Geophysical investigation of road failure along Lagos-Badagry expressway using electrical resistivity imaging

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Abstract. Geophysical investigations of road failure using Two-dimensional (2D) electrical resistivity imaging was carried out along Lagos – Badagry expressway, Lagos State, Nigeria with a view to determining the subsurface geological structures that may pose a danger to the highway. The study was conducted on five worrisome parts of the highway, namely: Iyana Isashi, Iyana Era, Agbara, Magbon and Oko Afo, using Constant Separation Traversing (Wenner array) to obtain three (3) profiles at each location. ABEM Terrameter SAS 1000 was used for the survey which displays apparent resistivity values digitally. The data was processed with the aid of the RES2DINV software to produce 2D images of the study area. The subsurface images showed that the resistivity lies between 3.89 Ωm and 401 Ωm, indicating variation in soil matrix. It was found that the causes of road pavement collapse on the road examined were the result of a mixture of clay topsoil/subgrade soils with resistance varying from 3.79 m to 83.3 m, waterlogged sands. This is due to ingress with characteristically low resistance values and a thin pavement, thus unable to withstand the lane's pressure.

Keywords: Road Failure, Electrical Resistivity, Geological structures, Imaging, Investigation

1. Introduction
Road failure is characterized as the inability of a typical road to provide its usable services by failing to provide a smooth running surface for vehicle operations [1]. It occurs when an asphalt surface no longer holds its original shape and develops material stresses capable of causing problems. Road failure problems include cracking, depressions, potholes, rutting, shoving, upheavals, and raveling. Flexible highways (i.e., strong and well-developed road interconnectivity) allow fast and seamless transportation of vehicles. They have become very useful for transporting persons, goods and services from one point to another, mainly in developing countries where other modes of transport such as rail, underground tube, air, and water transport systems have remained largely underdeveloped. However, many bad sections of the road were found to do more damage than good due to inadequate planning or being built on inept sub-grade and sub-base materials. They were blamed for several deadly crashes during traffic delays, breaking down cars, and losing precious time [2].
Many factors are responsible for road failures, including geological factors, geomorphological factors, geotechnical factors, road use, building, and maintenance practices [3, 4]. The geological factors affecting road collapses include the soil's condition and the near-surface geological series, the existence of geological formations such as fractures and faults, the existence of ancient stream channels, presence of cavities and shear zones[5, 6]. Topography and surface/surface drainage system are the geomorphological considerations. Other considerations considered by some researchers include: flawed infrastructure and poor road layout [7, 8]; inadequate maintenance [9, 10]; traffic consequences, and human impacts [11, 12]; geological collapse [13]; the occurrence of undetected structural properties, such as cracks and ground borders, and building of roads on a weathered base [14].

Road transport is an essential factor in every community's urban growth since it influences the construction path and scope. It also plays a crucial role in achieving national growth and contributes to its general success and social functioning. The existing circumstances on several of Nigeria's roads have raised different players' involvement in the use and protection of our highways. It has become a massive burden on federal, state, and municipal governments to rehabilitate the roadways. Despite numerous attempts at reconstruction, most stretches of our highways collapse indefinitely shortly after commissioning. Such recovery has been an ongoing affair and a tremendous financial strain on all levels of government. Any substantial amount of money allocated to the rebuilding and maintenance of roads in the country, overlaid with asphalt concrete to boost their resilience, could have been reduced if adequate geological and geophysical advice had been received before building such roads.

Geophysical researches provide the geotechnical knowledge needed in the infrastructure design to improve the strength and stability of the highways. The applications of such geophysical investigations are used for the determination of bedrock depth, structural mapping and evaluation of subsoil competence [15]. The use of electrical resistivity imaging to tackle a wide range of hydrological, environmental, and geotechnical issues is becoming increasingly widespread. Two-dimensional (2D) electrical resistivity imaging is also used to identify underwater cracks and cavities, geotechnical testing on buildings, highways, bridges, and dam building. The approach has proved to be a successful tool for detecting irregularities and determining subsurface geology complexity[16, 17]. The 2D visualization of electrical resistivity was used to explore areas of highly complex geologies.

Lagos has one of West Africa's largest and most robust road networks[18]. Still, roads in many state areas are typically in bad conditions, causing vehicle destruction, leading to dangerous traffic conditions, accidents, and travel time delays. The Lagos-Badagry expressway is known as the local name for the Trans-West African Coastal Highway portion of Nigeria. The failure of it bothers frequent users' minds as almost every segment of the road has failed to lose life and property, human injury due to collisions, and trouble transporting goods along the route. It is one of the popular highways in Lagos State. The 60.3 km expressway (from Eric Moore in Surulere to Badagry) is synonymous with potholes, depressions and cracks on both sides of the road [19].

The roads investigated in this study have protracted failure characteristics such as, potholes, cracks, depressions and water percolated channels. This failure becomes incessant despite previous rehabilitation efforts.
2. Materials and Methods

2.1 Description of the Study Area

The locations investigated are along Lagos-Badagry expressway, Lagos Nigeria. The road connects to some part of Ogun State (Agbara and Igbesa). It also connects Lagos, Nigeria with Republics of Benin, Togo, Ivory Coast, Dakar, Senegal and Ghana. The expressway can be linked from Ikeja through Oshodi – Apapa expressway at Mile 2.

2.2 Scope of the Study

The study was conducted on five spoilt parts of the highway as shown in Figure 1

![Fig 1. Map showing the locations](image)

2.3 The Study Area Geological Setting

The research area is along the expressway Lagos – Badagry and is based in Ojo and Badagry Local Governments, in the southwest region of Nigeria, within Lagos west. The research area's geographical environment shows that it sits entirely within the vast Dahomey basin, which stretches almost from Accra to Lagos. The region is underpinned by littoral and lagoon layers with recent sediments. The coastal belt extends from roughly 8 km towards the Republic of Benin's boundary to 24 km towards the eastern end of the Lagos lagoon[20]. The field is made up of clay soil, unconsolidated sands, and mud with a differing proportion of vegetable matter in the coastal areas, while the alluvial layer consists of coarse clay unsorted sand with clay lenses and small pebble beds [21]. The research field lies under the biological region of wetland soils and is situated on the coast where fresh water empties into the Atlantic. It has a deltaic base and tidal flats of volcanic origin.

2.4 Physiography and Climate of the Study Area

Lagos State is situated on the southwestern coast of Nigeria, roughly between 6022’N and 6052’N latitudes and 2042’E and 3042’E longitudes[22]. The Republic of Benin surrounds it on the west while the state's southern border is formed by the Atlantic coastline, 180 km long. It shares its eastern and northern borders with the State of Ogun. Lagos is Nigeria's largest city and geographically divided into two primary regional regions – the "Island" and the "Mainland" and was the country's capital until being replaced by Abuja on 12 December 1991. Lagos will remain Nigeria's commercial nerve center. Farming and fishing are the principal occupations of study area residents.
Two big seasons occur in the field of study. There are wet and dry seasons; there is a rainy season from April to July (heavy rain season) and from October to November (mild rain season). A very brief dry season takes place in August and September, and a long dry season spell occurs from December to March. The research region has a moist equatorial climate above 1800 mm with mean annual rainfall and faces an average yearly temperature of 27°C.

Due to harmattan, humidity is high throughout the rainy season and decreases to its lowest level throughout December but usually high and rarely below 70 percent. Marsh trees, wetlands, and coastal swamp forests comprise the plant cover, including freshwaters and mangroves. In general, the relief trend in the study region represents the State's coastal position. Water is the most significant topographical feature in the study region within the State of Lagos. Water and wetlands occupy more than 40 percent of Lagos State's total land area, and a further 12 percent is prone to seasonal flooding[23].

2.5 Data Acquisition Method

The four electrodes were symmetrically positioned along a straight line for field configurations in the electrical resistance method, the current electrodes on the outside, and the inside's potential electrodes. Both current and potential electrodes have been moved along a profile with constant spacing between the electrodes and progressively shifting the entire spread. A minimum of one person was required to handle each of the electrodes with its connecting cable and an additional person handled the recording equipment; thus making a five-man data collection crew for this survey. The electrode spread (Wenner array configuration) for data collection along the three profiles in each of the locations used electrode spacing of 10 m, 20 m, 30 m and 40 m, covering a length of 200 m was surveyed for each profile. Tthe ABEM Terrameter SAS 1000 was used during the field work. Three traverses parallel to the road segment were established at each location and had a length of 200 m each (Figure 2).

![Fig 2. Profile Orientation along Road Segment](image)

2.6 Data Processing

For the 2D method of resistivity, the raw field data is analyzed using Res2dinv. This is a window-based computer software that automatically calculates the 2D resistivity model for the data collected from the subsurface electrical survey. The forward modeling subroutine is applied in the calculation of the apparent resistivity values, and the inverse procedure depends on an iterative smoothness-constrained least-squares algorithm. The forward simulation subroutine is used to measure the apparent resistivity values, and an iterative smoothness-constrained least-square algorithm is used to construct the inverse method. The inversion method eliminates geometric effects from the false segment and provides a picture with true depth and actual resistivity. The algorithm produces a cross-
section of resistivity, measures the apparent resistivity for that cross-section, and contrasts the apparent resistivity determined with the apparent resistivity measured. The iteration proceeds until an objective function which is limited by combined smoothness is minimized.

3. Results and Discussion

The electrical resistance maps of the subsurface of the earth collected in the sample region are shown in Figure 3-7.

Fig 3a. Result of 2D inversion of profile 1 at Iyana Isashi

Fig 3b. Result of 2D inversion of profile 2 at Iyana Isashi
Three profiles were established at Iyana Isashi, and the results are shown in Figure 3a-3c. For profile 1 (Figure 3a), the lateral extent is 200 m. At the lateral distance of 15 m to 120 m, to a particular depth of 24.9 m, a formation of clayey sand was observed with resistivity value starting from 219 Ωm to 237 Ωm while clay settlement with resistivity slightly above 50 Ωm is confined within the sand from a depth of 2.5 m to 25 m at the lateral distance of 120 m to 160 m. At the lateral distance of 40 m to 90 m, to a depth of 30 m, a formation of sand was observed with resistivity value of 258 Ωm.

For profile 2 Figure (3b), at a lateral distance of 15 m to 40 m to the depth of 12.8 m from the surface, a formation of clayey sand was observed with resistivity value ranging from 188 Ωm to 205 Ωm. At the lateral distance of 80 m to 100 m to the depth of 18.5m from the surface, a formation of clay was observed with resistivity value from 50 Ωm to 100Ωm. At the lateral distance 110 m to 200 m to a depth of 24 m from the surface, a formation of sand was observed with resistivity value ranging from 132 Ωm to 144 Ωm, while a formation of clayey sand was observed at the depth of 31.9 m with resistivity of 205 Ωm.

Figure 3c shows profile 3 at Iyana Isashi. At a distance of 60 m to 140 m to a depth of 24.9 m, clayey sand was observed with resistivity value ranging from 227 Ωm to 248Ωm, while a formation of clay content was observed at a lateral distance of 160 m to 180 m, to a depth of 30 m from the surface with the resistivity value of 100 Ωm. From lateral distance of 40 m to 140 m to a depth of 24 m to 30 m, a formation of clayey sand was observed with the resistivity value of 254 Ωm.
Fig. 4a. Result of 2D inversion of profile 1 at Iyana Era

Fig 4b. Result of 2D inversion of profile 2 at Iyana Era
Figure 4a is profile 1 at Iyana Era. It depicts low resistivity value of 92.4 Ωm at a lateral distance of 80 m to 100 m to a depth of 25 m from the surface, indicating clay formation, while a formation of sand with resistivity value starting from 130 Ωm to 147 Ωm was observed between 40 m to 200 m along the profile to a particular depth of 24.9 m through the surface. A relatively low resistivity value from 166 Ωm to 212 Ωm was also noted from 90 m to 160 m at 25 m to 31.9 m depth.

Figure 4b is profile 2 at Iyana Era. This profile is dominated by dry clay, mud and sand from 40 m to 200 m at depth about 31.9 m from the surface with the resistivity ranging from 136 Ωm to 154 Ωm, but clay sediment is formed within the sand and mud at 80 m to about 105 m, along the profile at depth 18.5 m from the surface with the resistivity ranging from 92.7 Ωm to 120 Ωm. At 15 m to 40 m and from 80 m to 170 m on the profile at depth 2.5 m to 7.5 m and 31.9 m from the surface are characterized by relatively low resistivity, ranging from 175 Ωm to 227 Ωm. This was observed to be clayey sand formation.

Figure 4c is profile 3 at Iyana Era. At 15 m to 165 m along the profile from the surface up to 31.9 m depth is characterized by low resistivity, varying from 125 Ωm to 140 Ωm. Confined within this sandy clay formation, are clay formation with low resistivity value of 87.7 Ωm to 100 Ωm at lateral distance of 120 m to 130 m to a depth of 7.5 m from the surface and sandy and clayey sand with resistivity values ranging from 177 Ωm to 199 Ωm at 55; 158 Ωm at 90 m to 125 m respectively.
**Fig 5a.** Result of 2D inversion of profile 1 at Agbara

**Fig 5b.** Result of 2D inversion of profile 2 at Agbara
For profile 1 at Agbara (Figure 5a), there is low resistivity ranging from 3.52 Ωm to 11.3 Ωm at lateral distance of 80m to 120m to a particular depth of 24.9m from the surface. This was observed to be peat mixed with clay. A large formation of clayey sand is observed at the depth of 30 m to 31.9 m with resistivity from 116 Ωm to 287 Ωm, from 40 m to 160 m spread along the profile. Above this formation is a layer of relatively low resistivity.

Figure 5b is profile 2 at Agbara. From 120 m to 180 m spread and to a particular length of 24.9 m in depth via the surface, is a relatively low resistivity with value ranging from 110 Ωm to 116 Ωm. This could be as a result of clay compacted. From 40 m to 100 m lateral spread, is a zone of resistivity ranging from 159 Ωm to 186 Ωm. This was observed to be sandy clay formation. Confined within this zone, is a local zone of relatively low resistivity of 110 Ωm to 116 Ωm at 60 m to 80 m spread and to a depth of 7.5 m through the surface.

For profile 3 at Agbara (Figure 5c), the spread from 60 m to 120 m, from the surface to 18.5 m depth was characterized by resistivity in the range of 47.7 Ωm to 79.8 Ωm. This was observed to spread from 40m to 160 m from 34.9 m depth to 31.9 m with resistivity from 79.8 Ωm to 134 Ωm, indicating sandy clay. Within this zone, is a zone of a lower resistivity starting from 3.44 Ωm to 18.2 Ωm, from 80 m to 100 m spread and to a particular depth of 18.5 m via the surface. This was recorded to be peat mixed with clay. From 120m spread up to 180 m and to a depth of 24.9 m from the surface, is a zone of relatively low resistivity of 17.8 Ωm to 22.5 Ωm. This was also observed at 15 m to 55 m along the profile.

**Fig 5c.** Result of 2D inversion of profile 3 at Agbara
Fig 6a. Result of 2D inversion of profile 1 at Magbon

Fig 6b. Result of 2D inversion of profile 2 at Magbon
Figure 6a shows profile 1 at Magbon. It shows value of resistivity starting from 328 Ωm to 363 Ωm from the surface up to 31.9 m depth from 15 m to 100 m spread along the profile. This implies sand formation. Localized within this formation, is a zone of relatively low resistivity at 25 m to 38 m via the profile up to a particular depth of 10 m from the concerned surface. This was also observed from 145 m to 180 m along the profile. At 105 m to 145 m from the surface up to 31.9 m depth, is a zone of resistivity from 254 Ωm to 292 Ωm and confined within this is a zone of relatively low resistivity from the surface up to 12.8 m depth at 110 m to 130 m.

Figure 6b shows profile 2 at Magbon. A large section of the profile is characterized by resistivity ranging between 325 Ωm to 389 Ωm from 15 m to 200 m spread and to a depth of 7.5 m to 31.9 m. This implies sand formation. Within this formation, is a zone of relatively low resistivity varying between 208 Ωm and 297 Ωm at the surface from 70 m to 150 m spread through the profile and to 7.5 m in depth via the surface. This clayey sand formation was also observed at 31.9 m in depth at a spread of 50 m and 160 m.

For profile 3 at Magbon (Figure 6c), the spread from 70 m to 200 m, from the surface to 12.5 m depth was characterized by resistivity in the range of 29.2 Ωm to 74.5 Ωm. This was also observed at 15 m to 30 m through the profile to a particular depth of 12.5 m. This is as a result of clay settlements. Below this formation, is a zone of resistivity ranging from 119 Ωm to 151 Ωm at 12 m depth to 31.9 m, spreading from 90 m to 120 m along the profile. This was as a result of sandy clay formation. From 40 m to 65 m along the profile, there is also a zone characterized by relatively low resistivity of 94.2 Ωm.
Fig 7a. Result of 2D inversion of profile 1 at Oko Afo

Fig 7b. Result of 2D inversion of profile 2 at Oko Afo
Figure 7a is profile 1 at Oko Afo. In this profile, is a zone of low resistivity ranging from 3.79 Ωm to 7.83 Ωm, from 40 m to 60 m spread and to a particular depth of 15m via the surface. This was observed to be peat mixed with clay. Below this is a zone of resistivity from 155 Ωm to 287 Ωm from a depth of 24.9 m to 31.9 m. This clayey sand formation was observed to have spread from 40 m to 90 m along the profile. From 90 m to 130 m along the profile and to a depth of 18.5 m, is a zone of resistivity of 83.3Ωm. This clay formation was also observed to have spread narrowly to 31.9 m depth. The same trend was observed from 160 m to 200 m through the profile to a particular depth of 12.8 m.

Figure 7b is profile 2 at Oko Afo. Most part of this profile is characterized by relatively low resistivity, starting from 97.2 Ωm to 151 Ωm and was observed to be sandy clay formation. This has spread from 15 m to 110 m along the profile and was observed to have stretched to 160 m along the profile from 24.9 m to 31.9 m depth. In this profile, there is also a zone of lower resistivity starting from 6.92 Ωm to 40.3 Ωm, from 150 m to 175 m spread and to a depth of 24.9 m via the surface. This was observed to be clay settlements. From 110 m to 150 m through the profile and to a depth of 18.5 m, is a zone of resistivity of 62.6 Ωm.

Figure 7c is profile 3 at Oko Afo. The spread from 70 m to 200 m, from the surface to 7.5 m depth was characterized by resistivity in the range of 169 Ωm to 226 Ωm. This deposition of sandy clay was also observed at a depth of 12 m, at 15 m to 30 m along the line. Below this formation is a zone of resistivity ranging from 261 Ωm to 281 Ωm at 12 m depth to 31.9 m, spreading from 90 m to 160 m along the profile. This was as a result of clayey sand formation. From 40 m to 65 m along the profile, there is also a zone characterized by relatively low resistivity of 243 Ωm.

Conclusion

The average value of apparent resistivity of the entire study location is 231.92 Ωm. This value characteristically placed the study areas in a sedimentary basin which is in agreement with the general geology of the area. Wet soils and the new groundwater have lower levels of resistivity. Usually, Clayey soil has a lower resistivity factor than sandy soil. This is because a single rock or soil sample's
resistivity depends on a variety of factors, such as porosity, degree of water saturation, and dissolved salt concentration.

In this work, geophysical investigation of Lagos-Badagry highway has been carried out as a means of establishing the geological factors that may have influenced the constant failure of the highway. Results from the study identified the possible causes of the expressway failure in the study area to include poor sub-graded materials and water-lodge sand which resulted in major cracks and unable to withstand heavy traffic plying this particular road. The presence of clay soil has contributed to the failure witnessed on the road. Clay has the ability of absorbing water which makes them swell and fail under the action of stress (movement of heavy vehicles). Other factors, like poor drainage pattern for runoff at the two sides of the road pavement could have also contributed to the failure.

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