine to coarse sand) for stable segments. The failed portions display resistivity values between (70.9-4522.7 Ω-m) with thickness spacing ranging from 8.8-19.1 m. The resistivity evaluated values varies from 62.4- 1904.7 Ω-m and displays thickness of 8.0-14.5 m for stable segments. The fourth layer with an indications of clay, clayey sand, fine–coarse sand with infinite thickness have resistivity determine values within the failed segment (14.8- 6772.1 Ω-m) while those obtained at the stable segments is (630.2 - 2685.5 Ω-m). The thickness of the clay in the failed segments ranges from 4.4-14.2 m while that of the Stable Segments (SS) has infinitesimal amount of clay in most layers. The results show that Vertical Electrical Sounding design for the failed (conk out) and stable subdivisions of the absolute road sub-grade displayed that the 80 % of the failed segments (FS) are greatly associated with reduced (lower) resistivity values (clayey dominated layers) compared to the stable portions for most layers. The low-level resistivity values of the failed segments may suggest (inculpate) the occurrence of high clay settlement (contents) in the sub-formation at various depths as well as the damp seasonal effect, subpar infill materials, and low-quality materials on the road.

Protective capacity Map

The protective capacity maps (Figure 42-46) indicates that road sections are not very protected since the protective capacity rating ranges from poor to moderate (< 0.69) in all investigated parts of the study areas. The protective capacity shows the presence of clay material in the study areas thereby enhancing the causes of the road failures in some sections of the researched areas.

CONCLUSION

Geophysical investigations of several failed and stable sections of Delta State road have been carried out to establish the factors that may have influenced the continuous failure of some portions of the road. These post-construction investigations suggest significant solutions to road sections failures. Results from the study identified the possible causes of the road failure in the study areas to include poor surface and sub-graded materials (materials with clay composition); shallow water table and water-lodge sand which resulted in major cracks and unable to withstand heavy traffic plying this particular road. However, some segments of the road are still stable with moderate and high resistivity values. The presences of expansive, collapsible and compressible clay, sandy clay and clayey sand on the topsoil and sub-grade soil under changing weather conditions have contributed to the failure witnessed on the road. This is as a result of the fact that they constantly expand and contract resulting to cracks. Clay has the ability of absorbing water which makes them swell and fail under the action of stress (movement of heavy vehicles).

The findings from the unstable (failed) road sections show that the reasons for road failure in the study locations are likely the shallow water table near the surface with a high moisture content and a weathered layer with a clayey composition (low resistivity values). This means that the primary reason why some sections do not reach their intended goal that is, fail before the appropriate age is due to these clayey formations with low resistivity (< 105Ωm), which have been found through research conducted both inside and beneath the earth's surface in weak zones.The failure might have also been caused by additional factors, such as an inadequate drainage design for runoff at the two sides of the road portions. Laterite materials are good subgrade materials to have while building a road. The road may eventually fail due to further contributing (boosting) elements such an inadequate or unsuitable drainage system, poor construction materials, thin road covering, and lack of maintenance. Excavation of clayey areas of the road should be done to replace them with suitable fill materials (quarry dust), 5–7 meters below the surface of the road. Long-term water suspension on road segments should be avoided as this reduces the intermolecular bonding between molecules and also an adequate drainage system should be installed. For the purpose of improving results, it is advised that further integrated geophysical techniques, such as dipole-dipole, amplified wenner array, seismic refraction, etc., and soil index strengths (geotechnical technique) be used. Additionally, careful data correlation on road failure sections should be carried out.

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