



# **Investigating Road Pavement Failure in Oworonshoki, Kosofe Area of Lagos, Using Geophysical and Geotechnical Methods**

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## **Authors' contributions**

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## **ABSTRACT**

An assessment of the immediate causes of persistent road pavement failure in Oworonshoki, Kosofe area of Lagos, Nigeria using geophysical and geotechnical methods was carried out. Six traverses were occupied in the study area along the alignment of the road. Electrical Resistivity Imaging (ERI) data using the Wenner array were acquired along the six traverses. These were followed by six (6) Vertical Electrical Sounding (VES) data along the traverses. On traverse 1 are VES 1 and 2, on traverse 2 are VES 3 and 4, on traverse 3 are VES 5 and 6. One boring and three Cone Penetration Testing (CPT) were conducted along traverse 6 while the three CPTs were carried out on traverse 3, 4 and 5 respectively. The inverted 2D results reveal that resistivity values vary from 6.74 – 1333  $\Omega$ m in the study area. Four resistivity structures are delineated which are peat, clay/sandy clay, clayey sand and sand. The peat has resistivity values ranging from 6.74 – 17.7  $\Omega$ m, clay/sandy clay (20.9 – 86.9  $\Omega$ m), clayey sand (96.3 – 194  $\Omega$ m) and sand (245 – 1333  $\Omega$ m). The peat is laterally extensive and occurs from the surface to a depth of 25 m. The peat is underlain by the clay which is fairly extensive across the area of study with a thickness of 2.5 – 20

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m in most location. The Cone Penetration Tests (CPT) reveal cone resistance values that progressively varies from 0 – 101 kg/m<sup>2</sup> from the surface to a depth of 17 m, indicating dense earth materials at deeper depth while at near surface, they are incompetent soft clayey earth materials. The laterally extensive peat and clay units underlying the road pavement, extending up 30 m depth as revealed from the 2D ERI, the geoelectric investigation and the borehole are suspected to be responsible for the persistent settlement, rutting and pitting of the road pavement. The thickness of the peat/clay and the lateral extent may not be economically admissible for excavation during construction. Pile foundations to the dense gravely sand at 40 m depth along the stretch of the road is therefore recommended for stable road pavement.

*Keywords: Electrical resistivity; pavement; clay; geotechnical; road failure.*

## 1. INTRODUCTION

A good and reliable transport network remains vital for business, commerce, movement of goods and services in an economy. Roads are integral part of the transport system. Road transportation is an important element in the physical development of any society as it controls the direction and extent of development. Furthermore, road plays a significant role in achieving national development and contribute to the overall performance and social functioning of the community [1]. It is acknowledged that roads enhance mobility and thus take people out of isolation. Since there is a very strong positive correlation between a country's economic development and the quality of its road network, a country's road network should be constructed in an efficient way in order to maximize economic and social benefits [2].

Though road usage, construction practices and maintenance have been reported to be responsible for road failures [3], field observation and laboratory experiments have shown that road failures are not primarily due to road usage, inadequate supervision, poor construction materials, non-compliance to specifications/design problems alone but can equally arise from inadequate knowledge of the characteristics and behaviour of residual soils on which the roads are built [4]. Consequently, geological and geophysical experts have often emphasized lack of adequate information on the nature of subsurface conditions prior to construction as a major contributor to this phenomenon. After all, every engineering structure is seated on geological earth materials [5,4,6,7,8,9]. Studies have identified that the non-recognition of the underlying geology in the design of these roads as a major factor causing incessant road failure in Nigeria [6,7]. Geological factors such as the nature of topsoil (subgrade) and the near surface geologic sequence, existing

geological structures such as fractures and faults, existence of ancient stream channels, and shear zones constitute geohazards that can impair the stability of any road structure. Hence, it is imperative that these factors are properly investigated prior to any road construction.

A lot of reasons have been suggested for the incessant failure of roads in Nigeria. These include presence of expansive clays such as montmorillonite, chlorite, halloysite, etc. [10,5], heterogeneity of the subgrade materials [11,5], presence of undetected linear features, such as joints, fractures and rock boundaries [6]. In the past two decades, the field of geophysics has proved quite relevant in highway site investigations [12]. However, in an attempt to unravel causes of persistent failure of roads across the country, various researchers have identified chiefly the underlying geologic conditions among the other factors to be responsible for the problem [6,7,8].

Oworonshoki in Kosofe is a densely populated area of Lagos. The area is characterized by persistent road pavement failure on the complete stretch of the road in the area (Fig. 1). This therefore necessitated the integration of geophysical and geotechnical methods to unraveled the cause of the persistent failure of the road. The geophysical techniques will help to determine the nature of the soils and the near-surface geologic sequence that characterize the proposed road segment. Geophysics will also identify the presence of geologic structures such as fractures, faults, geologic contacts/joints and other weak zones that have made the road vulnerable to failure after construction over the years. The geotechnical method on the other hand would determine the geotechnical properties of the subsurface lithology underlying the road pavement in the study area and their implications on the integrity/stability of the road. Both methods should reveal a good correlation in

their results. In this study therefore, geophysical and geotechnical methods were integrated to investigate the immediate causes of persistent road pavement failure in Kosofe Area of Lagos, Southwest Nigeria.

### 1.1 Geology and Geomorphology of the Study Area

The study area is underlain by the Coastal Plain Sand which is made up of loose sediment ranging from silt, clay and fine to coarse grained sand. The littoral lagoonal deposits are made up of clay, silt, and sands of coastal plains. The

coastal belt varies in width from about 8km near the Republic of Benin border to 24 km towards the eastern end of the Lagos Lagoon [13]. The age Oligocene to Recent was assigned to this formation on the basis of fauna contents (Fig. 2). The study area is located in Oworonshoki, Kosofe area of Lagos, Southwestern Nigeria. It lies within Longitudes; 3°24'01" E - 3°24'02" E and Latitudes; 6°33'10" N - 6°33'13" N. The study area is accessible through network of roads. It is linked by many major and minor roads from mainland Lagos. The topography is flat, low lying and gently slopes and borders the Lagos lagoon (Fig. 3).



Figure 1. Persistent failed segments of the road in the study area.

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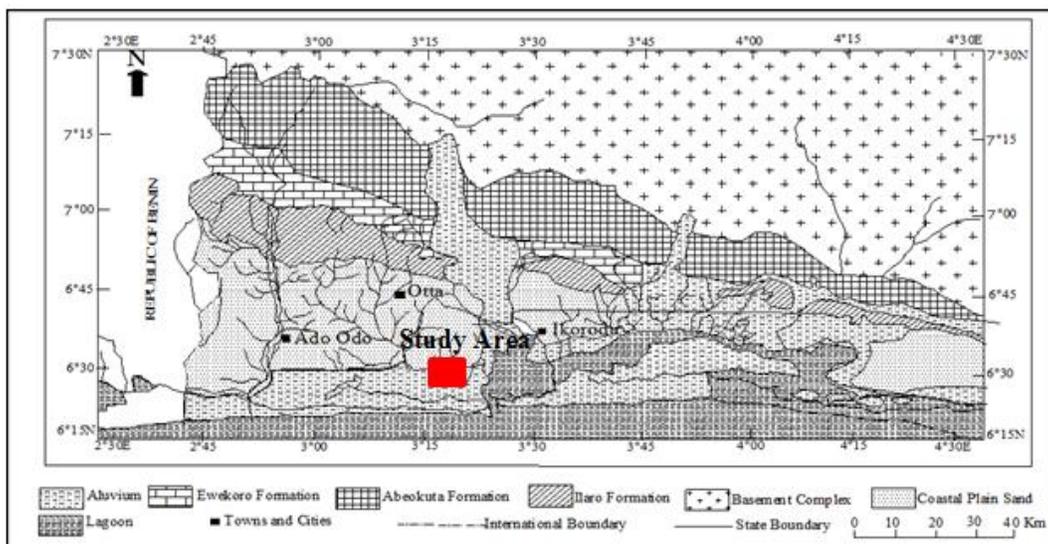
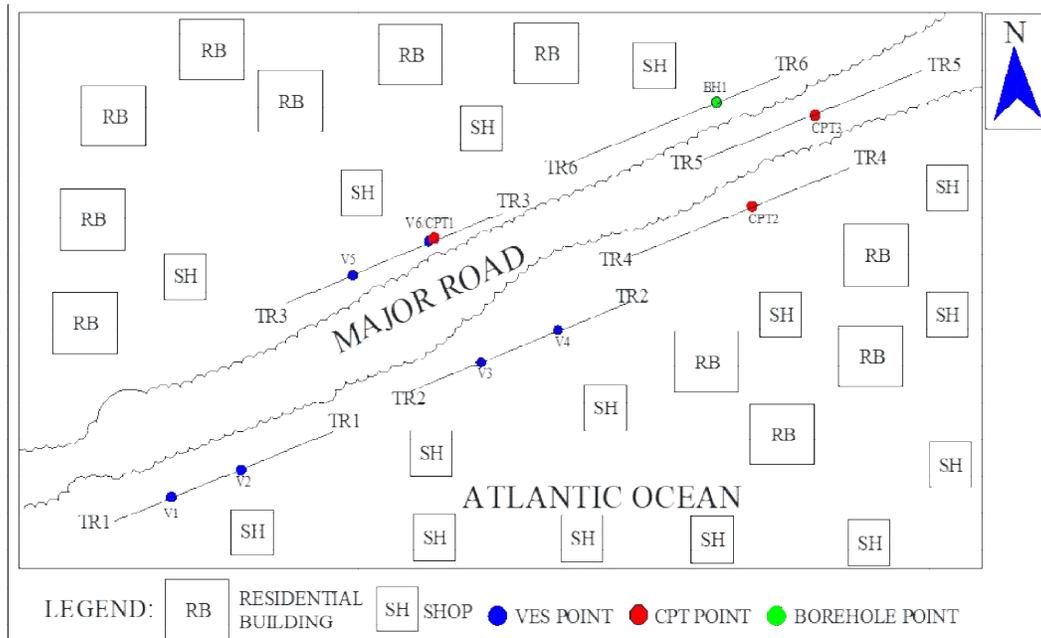


Fig. 2. Geological Map of Lagos State (After Kogbe, [14])



**Fig. 3. Base map of the study area**

## 2. MATERIALS AND METHODS

### 2.1 Data Acquisition and Processing

#### 2.1.1 Geophysical investigation

The 2D electrical resistivity imaging (ERI) investigation and the 1D vertical electrical sounding (VES) were carried out using the PASI Terameter GL-12 series along six traverse lines. The ERI profile lines were oriented in NE – SW in the parallel to the road alignment (Fig. 3). Traverse 1 – 3 is 200 m in length each while traverse 4 – 6 is 100 m each. The data were acquired using Wenner electrode configuration (Fig. 4) with minimum and maximum electrode spread of 10.0 m and 60.0 m, respectively. The data obtained were processed and inverted using the RES2DINV software with a least-square inversion algorithm using a regularization technique [15]. A total of six (6) VES points were occupied in the study area. The VES points were distributed across the traverse lines based on interpreted anomalous points on the traverse lines. On traverse one are VES 1 and 2, on traverse 2 are VES 3 and 4, on traverse 3 are VES 5 and 6 (Fig. 3). Schlumberger electrode configuration was used for the VES and the maximum current electrode spread was 200 m. The data were partially curve-matched before being inverted using WINRESIST. The VES on

each traverse were combined to generate the geoelectric section across each traverse.

#### 2.1.2 Geotechnical investigation

The procedures adopted for boring, standard penetrometer test (SPT) and cone penetrometer test (CPT), were in accordance with the British standard code of practice for site investigations, B.S 5930 (1999). One (1) hole designated as BH1 was bored on traverse 6 within the study area to a depth of 45 m using percussion boring method. The boring involves the use of shell and auger tools to cut through the soil strata to the total depth of boring. Disturbed soil samples were collected at every 75 mm. Also, undisturbed samples were collected in the cohesive soil using a 100 mm internal diameter open tube sampler fitted with a cutting shoe. The SPT was conducted in cohesionless soil using a thick-walled split spoon that was about 35 mm in internal diameter driven into the soils through several blows from 65 kg hammer falling from about 760 mm height. The resistance “N” value of the SPT shows the empirical evaluation of the soil’s consistencies; it is used to assess the strength, bearing capacity and compressibility of the granular soil. The collected soil samples were well preserved and transferred to the laboratory for further testing.

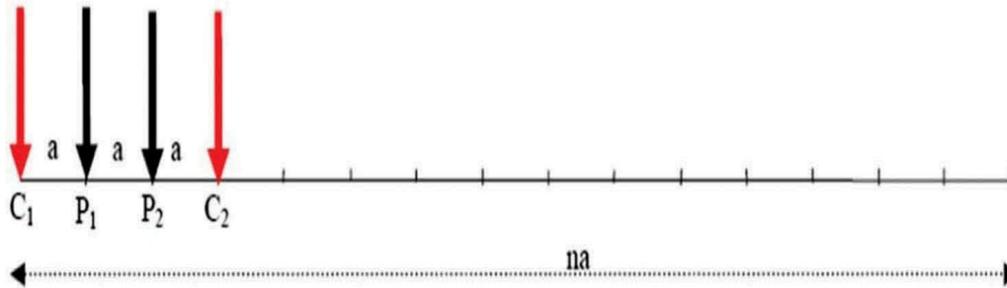


Fig. 4. Wenner array for 2D ERI data measurements

2.5 ton cone penetrometer testing (CPT) was equally used to measure the in-situ strength of the soil within the study area. A total number of three (3) CPTs denoted as CPT 1-3 were carried out within the area of study along the traverses. Along traverse 3 is CPT 1 and to which VES 6 is parametric (Fig. 3). On traverse 4 is CPT 2 and on traverse 5 is CPT 3 (Fig. 3).

### 3. RESULTS AND DISCUSSION

The program Res2dinv was used for this processing. Models for 2D resistivity inversion program comprise rectangular blocks (cell). The bottom of a block corresponds to a data point which is approximately equal to its effective depth. The software computes, by inversion, the true resistivity of the subsurface that agrees with the measured apparent resistivity values from the survey.

#### 3.1 Geophysical Investigation

##### 3.1.1 2D Resistivity investigation

The inverted 2D resistivity models across the six traverses in the study area show that along traverse 1, 2 and 3 a lateral distance of 200 m was covered and a depth of 31.9 m is imaged on each of the traverse, while across traverse 4, 5 and 6, a lateral distance of 100 m was covered and a depth of 15.9 m is imaged. Resistivity varies from 6.74 – 1333  $\Omega$ m across the six traverses.

On traverse 1, 2 and 3, resistivity values varies from 8.95 – 1333  $\Omega$ m. Four (4) subsurface resistivity structures are indicated, which are peat, clay/sandy clay, clayey sand and sand. The resistivity of the peat varies from 8.95 – 14.7  $\Omega$ , surficial and laterally extensive across the three traverses except on traverse 2 where it terminates at 70 m horizontal distance and relatively shallow to a depth of 12 m. The peat

varies in thickness from the surface to a depth of 25 m (Figs 5 – 7). The clay/sandy clay varies in resistivity values from 20.9 – 79.1  $\Omega$ m. The clay/sandy clay underlies the peat, laterally extensive across the three traverses and makes prominent and extensive surface expressions along traverse 2, with thickness varying from 2.5 – 20 m across the three traverses (Figs 5 – 7). The clay/sandy clay is underlain by clayey sand across the three traverses with depth varying from 7 – 28 m and with resistivity values ranging from 96.3 – 194  $\Omega$ m (Figs 5 – 7). Underlying the clayey sand is the sand having resistivity values varying 291 – 1333  $\Omega$ m, at a depth range of 20 – 31.9 m. The peat and clay/sandy clay strata which occur from beneath the road pavement to a depth of 20 m in most locations along the stretch of the road are considered to be incompetent earth materials on which road pavements may be laid. These incompetent earth materials are prone to triggering differential settlements of the pavements because of their low permeabilities despite their which has the tendency to make them shrink and swell in continuous cycle. This will eventually lead to the failure of the overlying road pavements by buckling, rutting and pitting.

On traverses 4, 5 and 6, resistivity values vary from 6.74 – 591  $\Omega$ m which delineate four resistivity structures that are peat, having resistivity values varying from 6.74 – 17.7  $\Omega$ m, clay/sandy clay (24.1 – 86.9  $\Omega$ m), clayey sand (120 – 165  $\Omega$ m) and sand (245 – 591  $\Omega$ m). The peat and the clay/sandy clay are surficial, fairly extensive and occur at depth range of 0 – 9 m (Figs. 8 – 10). These are underlain by clayey sand and sand that are laterally extensive across the traverses and at a depth range of 9 – 15.9 m. The columns of peat and clay/sandy clay are the incompetent geologic materials that are suspected to be responsible for the persistent road pavement failure in the study area.

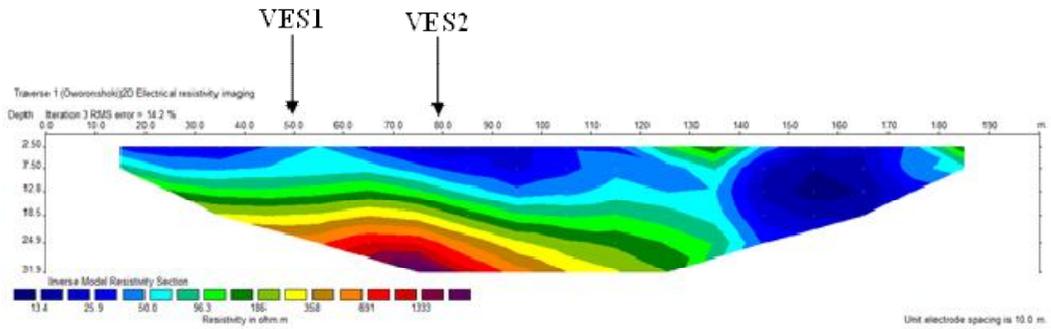


Fig. 5. 2D resistivity section along traverse 1

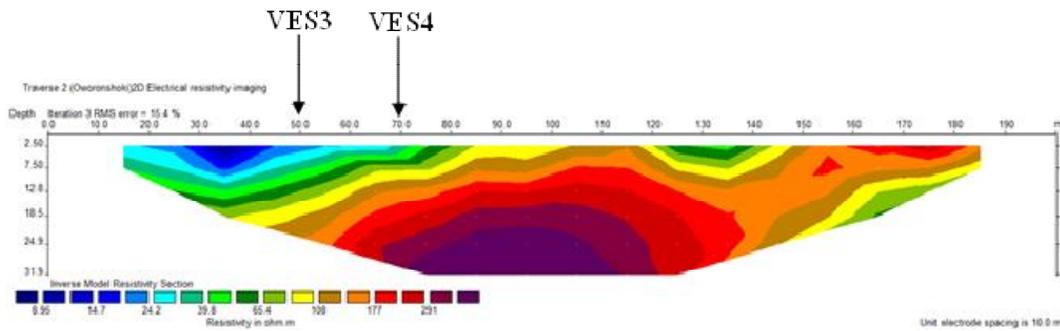


Fig. 6. 2D resistivity section along traverse 2

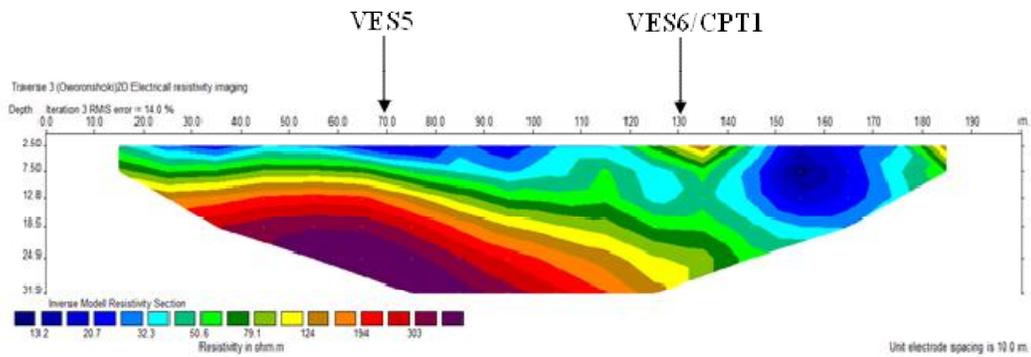


Fig. 7. 2D resistivity section along traverse 3

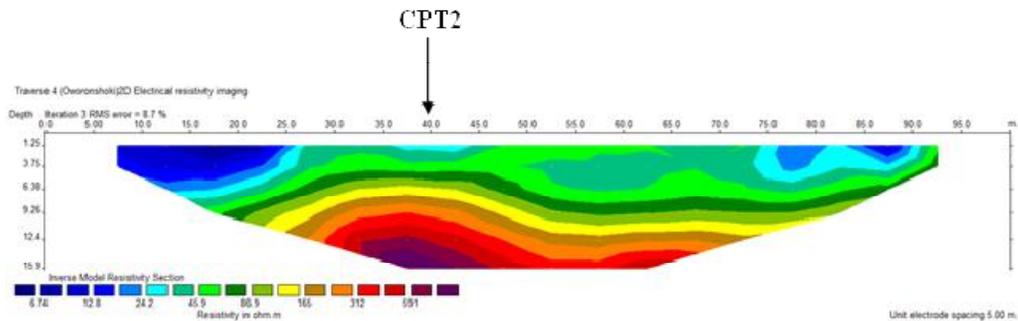


Fig. 8. 2D resistivity section along traverse 4

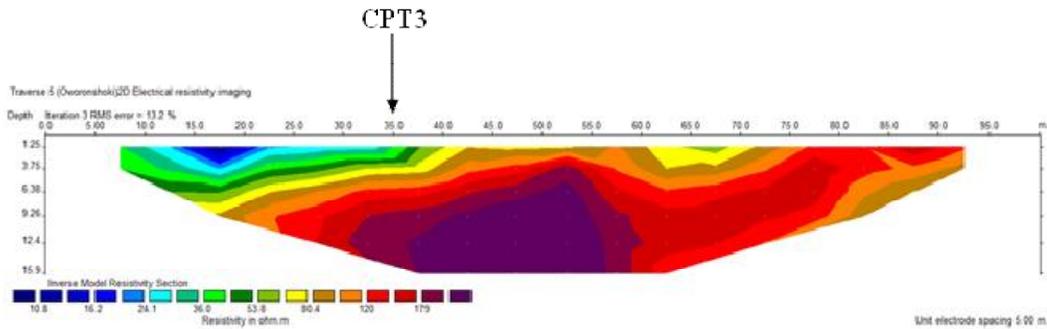


Fig. 9. 2D resistivity section along traverse 5

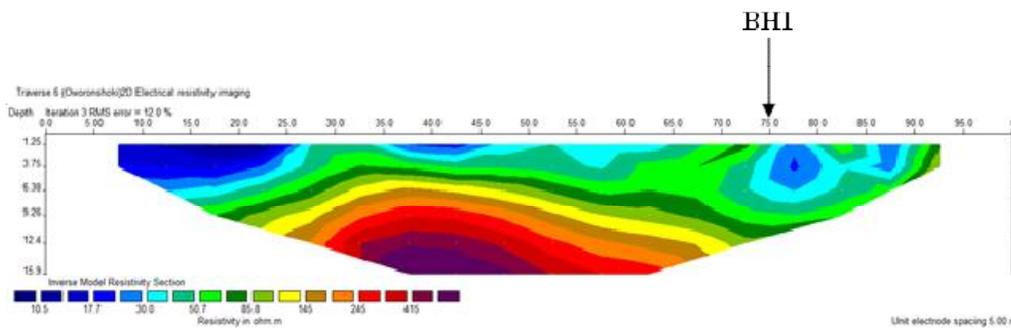


Fig. 10. 2D resistivity section along traverse 6

### 3.1.2 1D Vertical Electrical Sounding (VES)

The results of the VES across the entire study area are presented in Table 1. Resistivity values vary from 8.9 – 216.4  $\Omega\text{m}$ . Five to six geoelectric layers are delineated which are the topsoil, peat, clay, sandy clay, clayey sand and sand. A maximum depth of 37.5 m is delineated.

On traverse 1 are VES 1, and 2 which delineate topsoil with resistivity and thickness values of 94.8 – 123.8  $\Omega\text{m}$  and 0.6 m respectively, clay with resistivity and thickness of 19.4 – 47.4  $\Omega\text{m}$  and 1.4 – 30.0 m respectively, sandy clay with resistivity and thickness 86.8 – 95.6  $\Omega\text{m}$  and 5 m respectively, peat with resistivity and thickness values of 8.9  $\Omega\text{m}$  and 30 m and sand with resistivity and thickness values of 123.5- 136.4  $\Omega\text{m}$  and 4 respectively (Fig 11A). Unlike the 2D results where the incompetent peat and clay substrata appear to be near-surface only along traverse 1, however the VES reveals that the peat is more deep-seated at 36 m and may not be laterally extensive across the entire traverse. This may be suspected to be responsible for the persistent road pavement failure at some specific sections along the road.

On traverse 2 are VES 3 and 4. These reveal the topsoil with resistivity and thickness values of 132.7 – 138.2  $\Omega\text{m}$  and 0.7 m respectively. The clay has resistivity and thickness values ranging from 43.5 – 46.8  $\Omega\text{m}$  and 1.7, sandy clay with resistivity and thickness 51.1  $\Omega\text{m}$  and 15.1 m respectively, clayey sand with resistivity and thickness values of 87.6 – 98.2  $\Omega\text{m}$  and 7.7 – 9.3 m respectively, and sand, having resistivity values ranging from 131.6 – 203  $\Omega\text{m}$  but the thickness values could not be determined (Fig. 11B). The VES results along this traverse agree with the 2D ERI results along the traverse (Fig. 6).

On traverse 3 are VES 5 and 6. VES 6 is parametric to CPT 1 on the traverse 1. On traverse 3 are delineated topsoil with resistivity and thickness values of 107.3 – 139.9  $\Omega\text{m}$  and 0.5 – 0.7 m respectively, clay having resistivity and thickness values of 49.2  $\Omega\text{m}$  and 1.3 m, sandy clay with resistivity and thickness values ranging from 60.7 – 64.4  $\Omega\text{m}$  and 1.1 – 13.1 m respectively, clayey sand with resistivity and thickness values of 96.7 – 103.1  $\Omega\text{m}$  and 4.4 – 18.6 m and sand, having resistivity and thickness values varying from 197.8 -216.4  $\Omega\text{m}$  and 6.9 – 8.9 m (Table 1).

Table 1. VES results

VES No	Layers	Resistivity ( $\Omega m$ )	Thickness (m)	Depth (m)	Curve type	Lithology
1	1	94.8	0.6	0.6	HKH	Topsoil
	2	47.4	1.6	2.2		Clay
	3	95.6	5.0	7.2		Sandy Clay
	4	19.4	30.3	37.5		Clay
	5	136.4	---	---		Sand
2	1	123.8	0.6	0.6	HKH	Topsoil
	2	45.1	1.4	1.9		Clay
	3	123.5	4.0	5.9		Sand
	4	8.9	30.0	36.0		Peat/Clay
	5	86.8	---	---		Sandy Clay
3	1	138.2	0.7	0.7	HA	Topsoil
	2	46.8	1.7	2.4		Clay
	3	87.6	9.3	11.6		Clayey Sand
	4	203.0	---	---		Sand
4	1	132.7	0.7	0.7	HKH	Topsoil
	2	43.5	1.7	2.4		Clay
	3	98.2	7.7	10.1		Clayey Sand
	4	51.1	15.1	25.2		Sandy Clay
	5	131.6	---	---		Sand
5	1	139.9	0.7	0.7	HKH	Topsoil
	2	49.2	1.3	2.0		Clay
	3	199.0	6.9	8.9		Sand
	4	103.1	18.6	27.5		Clayey Sand
	5	216.4	---	---		Sand
6	1	107.3	0.5	0.5	HKH	Topsoil
	2	60.7	1.1	1.6		Sandy Clay
	3	96.7	4.4	6.1		Clayey Sand
	4	64.4	13.1	19.2		Sandy Clay
	5	197.8	---	---		Sand

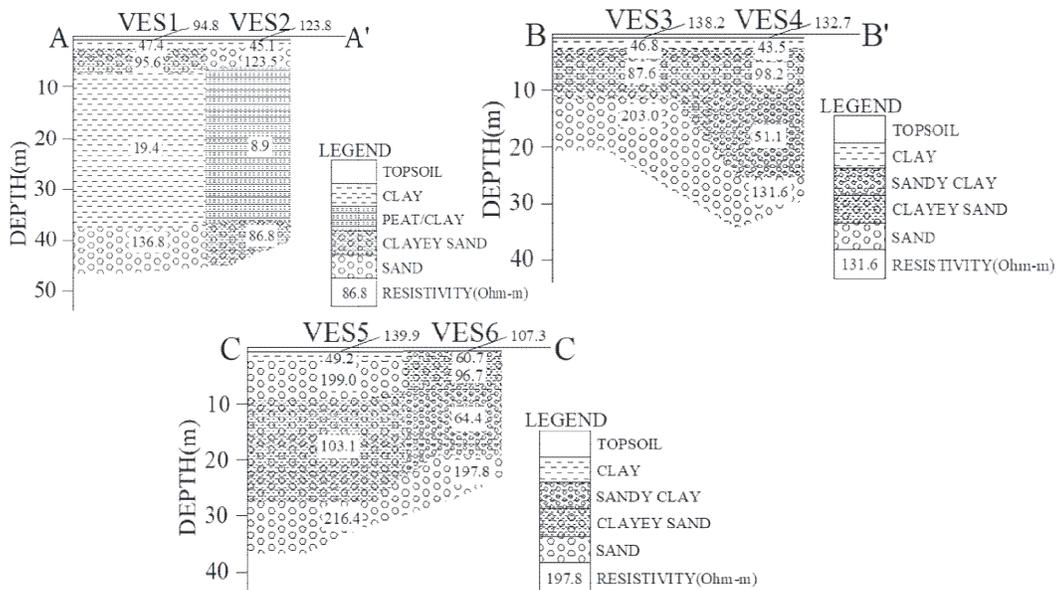


Fig. 11. Geoelectric section along traverse 1, 2 and 3



### 3.2.2 Cone penetration test (CPT)

Three (3) cone penetration tests (CPT) results conducted to determine the relative strength of the near-surface strata and also to assess the in-situ relative density of the soil at selected points along the stretch of the road in the study area are shown in Fig. 13.

On traverse 3 is CPT 1 which is parametric to VES 6 on the traverse. 6 m depth was penetrated by the CPT. The cone resistance values progressively increases from 0 – 100 kg/m<sup>2</sup> (Fig. 13). The cone resistance values are indications of very soft clay to soft clay near-

surface, while at > 4 m depth, the cone resistance values, 50 – 100 kg/m<sup>2</sup> indicate medium dense to dense geologic material [16]. The CPT result here agrees with the VES within the same depth range, which denotes clayey sand with resistivity value of 96.7 Ωm (Fig. 14).

On traverse 4 is the CPT 2. A total depth of 6 m was penetrated similarly to CPT 1. The cone resistance values at this location progressively increases from 0 – 101 kg/m<sup>2</sup> (Fig. 13). These values as well are indications of incompetent very soft clay to soft clay near-surface at < 3 m depth with cone resistance value 0 – 35 kg/m<sup>2</sup>.

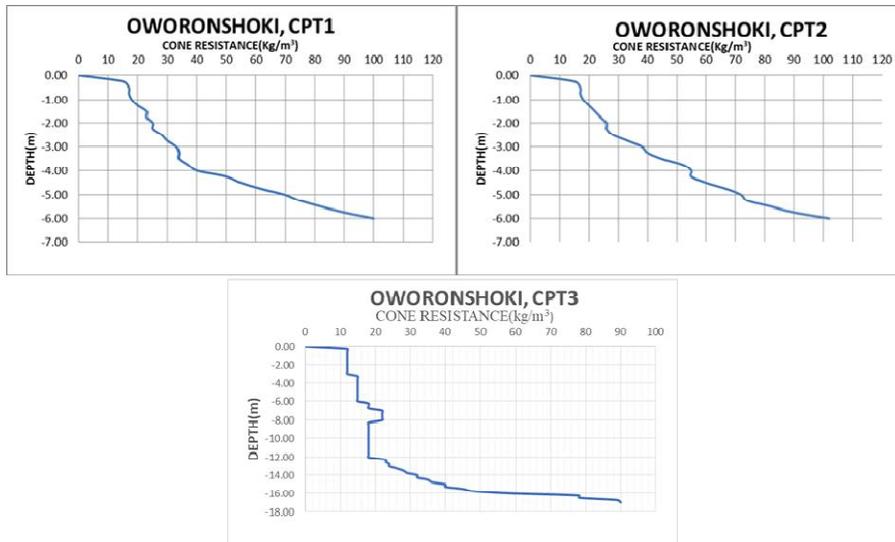


Fig. 13. CPT results along traverse 3, 4 and 5

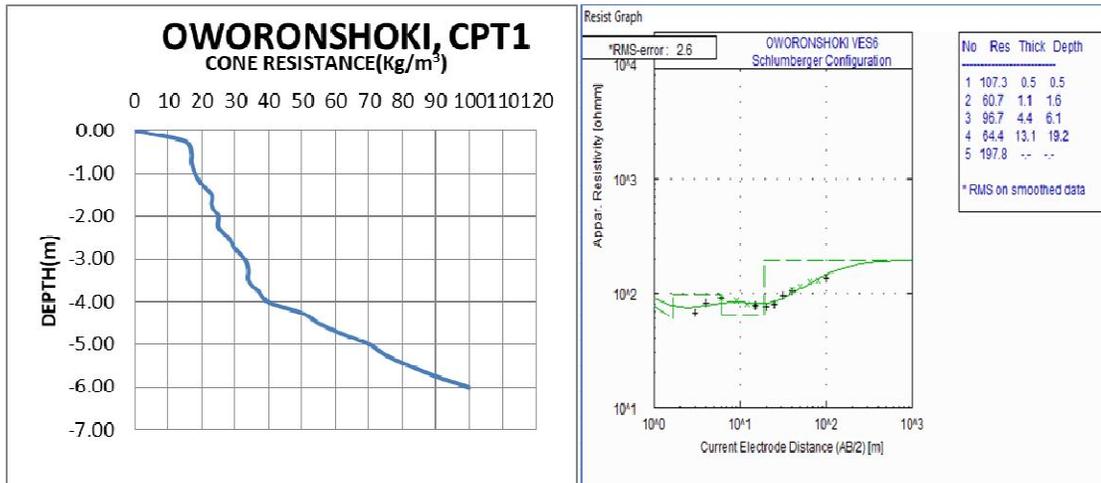


Fig. 14. CPT and VES 6 on traverse 3

On traverse 5 is CPT 3. A depth of 17 m was penetrated and the cone resistance values range from 0 – 90 kg/m<sup>2</sup>. The cone resistance values are fairly constant from the surface to a depth of 12 m at 10 - 22 kg/m<sup>2</sup> (Fig. 13). The values then increase gradually from 18 kg/m<sup>2</sup> to 90 kg/m<sup>2</sup>. The values indicate dense earth materials at deeper depth while at near surface, they are indications of the soft clayey earth materials (Fig. 13).

#### 4. CONCLUSION

Geophysical and Geotechnical methods were integrated to assess the immediate causes of persistent road pavement failure in Owaronshoki, Koshofe area of Lagos, Nigeria.

Six traverses were occupied in the study area along the alignment of the road. Traverse 1, 2, 3, 4 and 6 were laid on both sides of the road while traverse 5 was laid directly on the failed section of the road. 2D Electrical resistivity imaging (ERI) data using the Wernner array were acquired along the six traverses. These were followed by six (6) vertical electrical sounding (VES) data along the traverses. On traverse 1 are VES 1 and 2, on traverse 2 are VES 3 and 4, on traverse 3 are VES 5 and 6. One boring and three cone penetration testing (CPT) were also conducted in the study area. The boring was carried out along traverse 6 while the three CPTs were carried out on traverse 3, 4 and 5 respectively.

The 2D ERI results reveal lateral distances 200 & 100 m and corresponding imaged depths of 31.9 & 15.9 m along traverse 1 – 3 and traverse 4 – 6 respectively. The inverted 2D results reveal that resistivity values vary from 6.74 – 1333 Ωm in the study area. Four resistivity structures are delineated which are peat, clay/sandy clay, clayey sand and sand. The peat has resistivity values ranging from 6.74 – 17.7 Ωm, clay/sandy clay (20.9 – 86.9 Ωm), clayey sand (96.3 – 194 Ωm) and sand (245 – 1333 Ωm). The peat is laterally extensive and appears to occur from the surface to a depth of 25 m. The peat is underlain by the clay which is fairly extensive across the area of study with a thickness of 2.5 – 20 m in most location. The sandy clay and the sand are located deep in the subsurface and fairly extensive as well across the study area. The 1D VES results delineate five to six geoelectric layers which are the topsoil, clay, sandy clay, peat, clayey sand and sand. A maximum depth of 37.5 m is delineated and resistivity values vary

from 8.9 – 216.4 Ωm. The topsoil has resistivity and thickness values ranging from 94.8 – 139.9 Ωm and 0.5 – 0.7 m, clay (19.4 - 49.2 Ωm and 1.3 – 30 m), sandy clay (51.1 – 95.6 Ωm and 1.1 – 15.1 m), peat (8.9 Ωm and 30 m), clayey sand (87.6 – 103.1 Ωm and 4.4 – 18.6 m) and sand (197.8 – 216.4 Ωm and 4 – 8.9 m). The boring reveals a total BH depth of 45 m with six zones. The zones from the surface to 40 m depth are brown silty clayey sand, soft dark grey peaty clay, reddish silty sandy clay, dark grey organic silty clay, grey silty sandy clay (which are incompetent earth materials). Standard Penetration Tests (SPT) at 40, 43 and 45 m depths with corresponding N-values of 45, 39 and 39 reveal a dense to very dense reddish brown sand (that is medium to coarse) with occasional gravels from 40 – 45 m depth. The Cone Penetration Tests (CPT) reveal cone resistance values that progressively varies from 0 – 101 kg/m<sup>2</sup> from the surface to a depth of 17 m, indicating dense earth materials at deeper depth while at near surface, they are indications of the soft clayey earth materials.

Obviously, the results from the geophysical techniques have a good agreement with those from the geotechnical methods. The laterally extensive peat and the clay units underlying the road pavement and extends up 30 m depth as revealed from the 2D ERI, the geoelectric investigation and the Borehole are suspected to be responsible for the persistent failure of the road pavement by settlement, rutting and pitting in the study area. The thickness of the peat/clay and the lateral extent, which is rather high and long respectively, may not be economically admissible for excavation during construction. Raised pile foundations to the dense gravelly sand at 40 m depth along the stretch of the road is recommended for stable road pavement in the study area.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Adiat KAN, Akinlalu AA, Adegoye AA. Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. NRIAG Journal of Astronomy and Geophysics. 2017;6:244–255.

2. Ighodaro CAU. Transport infrastructure and economic growth in Nigeria. J. Res. National Dev; 2009;7(2).
3. Adegoke-Anthony WC, Agada AO. Geotechnical characteristics of some residual soils and their implications on road design in Nigeria. Technical Lecture, Lagos. 1980;1-16.
4. Ajayi LA. Thought on road failures in Nigeria. Nigerian Eng. 1987;22(1):10-17.
5. Mesida EA. The relationship between the geology and the lateritic engineering soils in the northern environs of Akure, Nigeria. Bull. Int. Assoc. Eng. Geol. 1987;35:65-69.
6. Momoh LO, Akintorinwa O, Olorunfemi MO. Geophysical investigation of highway failure – a case study from the basement complex terrain of southwestern Nigeria. J. Appl. Sci. Res. 2008;4(6):637-648.
7. Oladapo MI, Olorunfemi MO, Ojo JS. Geophysical investigation of road failures in the basement complex areas of southwestern Nigeria. Res. J. Appl. 2008;3(2):103-112.
8. Adiat KAN, Adelusi AO, Ayuk MA. Relevance of geophysics in road failures investigation in a typical basement complex of southwestern Nigeria. Pac. Jour. Sci. Tech. 2009;5(1):528-539.
9. Adeyemo IA, Omosuyi GO. Geophysical investigation of road pavement instability along part of akure-owo express way, Southwestern Nigeria. Am. J. Sci. Ind. Res. 2012;3 (4):191-197.
10. Mesida EA. Some Geotechnical properties of residual mica schist derived subgrade and fill materials in the ilesha area, Nigeria, No. 1986;33:14-17.
11. Adeleye AO. Geotechnical investigation of subgrade soil along sections of ibadan-ife highway, unpublished M.Sc. project, Obafemi Awolowo University, Ile-Ife. 2005;18:192.
12. Nelson RG, Haigh JH. Geophysical investigation of lateritic terrain. In: Ward, S.H. (Ed.), Geotechnical and Environmental Geophysics, Geotechnical, vol. 2. SEG, Tulsa. 1990:133-154.
13. Jones MA, Hockey RO. The geology of part of Southwestern Nigeria. Nig. Geol. Surv. Bull. 1964;31:101.
14. Kogbe CA. Geology of Nigeria, 2nd edition, Rock View (Nigeria) Ltd. 1989;59.
15. Loke MH, Barker RD. Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophysical Prospecting. 1996;44(1):131-152. DOI: 10.1111/gpr
16. Schmertmann JH. Discussion of deep sounding test results and the settlement of spread footings on normally consolidated sands. Geotechnique. 1969;19(2): 316-317.

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