Recurrent Flood-Washed Flexible Pavement Failures in Wilberforce Island, Nigeria: Proposed Solutions

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ABSTRACT

Apart from flooding homes and making several persons homeless for weeks, the 2022 Flood in Nigeria destroyed the only major road into the Wilberforce Islands, just as it occurred in 2012. The three major damaged portions of this lone road that connects the State University and the Bayelsa Cargo Airport with the State Capital in Yenagoa were at Coordinates N4º 58' 48", 6º 12'0"E (Airport Junction), N4º 59' 9", 6º 8' 48"E about 4.5 km from the University town and at N4º 59' 26", 6º 7' 51" close to Ogobiri, where some staff and students also reside. All the failures had similar pattern and root cause of piping through the heaped sand that serves as the sub-grade and base course to the asphalt-finished flexible pavement. The critical locations are flood plains and zone in the predominantly below sea level mangrove region of the Delta. Previous geophysical survey studies, using Abem Terrameter (SAS 1000) for the Vertical Electrical Sounding (VES) by Schlumberger configuration was carried out. Maximum current electrodes spread of 1000m and and potential electrodes of 40.0m were adopted. The resistivity data obtained was interpreted using computer software programme, RESIT. The three flood-washed locations were within the five VES stations investigated in order to evaluate the depth affected. It was observed that the depth below the subsoil, 4.0m to about 30.0m, has remarkable low resistivity between 18 Ωm and 154.2 Ωm, Within this depth, lies the section mainly affected by the flood-washed. The results from the geo-electric layers and lithology showed that the plains have rich deposit of silts and Clay beneath the sediments transported during flooding and serving as a seal that prevents seepage into the aquifers in the plain. Practical and permanent solution to this cyclic pavement failure requires grade separated rigid pavements (bridges or flyovers) in the identified sections, if necessary. Diversion of the flood water into the aquifer beneath the alluvial Clayey soil, as a way of conserving fresh water is also necessary in the study area. The modification of the pavement design around the frequently breached locations, using the information from this research about the depth of Clay and fine Sand along this road, should also be given consideration

Keywords: VES, Flooding, Geophysical surveying, Pavement failure, Grade- separated reinforced concrete pavements, Aquifer Recharge

INTRODUCTION

Towards the end of 2022, another episode of a 10-year Return flood, aggravated by the release of excess stored water in a dam in Cameroon in one hand and failure to heed predictive advise from a meteorological station affected many people in Nigeria, especially at the Confluence town of Lokoja in Niger State and in the riverine delta regions of Bayelsa and Rivers States. In the subsequent review of the development recently (2024) with the second author, it was discovered that the spots where the highway was breached again were at about the same sp ot of the previous pavement failure.

The sand-filled base course method used in the road construction is more or less a levee and locations of the failures are all in stream bed flow with the pavement almost perpendicular to the direction of flow. This the pavement is technically serving as a small earth embankment dam or levee that retains the flood water. With neither culvert nor French drain tochannel the flood water to the other side of river course, the slope of the pavement was too thin to create enough head to resist the hydrostatic pressure of the accumulated water in the upstream side. This was responsible for the piping erosion that leads to the washing away of the sand used in paving the highway. The erosion was easy because there was no impervious core within the section of the highway.

The electrical properties of the subsurface can be explored either electrically or electromagnetically. Broadly speaking, the electrical methods exploits the flow of a steady current in the ground, either direct or sinusoidal, while the electromagnetic ones rely on the phenomenon of electromagnetic induction and the wave character of the electromagnetic field (Parasnins, 1997). In resistivity method, current is measured to determine an effective or apparent resistivity of the subsurface. Direct current resistivity method measures the apparent resistivity of the subsurface effects, soil type, bedrock features, contaminated and groundwater potential. The method has been used extensively in groundwater investigation in the basement complex terrains and in the sedimentary basins. Electrical prospecting is far more diversified than the other geophysical methods. Other methods require electric currents or fields which are introduced into the earth artificially and in this respect are similar to the seismic techniques.

Application of Electrical Resistivity Method

The use of electrical resistivity for both groundwater resources mapping and for water quality evaluation has increased dramatically over recent decades in much of the world due to rapid advances in microprocessors and associated numerical modeling solutions. The Vertical Electrical Sounding (VES) has proved very popular with groundwater studies due to simplicity of the technique (Adewumi and Olorunfemi, 2005; Gholam & Mohammad, 2005). Also, lateral and vertical discontinuities in subsurface geoelectrical structures can be delineated by electrical resistivity methods implemented in profile and sounding modes. The sounding mode, referred to as the deep resistivity sounding (DRS) has been used to obtain vertical resistivity structures at depths as great as 4-5km (Sigh & Jimmy, 2006). The resistivity method can be employed to delineate possible aquiferous zone and determine the groundwater potential (Al-Sayed & El-Qady, 2007).

The resistivity survey may be combined with electromagnetic survey to map the lithology of the near-surface unconsolidated sediments, glacier ice thickness and aquifers. The procedure provides adequate method of mapping caves within limestone bedrock. There is an increasing amount of interest in the use of high-resolution resistivity surveys in the investigation of closed landfills.Electrical resistivity subsurface imaging can be used to locate old foundations concealed beneath (John, 1997). It can also be applied to locate the presence of massive ice and frozen ground. Vertical Electrical Sounding (VES) method has been used in determining the existence of clay deposit. Clay minerals are nearly ubiquitous in the earth’s upper crust. They offer a unique record of earth process and earth’s history (Omeimen, 2000). VES has been successfully utilized to delineate preferential water flow paths in stratified soil profiles as well as to determined saline groundwater table in a uniform soil (Larisa *et al*., 2001). The wide use of resistivity survey in groundwater investigations, engineering foundation problems and environmental studies has given electrical methods of geophysical prospecting a good song of ode. Recently, a lot have been put into studying the environment than before (Adetola *et al*., 1999).

Electrical prospecting are being employed to an increasing extent in engineering geology, where resistivity measurements are used for finding the depth to bedrock and also in geothermal exploration (Dobrin, 1976). The method adopted in this work allows for the delineation of various formation types, thicknesses and depth of the geo-electric layers. The knowledge of various formation types for environmental and engineering uses can be applied to determine structures and building that may be erected. The necessity to pre-geophysical investigation of a proposed civil structure cannot be ignored since this will help in designing of structures that will withstand the test of time. The nature of the soil or rock supporting road structure becomes an extremely undisputable issue of safety, road integrity and durability (National Cooperative Highway Research Program, NCHRP, 2006). Actually, frequent failure of roads has become a common occurrence in many parts of this State and the country in general. This is common during rainy seasons, leading to the recurrent rehabilitation and reconstruction of roads which in most cases do not receive prompt attention from the government.. These have constituted some financial burden to the various tiers of government.

Geotechnical engineering practices require investigations of the soil and the subsurface at sites chosen for engineering constructions. This is routinely done to ascertain the suitability of the earth materials at such sites for proposed structures i.e. in terms of bearing capacity and/or hosting fitness (Ibitoye, *et a.l*, 2013). Three causative factors of road failures are natural causes, anthropogenic activities, and failures occasioned by poor construction design according to Obiora *et al*., (2021).

According to Abraham and Ibe (2025), the formation underlying the failed portions of the roads are predominantly clays and peat, loam and mud. That the instability associated with some parts of the roads are due to Clay volumetric variation as a result of variation in moisture content, high moisture content of peat, loam and mud facilitate compression of some failed portions of the roads due to loads. The average elevation of the study area stands at about 9.5m above sea level as determined from the global positioning system (GPS) readings. The most recent impact of the 2022 Flooding in the area are as seen in Plates 1- 3.

Plate 1: The eroded flexible pavement at the junction to the Cargo Airport along Amassoma Road ([1]Adedokun, 2022)


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Plate 2: Footbridge constructed over the washed-off pavement to link Tombia community with Amassoma Road (Adedokun, 2022)

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Plate 3: Reconstruction of the failed pavement along Ogobiri - Amassoma Way (Adedokun, 2022)

Brief Geology of the study area

The study area, is Bayelsa State, The study area, (Fig. 1), is in Bayelsa State which lies between Latitudes 4^0 15'North and 5^0 23'North; and Longitudes 5^0 15'East and $6^0$45' East at the core of Niger Delta region. Geographically, the state is situated within lies within the Niger Delta Basin, where three major depositional environments typical of most deltaic environments (marine, mixed and continental) are observable. These are represented by three chrono-statigraphic units namely Benin Formation in the upper layer, Agbada Formationin the middle and Akata Formation in the lowermost which have been recognized and described in the subsurface of the Niger Delta Basin (Short & Stauble, 1967).

The main objective of this paper is to conduct a geophysical survey of the terrain to determine the geology of the area and identify depths and locations of aquifers and see if some of the floodwater could be filtered and then used as groundwater recharge into the located aquifers through boreholes around the floodplain to preserve freshwater for use in the study area. The second objective is to propose engineering solution(s) to frequent pavement failure along Amassoma Highway.

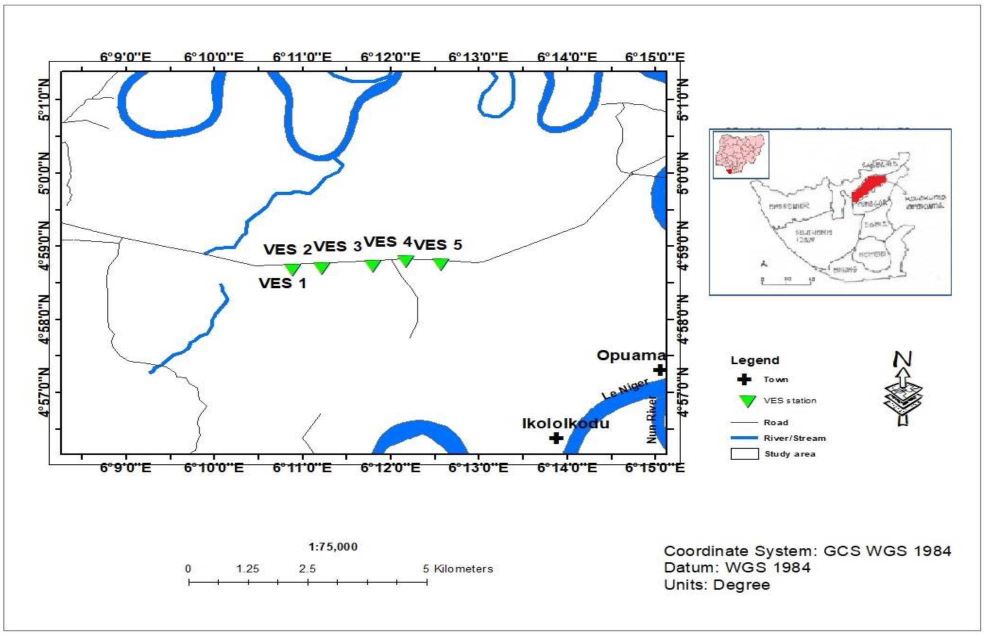

Figure 1: Map of Bayelsa State showing the study area and the positions of VES stations.

METHODOLOGY

Five Schlumberger Vertical Electrical Soundings (VES) were carried out in the study area depicted as VES 1 to VES 5. The stations were carefully selected along the road under investigation. Abem Terrameter (SAS 1000) equipment was used with a maximum current electrode separation AB of 1000m and maximum potential electrode separation of 40m. The maximum depth of investigation is between 0.1 to 0.3 times the current electrode spread AB length (Bernard, 2003). Whenever current (I), was introduced into the ground, from the Terrameter, by means of two current electrodes (A and B), the potential drop (V) between a second pair of electrodes M and N placed in line in between the pair was measured and the value of Resistance R (V/I) displayed and recorded. The field measurements were taken at AB/2 1.00, 1.50, 2.00, 3.00, 5.00 6.00, 8.00, 10.00, ……………………….200.00, 250.00, 300.00, 350.00, 400.00, 500.00m.While corresponding values of MN were 0.25, 0.5, 1.0, 2.5, ……… 20.0m With the electrodes driven into the ground for not less than 20.00m, good contact with ground was maintained and accurate survey method required that the distance between potential electrodes (MN) and current electrodes (AB) must be 5MN ≤ AB, Fig. 2. The product of the resistance R (V/I), read from the instrument, T, and the Geometric factor K which has to do with the arrangement of electrodes gives the apparent resistivity and for the Schlumberger electrode configuration used, AM = MN = NB, AT = TB, (Telford, *et al*., 1990).

$$\ell_\alpha = K\frac{V}{1} = KR \qquad (1)$$

$$K = 2\pi\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]^{-1} \qquad (2)$$

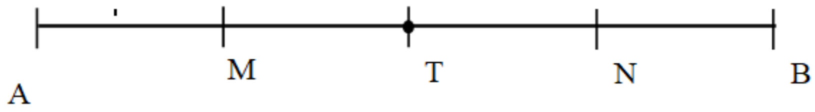

Figure 2: Schlumberger electrode configuration for VES.

The Apparent resistivity value was calculated each time the electrodes were expanded and the reading taken.. Computer software programme, RESIT, was employed to invert the field data to 1D resistivity images, where the Apparent resistivity values were plotted against half-electrode spread (AB/2) and thus produced the geo-electric layers for the five VES stations (VES 1 to VES5).

RESULTS AND DISCUSSION

The summary of the lithology obtained and the geo-electric layers for each of the VES stations in the study area are shown in Fig (1a – 5a) and Fig. (1b - 5b) respectively. The apparent resistivity curve types obtained are QHA for VES1, QH for VES (4 and 5), HKA for VES 2 and KHA for VES 3. Each layer in all the stations (VES 1 – VES 5) was considered together with a view to following the trend, in all, from the topsoil to the depth where the effect of the flood-washed stopped. This gave the information about the affected depth, from the surface, to which necessary solutions must be applied. In all the locations where the geophysical survey was conducted, the topsoil, which was mainly silt and unconsolidated materials has highest resistivity than the subsoil except in VES 3.

Each of the layers is presented as (observed resistivity, thickness and depth): For the first layer; VES 1 (327.2Ωm, 1.9m, 1.9m), VES 2 (469.1 Ωm, 1.9m, 1.9m), VES 3 (49.9 Ωm, 0.8 m, 0,8 m), VES 4 (155.7 Ωm, 1.6m, 1.6 m) and VES 5 (244.0 Ωm, 1.7m , 1.7m). This wet topsoil has a depth ranging from 0.8m to 1.9m and resistivity values between 47.1 Ωm and 469.1 Ωm. The subsoil, generally of lower resistivity, can be considered as fine Clay of varying resistivity values from 24.0 Ωm to 189.8 Ωm at depths between 4.0m – 8.1m. This second layer has for VES 1 (122 Ωm, 2.8m, 4.6m), VES 2 (24.0Ωm, 6.2 m thick and extending to 8.1m below the surface), VES 3 (154.2Ωm, 3.8m, 4.6m).VES 4 (37.4 Ωm, 4.1m, 5.7 m). and VES 5(189.8Ωm, 2.3m, 4.0m) , This layer could be generally fine sandy Clay.

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In the third layer, resistivity, thickness and depth are, like as presented in the first two layers, arranged the same way; VES 1(28.1Ωm, 14.4.0m, 19.0m), VES2 (2366.1 Ωm, 32.8.0m, 40.9.0m), VES 3(18.2Ωm, 25.1.0m, 29.10m), VES 4 (30.1Ωm, 13.0m, 18.8.0m) and VES 5(4.2Ωm, 8.9.0m, 12.8m). Resistivity values are between 4.2Ωm and 2366.7Ωm within the depths 12.8 .0m and 40.90m in these layers. The third layer of VES 1,3, 4 and 5 have very low resistivity, 28.1Ωm, 18.2 Ωm, 30.1Ωm and 4.2 Ωm and can be considered as wet Clay. However in VES 2, the highest resistivity of the station is situated in this layer, being 2366.7Ωm with a thickness of 32.8m at a depth of 8.1m below the surface. The Aquifer in this station is located in layer three. The station that has the highest resistivity of the study area is located between the two flood-damaged sites, which are far apart by about 5km. The relatively resistive formation revealed could explain the main reason for no destructive impact of flood at this portion of the road. The relatively higher resistivity value of the layers down to substratum (last layer), in this station, could be considered as mainly medium coarse sand.

Layer four of all the station (VES1- VES 5) lies between 29.1m and 72.5m below the surface where resistivity range interval is 9.3Ωm to 1259.7Ωm. At this depth, the effect of flood does not exist in these layers which could be mainly wet Clay. In layer five of all the stations, resistivity range between 63.0Ωm and 1551.0Ωm and depth at interval 85.0m to the substratum. These layers, like the underlying ones, are mainly Clay except medium coarse Sand in VES 2. It is only in VES 1, (Fig. 1b), that the stratification revealed up to the six layer which is fine sand. It was observed that within the depth range in which the flood eroded the three locations of the road under consideration was between 4.0m to 30.0m depth, where remarkable low resistivity values were recorded. In all the stations, except in VES 2, resistivity increases down to the substratum. The summary of resistivity values, lithology, its thickness and depth below the surface is shown in Table 1. The summary of the geo-electric sections obtained (Table 1) for the area indicates that up to a depth beyond 10.00m, Clay or sandy Clay still exists as observed in VES1, 2, 3, 4 and 5 except in VES 2.

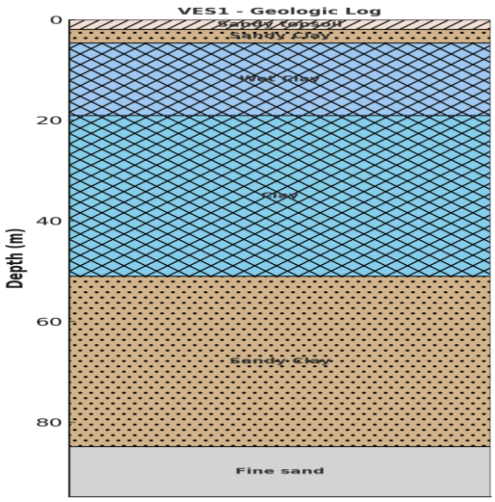

Fig. 1a: Lithology for VES 1

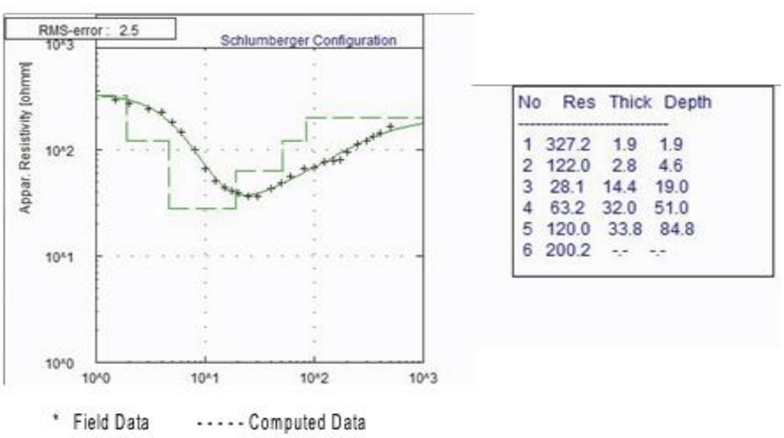

Fig. 1b: Geo-electric layers for VES 1

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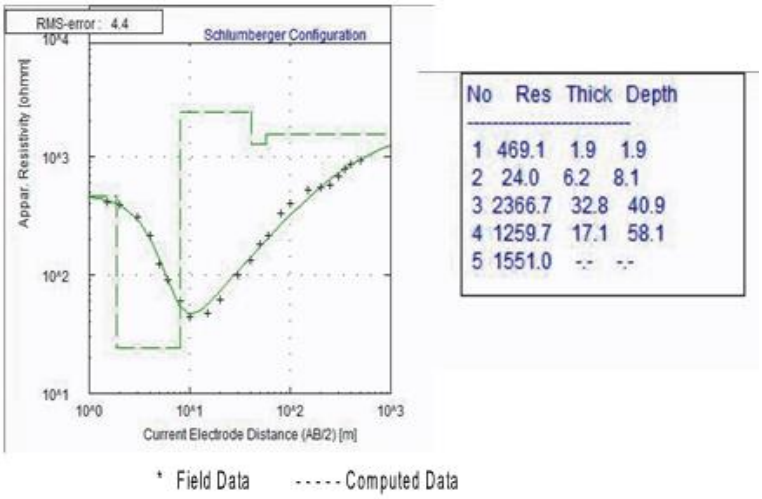

Fig. 2b: Geo-electric layers for VES 2

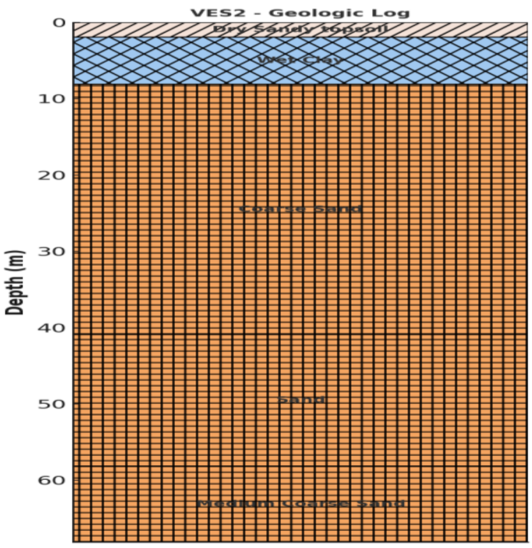

Fig. 2a: Lithology for VES 2

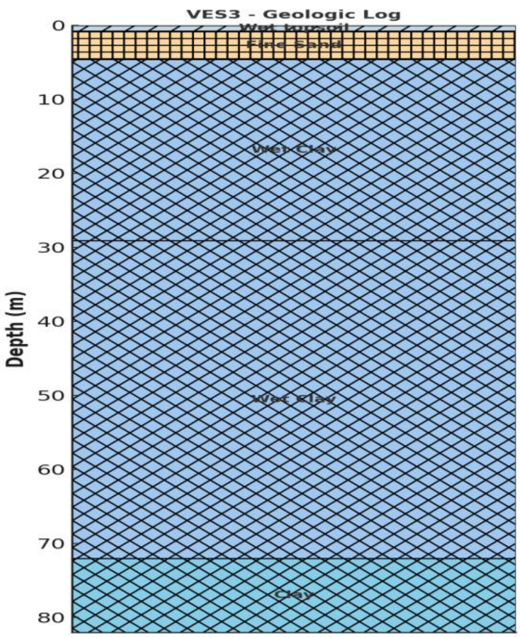

Fig. 3a: Lithology for VES 3

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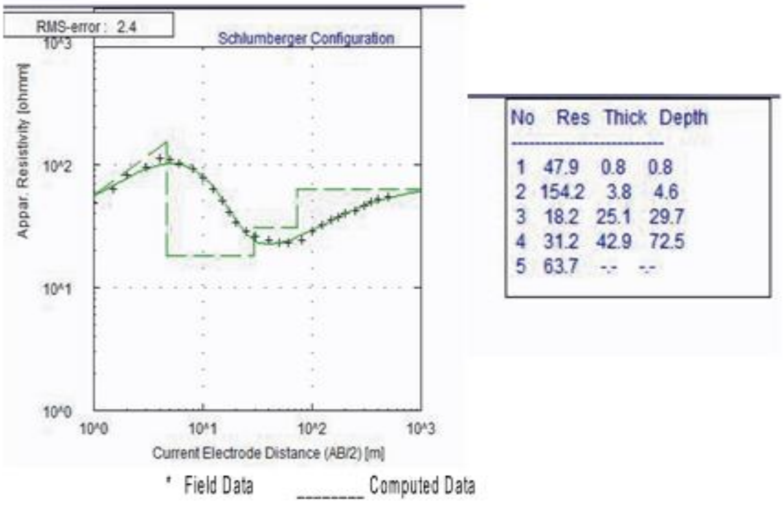

Fig. 3b: Geo-electric layers, for VES 3

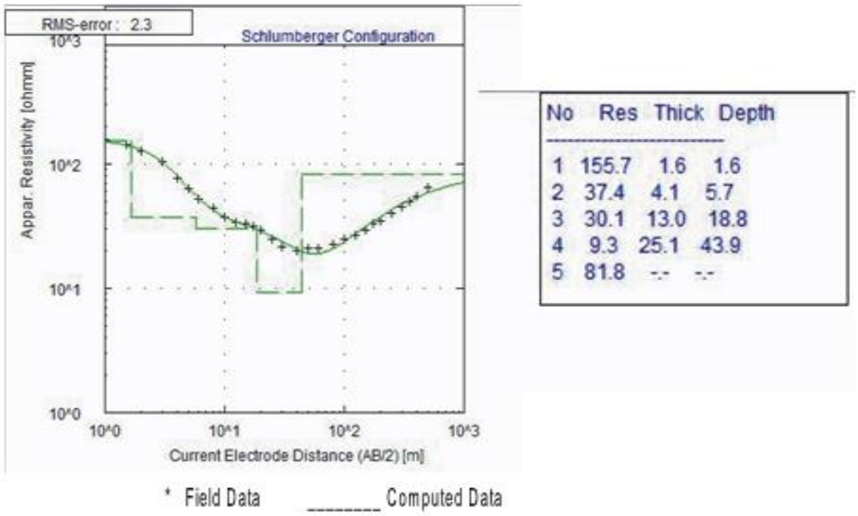

Fig. 4b: Geo-electric for VES 4

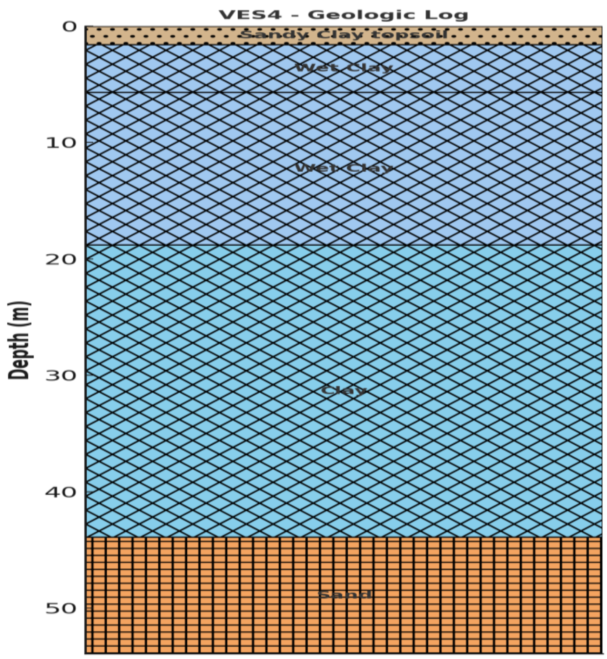

Fig. 4a: Lithology for VES 4

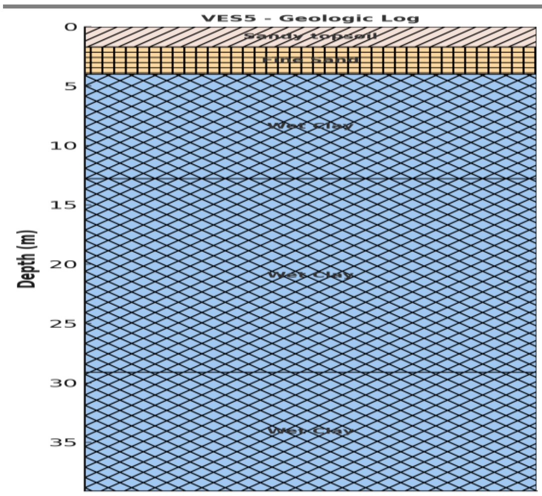

Fig. 5a: Lithology for VES 5

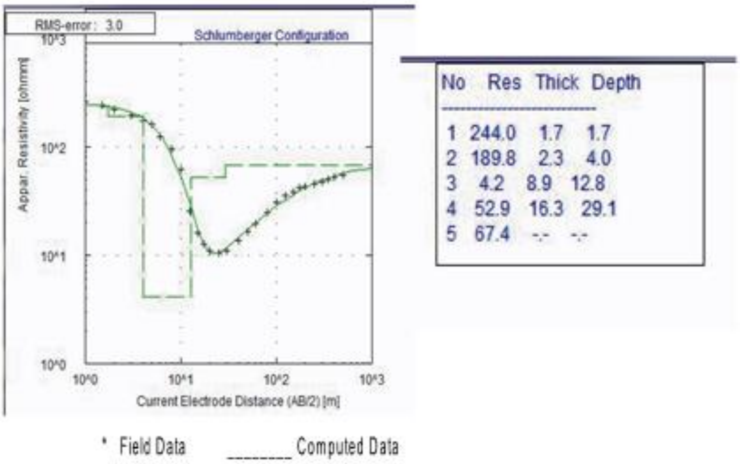

Fig. 5b: Geo-electric layers for VES 5

The geophysical survey report above shows that three engineering options are available to provide a permanent solution to the recurring 10-year cyclic breach of the only highway that connects the University town of Amassoma to the State Capital in Yenagoa.

1. Diversion of the flood water into the aquifer beneath the alluvial clayey soil as a way of conserving fresh water in the study area. This would also dilute the salty water wherever such groundwater are sourced, especially in communities with proximity to the seaside. However it is counselled that there should be relative filtration of the flood water before release into the aquifer beneath the clayey aquiclude that makes flooding a common phenomenon in the Study area. This recommendation was part of a Report prepared by our Committee for the Niger Delta University during the 2012 Flood episode.

2. The modification of the pavement design around the frequently breached locations. The method of construction in riverine area, close to the ocean is to use dredged sand as both subgrade and subbase course beneath the riding surface of flexible pavement made with asphalt. However, the highway which is naturally raised above the surrounding terrain has become more or less a levee or small dam. The breached areas are more or less putting hydrostatic pressure on the walls of the highway. Since the slope at those locations and generally along the highway is steep , less than 1:2, it is better to increase the slope to 1:3 with riprap placed on the inner side which now serves as an upstream surface to the highway. This should then be backed with an appropriate size and length of culvert connecting the flood water to the downstream side. Within the upstream side which now serves as a Reservoir,

appropriate locations where surface recharge of aquifers could be made should be drilled but have the upper part near the surface widened to contain sand filter medium and adsorption beds to reduce pollution of the aquifer water from washed organic and other hazardous impurities. From our previous studies, a minimum depth of 1.0 m of sand bed and 0.6 m of granular activated carbon bed would remove both filterable and non- filterable solids including some ubiquitous heavy metals such as lead (Pb), arsenic (As) Cadmium (Cd) in particular (Adewumi, 1999, 2006, Adewumi and Ogedengbe, 2006).

3. The third option is to create a grade-separated reinforced concrete bridge across the sections identified in the geophysical survey as a socio-economic intervention to ensure that the communities the highway connect to civilization will not be cut off in any future flood event. Given that both staff and students of the University are crucial for human capita development and communities along and in the local government depend on the highway to operate their businesses, this intervention is not beyond what the State government could do, more so for the presence of the Cargo Airport on that route.

Table 1: Summary of lithology, resistivity and depth showing the materials underneath

VES 1				
Layer	Resistivity	Thickness	Depth	Lithology
1	327.2	1.9	1.9	Sandy topsoil
2	122.0	2.8	4.6	Sandy Clay
3	28.1	14.4	19.0	Wet Clay
4	63.2	32.0	51.0	Clay
5	120.0	33.8	84.8	Sand Clay
6	200.2	--	--	Fine sand
VES 2				
Layer	Resistivity	Thickness	Depth	Lithology
1	469.1	1.9	1.9	Dry sandy topsoil
2	24.0	6.2	8.1	Wet Clay
3	2366.7	32.8	40.9	Coarse sand
4	1259.7	17.1	58.1	Sand
5	1551.0	--	--	Medium coarse sand
VES 3				
Layer	Resistivity	Thickness	Depth	Lithology
1	47.9	0.8	0.8	Wet topsoil
2	154.2	3.8	4.6	Fine sand

3	18.2	25.1	29.7	Wet Clay
4	31.2	42.9	72.5	Wet Clay
5	63.7	--	--	Clay
VEES 4				
Layer	Resistivity	Thickness	Depth	Lithology
1	155.7	1.6	1.6	Sandy Clay topsoil
2	37.4	4.1	5.7	Wet Clay
3	30.1	13.0	18.8	Wet Clay
4	9.3	25.1	43.9	Wet Clay
5	81.8	--	--	Clay
VES 5				
Layer	Resistivity	Thickness	Depth	Lithology
1	244.0	1,7	1.7	Sandy topsoil
2	189.8	2.3	4.0	Fine sand
3	4.2	8.9	12.8	Wet Clay
4	52.9	16.3	29.1	Wet Clay
5	67.4	--	--	Wet Clay

CONCLUSION

With one or more of the options above chosen and done, it is believed that the users and communities connected by this highway would not be affected by future flood episodes. Adopting aquifer recharge as proposed would ensure access to groundwater supply that would require minimal treatment.

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