E-ISSN : 2541-5794
P-ISSN :2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 4 No 4 2019

RESEARCH ARTICLE

Integrated Approach in Geophysical Investigation of Road Failure in Crystalline Basement Environment in South-western Part of Nigeria.

Olabanji Ojo[1]*, Victor Adejumo[2], Obaromi Olubunmi[2]

[1]*Department of Geological Sciences, Osun State University, Osogbo, Osun State, Nigeria.*
[2]*Zibronel Geosciences, Akure, Ondo State, Nigeria*

* Corresponding author : adeolu.ojo@uniosun.edu.ng
Tel.:+2348035626912. LinkedIn: OlabanjiOjo.
Received: Oct 1, 2016. Accepted: Nov 20, 2019.
DOI: 10.25299/jgeet.2019.4.4.2590

Abstract

The result of the geophysical investigation carried out to access the cause of road failure and remediation measures along Ilesha-Osogbo expressway, Osun State, South-western Nigeria is presented. The study involved integrating the dipole-dipole technique of electrical resistivity method with the ground penetrating radar (GPR) method. Two dipole-dipole traverses, one long and 20 short GPR profiles were established across the failed section of the road. The dipole-dipole data were interpreted using the Diprowin software to produce the pseudo-section while the GPR data were interpreted using the RadProwin to produce the radargram. The result revealed that the failed road exhibit incompetent layer of resistivity values ranging between 17 Ωm to 171 Ωm lying between two competent layers of resistivity values greater than 200 Ωm. A combination of the dipole-dipole technique and the GPR techniques revealed the depth extend to failure to about 4.5 meters to 5 meters deep which overlie a basement rock of undifferentiated gneiss, a rock that is easily prone to weathering. The water level was observed to occur at shallow depth of about 2 meters and infiltrates the entire weathered layer. The shallow groundwater level coupled with the water-logged clayey layer derived from the weathered materials from basement rock were found responsible for the failure of this section of the road. The study recommends the excavation of the waterlogged clayey layer to a depth of about 5 to 6 meters deep into the subsurface and replacement first with heavy boulders of granitic materials and later overlaid with a thick layer of highly resistive landfill materials such as laterite. The result of the two techniques used in this work have proved to be supportive due to the integration of the double dipole technique with the GPR technique, a relatively new technique recently being introduced into road failure mapping.

Keywords: Geophysical, road, failure, Idominasi, groundwater, clay

1. Introduction

Failed roads generally constitute one of the major challenges to transportation especially in most developing nations of the world. It has been described as next to power supply in Nigeria (Ifabiyi and Kekere, 2013) and has been a major setback to growth and development other countries. Not only has it causes deaths of several thousands of people worldwide, it has also resulted to loss of properties worth millions of dollars annually. A greater percentage of developing nations are located in Africa and Asia. In Nigeria, this challenge is beginning to gain government attention due to concerted effort towards to putting an end to this menace. Reports show that out of 192 countries of the world, Nigeria rank 191 (FRSC, 2011) in terms of unsafe roads. Hence, death toll due to road crashes has been put at 162 deaths per 10,000 populations. Road failures in Nigeria come in form of bulges, potholes, cracks and depression, all of which makes road non-pliable for road uses who are involved in day to day delivery of goods and services. Governments at all the three tiers of government are coming up with concerted effort towards resolving these situations in the country.

Roads in Nigeria has been classified into three. These include trunk A road which are highways that link state capitals together or dual carriage ways that link one part of the country to another. They constitute about 17% of the total national road network and the management of these types of road has been the responsibility of the federal government. The second, the trunk B roads which are intra-state roads which are managed by state governments constitute about 16% of the total road network of Nigeria (Ebhohimen and Luke, 2014) while the third, trunk C roads are locally constructed road that link the local communities together and serve the purpose of means of transportation for rural dwellers to move locally made goods and services from the rural area to urban markets. They constitute about 67% of the total road network in the nation.

These types of roads are under the management of the third tier of the government, the local governments. The construction and ultimate maintenance of all Nigerian roads are sole responsibilities of these three tiers of government in Nigeria. Most of these roads do fail while construction is ongoing stage and also after the completion of the project. Investigation indicated that lapses exists at the design and construction level. It is unfortunate to note that most contractors fail to take into consideration a number of factors during the design and construction of roads.

These include geologic factors such as nature of soil and the near-surface geologic sequence, existence of geological structures such as fractures and fault, presence of cavities, existence of an ancient stream channels and shear zones. These concealed subsurface structures and zones of weakness are controlled by regional fractures and joint systems and in conjunction with leaching of silica could result in rock deficiency are known to contribute to failure of highways and rail tracks (Nelson and Haigh, 1990).

Geomorphological factors have been related with the relief and surface/subsurface drainage systems which can be mapped by a combination of two or more geophysical and geotechnical methods (Olorunfemi *et al.*, 1986; Olorunfemi and Mesida, 1987; Ojo and Olorunfemi, 1995). Biological factor such as the presence of surficial materials such as buried organics within the subsurface especially in locally made roads. Adegoke-Anthony and Agada (1980) as well as Ajayi, (1987) observed that road failure usually prevalent in basement complex of Nigeria are not only attributed to the design, construction and usage of the roads alone but also to lack of understanding of the role of the influence of geomorphology and geology during the design and construction phases. It also has to do with inadequate knowledge characteristic nature of residual soils underlying the roads.

As a result, some roads are not capable to withstand stresses. Highway and road failure have become most noticeable almost all parts of Nigeria especially in the Western part of Nigeria seating on soils derived weathered materials from the migmatized and unmigmatized granite, schist, and rocks of the Pre-Cambrian Basement complex rocks. It is also prevalent in the Eastern part of the country sited in fairly competent and incompetent subsurface earth materials where intense erosion has washed away. This has serious obstructions and have been constituting serious economic setbacks to communities where they occur.

The present study desire to integrate the use of electromagnetic method and electrical method in geophysics using the ground penetrating radar (GPR) and the dipole-dipole array spread to unravel the causes, characteristic nature of road failure in Idominasi community, along Ilesha-Osogbo expressway and to proffer a solution to the way out of the problem associated with the failed portion of the road. This community lies within the crystalline basement complex of south western Nigeria. This is necessary because it is the only road that links the state capital, Osogbo with the industrialized Ilesha Township.

The road is a very important commercial pathway that links the economy of these two communities. The integration of these two methods becomes very necessary because the GPR technique would provide detail information depth to the failure, cause of the failure and the internal stratigraphy of the studied area. The dipole-dipole survey of the other hand would provide information about the resistivity variation of the subsurface rock of the study area. The results from these two methods would provide comprehensive information that is needed for tangible conclusions about the nature, the extent as well as probable remediation techniques needed in this failed portion of Ilesha Osogbo expressway.

2. Location and Accessibility of the Study Area

The study area, Idominasi, lies between Ilesha and Osogbo, two major towns in Osun state approximately between latitude 4° 40’E and 4°45’Eand between latitudes 7° 40’N and 7° 44’N north of the equator. The study area is surrounded by the following villages: Ijowa, Ibala, Iragun and Ipoye.

Geologically, the study area is part of the Ilesha Schist belts in South western Nigeria. Rocks within the area include undifferentiated gneiss, granite gneiss andbanded gneiss (See Figure 1). Structurally, the area is divided into two; the Iwaraja faults to the eastern and Ifewara to the western part (Folami, 1992, Elueze, 1988). To the west of the fault is mostly amphibolites, amphibole schist, meta-ultramafites, and meta-pelites while to the east are units with minor meta-pelite, a major component of quartzites and quartz schist. Olusegun *et al.*,(1995) and Rahaman, (976) observed that “these entire assemblages are associated with migmatitic gneisses and are cut by a variety of granitic bodies”.

The local geology of the study area is typical of the basement complex rock assemblage broadly grouped into gneiss-migmatite complex, mafic-ultramafic suite (or amphibolite complex), intrusive suite of granitic rocks and meta-sedimentary assemblages. A variety of minor rock types are also related to these units. The study area is made accessible by a network of roads that runs from Ilesha to Osogbo. Another road joins the expressway from Idominasi township. A major river (River Ora) running

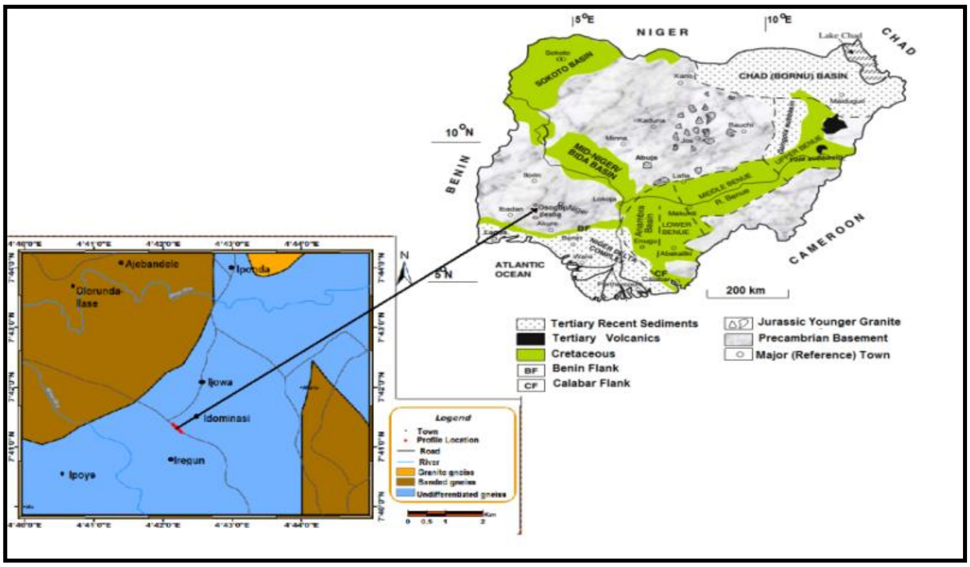


Fig. 2: GPR Profile Orientations along and across the failed portion of the Road

from east to the west and meandering southwards drains the entire area under study. Smaller river channels in the study area drains into River Ora.

This study area possesses is a typical tropical climate having more wet season months than the dry season months. The wet season commences in April till October while thedry season commences from November to March. The Köppen-Geiger climate classification consider the climate around the study area as Aw. The average annual temperature in Ilesa is 25.6 °C. The average annual rainfall is 1317 mm. The least amount of rainfall occurs in January but precipitation reaches its peak every September with an average of 222 mm. On the average, the highest temperature is about 28.6 °C around March while the coldest month is about 23.9 °C on average around August every year.

3. Materials and Methods

The ground penetrating radar (GPR) GSSI SIR 3000 monostatic equipment and the ABEM SAS 1000 resistivity meter were used for the exercise. Initial reconnaissance survey was carried out to map the geology and study the topographic layout of the studied area. This is followed by the establishment of a long traverse along the failed road using the global positioning system (GPS). Two dipole-dipole method of electrical resistivity technique were carried out along the failed portion of the road using ABEM SAS 1000 resistivity meter (terrameter). Results from this were interpreted using the Diprowin software to produce two pseudo-sections along the failed portion of the road. Zones of highly resistivity and low resistivity as well as depth to failure were identified from the pseudo-section. Also the electromagnetic wave was beamed into the subsurface using the (GPR SIR 3000) in order to view the subsurface depth extent to failure.

The beginning and the end of the traverse were properly georeferenced. The GPR instruments was used to make 20 parallel traverses across the failed portion of the road. The operation was carried out using the geologic scan preset parameters configured into the TerraSirch mode as shown; T-Rate = 100, Rate = 80, Range = max, Gain = 5 point auto, Survey wheel calibration = 1024 sample per scan), frequency = 400 MHz, Collection mode = distance, sample per scan format = 16 bit (default).Radargram obtained from these activities were interpreted for the possible cause to road failure, depth to road failure, stratigraphy of the study area. The depth to water level and mud were computed from the analysis and subsequently used to construct a 3D model of the depth to ground water and depth to weathered layer/basement interface. Results from the two techniques were compared and inferences from these were used to proffer solution towards remediating the problem.

4. Results and Discussions

Figure 2 shows the GPR profile orientations along failed road segment while Figure 3 shows the pseudo-section obtained using the dipole-dipole electrical method. Figure 4 to 15 shows the radargram obtained from GPR profiles. Figure 16 and 17 is the pictorial situation of the failed portion of the road.

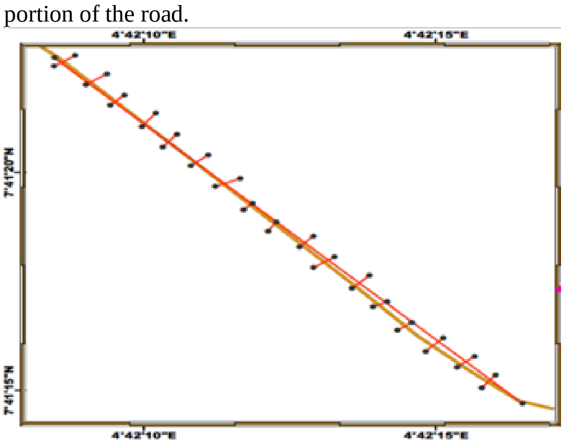


Fig. 2: GPR Profile Orientations along and across the failed portion of the Road

The results obtained from the dipole-dipole investigation reveals that the first part of the road is relatively stable (indicated in red colour in Figure 3) around Idominasi junction but progressively becomes unstable towards the south eastern direction (indicated in blue colour). This is exemplified by the low resistivity values obtained within the middle portion of the traverse.

The earlier part is underlain with thick lateritic material of about 20 meters' thickness with rubble of unweathered quartzite having resistivity values of between 325 Ωm and 621 Ωm. As the profile continues, failure begins to be prominent and the resistivity begin to reduce to as low as between 17 Ωm to 46 Ωm (Figure 3)

The 2-D resistivity pseudosection reveals relatively low resistivity values in the range of 46 and 69 Ωm at a depth range between 0.6 and 5.0 m typical of clay material. The extent of the failure is prominent at the top 5 m while, the failure reduces gradually at relatively deeper depth. However, at about 10 m depth, the effect was not noticeable. As shown in Figure 3, the depth to failure is about 2 m deep while beyond this depth, there seem to be a relatively competent layer underlying the muddy interval.

Stratigraphically, the area under investigation is underlain by clay to a depth of about 4 m to 44 m and basement below the strata. Within the failed portion, the entire basement is almost weathered and almost lacking as the resistivity is as low as 17-117 Ωm. About 20 short GPR profiles were established during the course of the survey with the aim of revealing the water level, subsurface stratigraphy and the disturbed layer. Analysis of the GPR profiles (Figures 4-15) reveal that the cause of the failed portion of the road is the closeness of the water level to the surface coupled with the low resistivity clay material. This extends to a depth of about 0 to 4.5 or 5 meters.

This result is similar to that obtained using the dipole-dipole technique. The material that constitute the overburden is rich in clay and varies in thickness from about 4 – 5 meters. The depth to the water level also varies from 1.40 meters in Figure 4 to 2.0 m in Figure 5. This result is also confirmed in the dipole-dipole that was run in the area which reveals the depth of 4.5 to 5 meters to the incompetent less resistive layer having resistivity values of 46 and 89 Ωm in Figure 4 and resistivity values of 14 and 171 Ωm in Figure 5. This observation is also obtained in Figures 6 to 15.

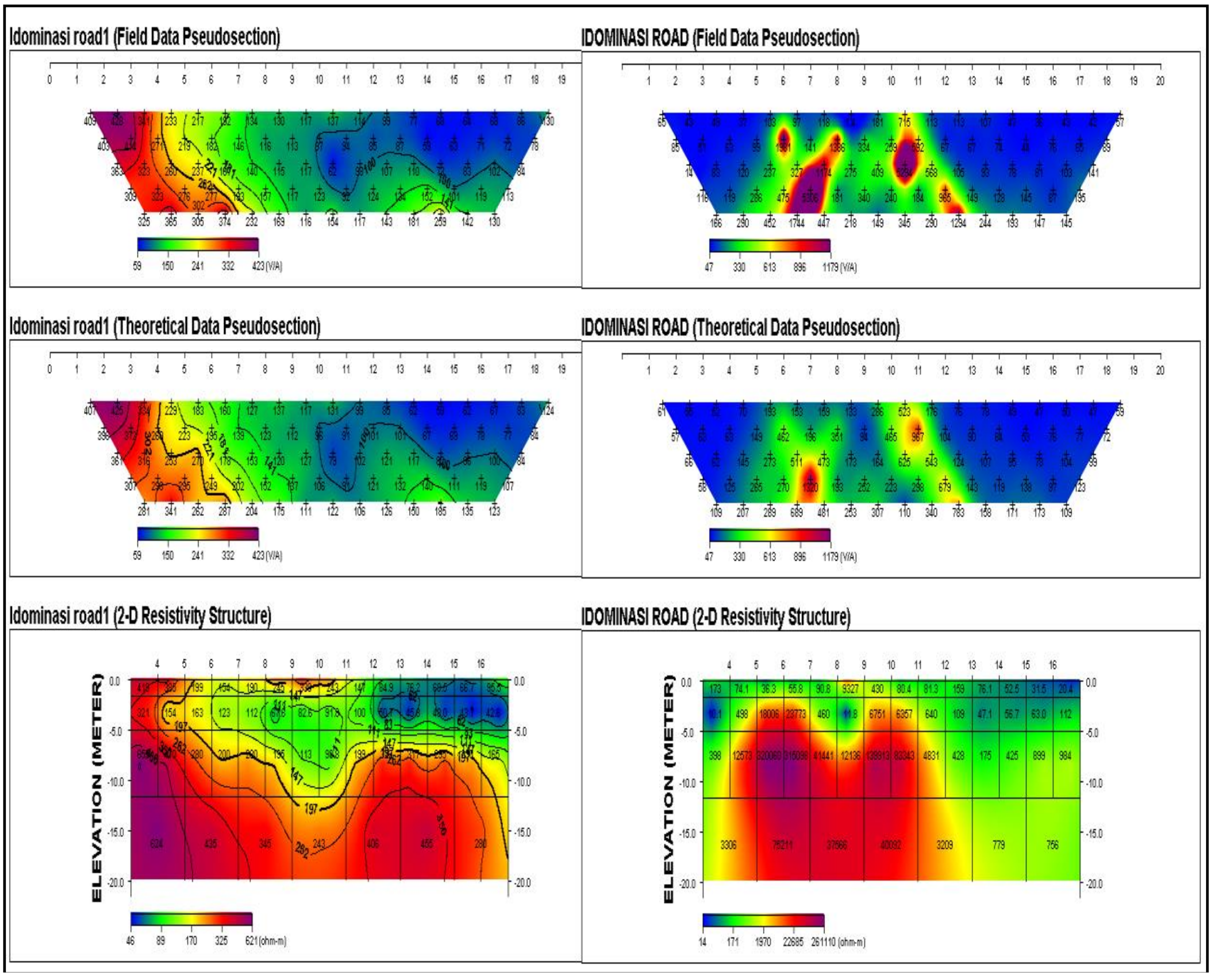


Fig. 3: Pseudosection of the failed portion of the from North to South.
(Red = competent highly resistive layer; Blue = low resistivity incompetent failed portion)

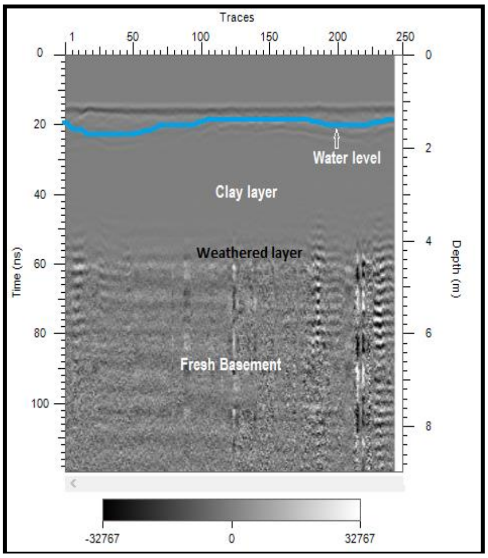


Fig. 4: GPR Radargram for Profile 1

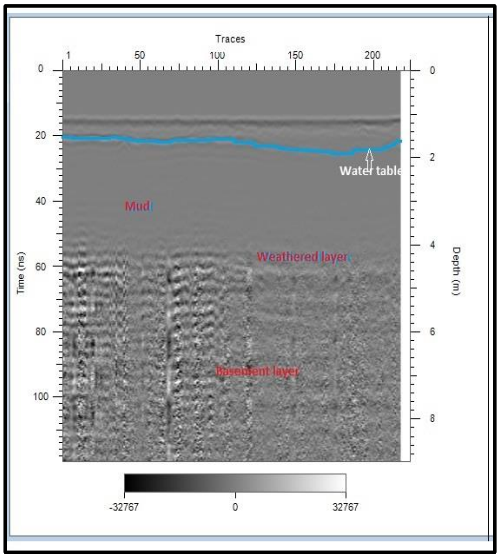


Fig. 5: GPR Radargram Profile 2

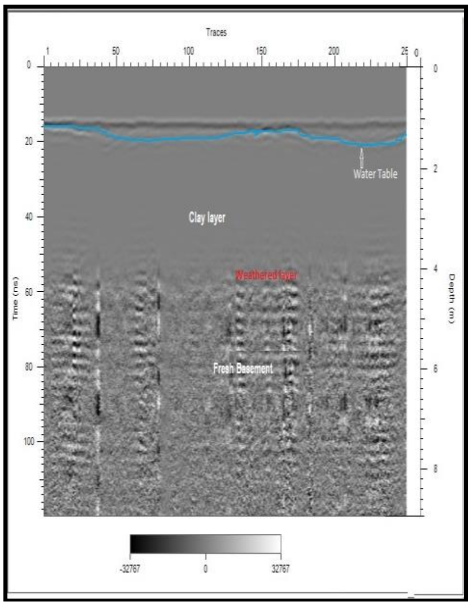
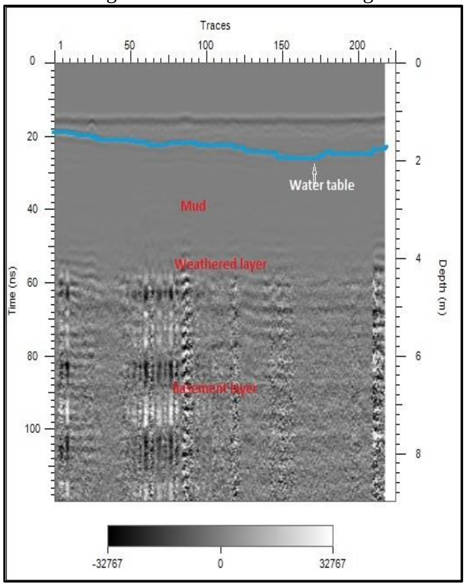


Fig 6: GPR Profile Traverse 3Fig



7: GPR Profile Traverse 4

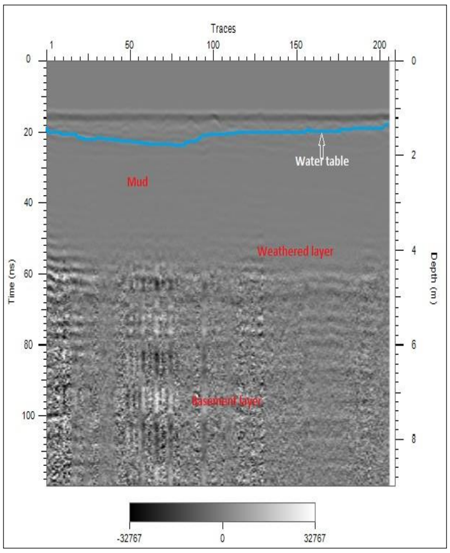


Fig 8: GPR Profile Traverse 5

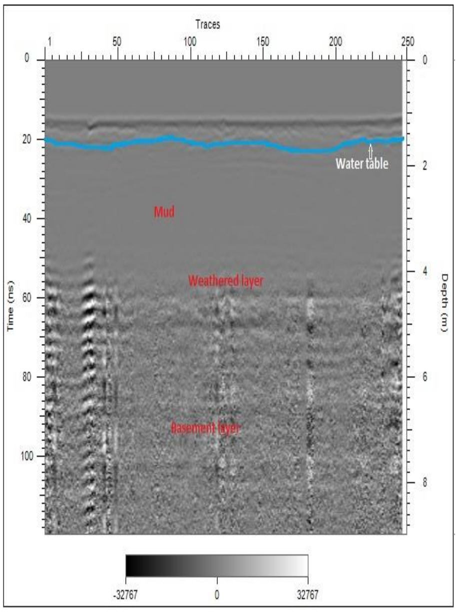


Fig 9: GPR Profile Traverse 6

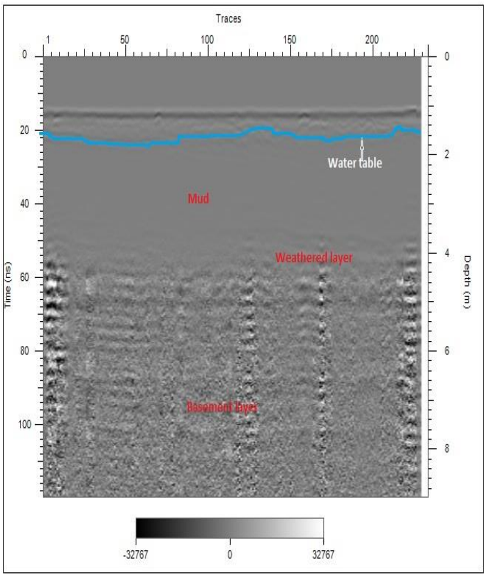


Fig 10: GPR Profile Traverse 7

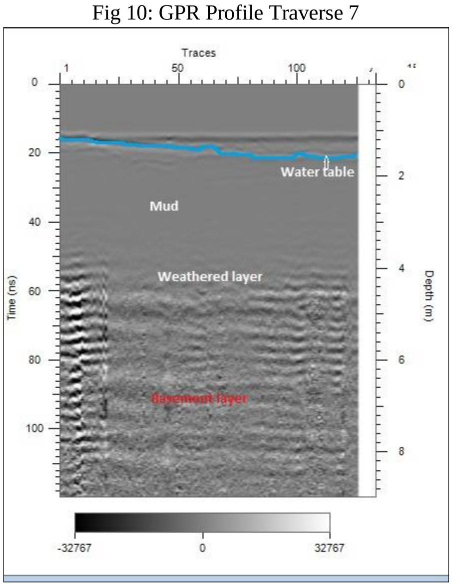


Fig 11: GPR Profile Traverse 8

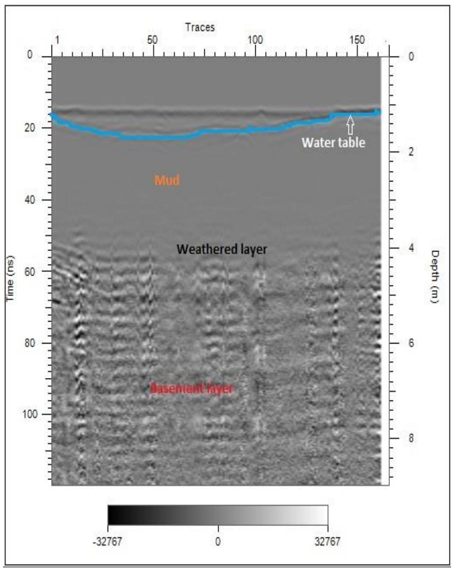


Fig 12: GPR Profile Traverse 9

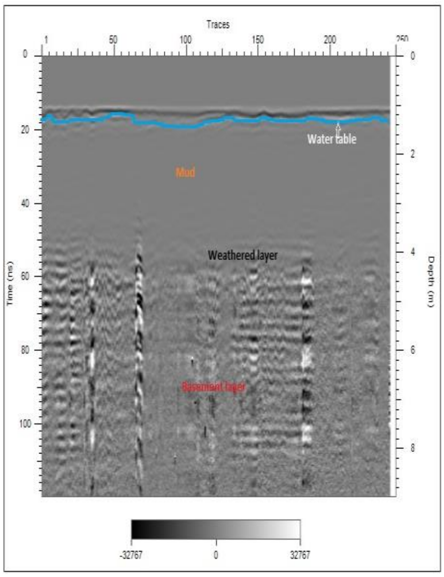


Fig 13: GPR Profile Traverse 10

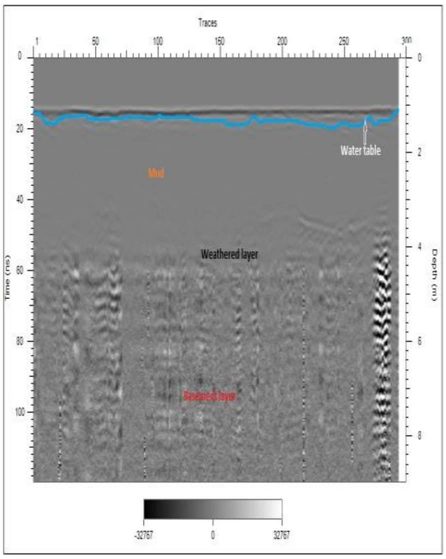


Fig 14: GPR Profile Traverse 11

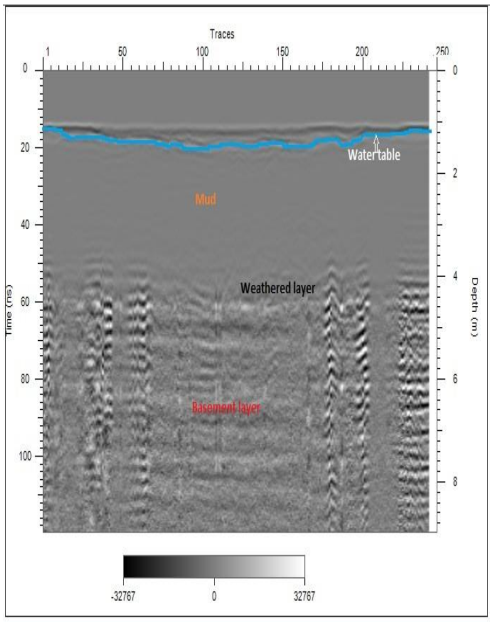


Fig 15: GPR Profile Traverse 12

Figure 16 and 17 shows the ongoing geophysical investigation using the GPR instrument as well as the dipole-dipole electrical resistivity instrument respectively.

Figure 16: Picture of the failed portion of the road and investigation using the GPR instrument

Figure 17: Picture showing ongoing dipole-dipole geophysical survey on the failed portion of the road

Table 1: Table showing First Dipole-Dipole Array Field Data

TRAVERSE ONE RESISTIVITY FIELD RECORD (DIPOLE-DIPOLE ARRAY)			
Date:			Observer:
Instrument Used: ABEM SAS 1000 terrameter			Traverse Azimuth
Traverse No. One (1)			Electrode Spacing: 5
Site Description:			Number of n = 5
Electrode Position C1 C2 P1 P2	Geometric Factor (K)	Resistance R (Ω)	Apparent Resistivity (Ω)
0 1 2 3	94.2478	4.3446	409
3 4	376.9911	1.0698	403
4 5	942.4778	0.38497	363
5 6	1884.9556	0.16367	309
6 7	3298.6723	0.098464	325
1 2 3 4	94.2478	4.5423	428
4 5	376.9911	1.0976	414
5 6	942.4778	0.34256	323
6 7	1884.9556	0.17121	323
7 8	3298.6723	0.11068	365
2 3 4 5	94.2478	3.6199	341
5 6	376.9911	0.71980	271
6 7	942.4778	0.27639	260
7 8	1884.9556	0.14664	276
8 9	3298.6723	0.092391	305
3 4 5 6	94.2478	2.4770	233
6 7	376.9911	0.58185	219
7 8	942.4778	0.25172	237
8 9	1884.9556	0.14695	277
9 10	3298.6723	0.11324	374
4 5 6 7	94.2478	2.3010	217
7 8	376.9911	0.48245	182
8 9	942.4778	0.17720	167
9 10	1884.9556	0.10213	193
10 11	3298.6723	0.070471	232
5 6 7 8	94.2478	2.0330	192
8 9	376.9911	0.38671	146
9 10	942.4778	0.14869	140
10 11	1884.9556	0.083077	157
11 12	3298.6723	0.051189	169
6 7 8 9	94.2478	1.4265	134
9 10	376.9911	0.30677	116
10 11	942.4778	0.12170	115
11 12	1884.9556	0.062223	117
12 13	3298.6723	0.035221	116
7 8 9 10	94.2478	1.3773	130
10 11	376.9911	0.30058	113
11 12	942.4778	0.12363	117
12 13	1884.9556	0.065282	123
13 14	3298.6723	0.046602	154
8 9 10 11	94.2478	1.2367	117
11 12	376.9911	0.25734	97
12 13	942.4778	0.065953	62
13 14	1884.9556	0.048762	92
14 15	3298.6723	0.035587	117
9 10 11 12	94.2478	1.45220	137
12 13	376.9911	0.25038	94
13 14	942.4778	0.10360	98
14 15	1884.9556	0.065972	124
15 16	3298.6723	0.043294	143
10 11 12 13	94.2478	1.2113	114
13 14	376.9911	0.22586	85
14 15	942.4778	0.11383	107
15 16	1884.9556	0.071055	134
16 17	3298.6723	0.054921	181
11 12 13 14	94.2478	1.0519	99
14 15	376.9911	0.22983	87
15 16	942.4778	0.11715	110
16 17	1884.9556	0.080555	152
17 18	3298.6723	0.07866	259
12 13 14 15	94.2478	0.81797	77
15 16	376.9911	0.15770	59
16 17	942.4778	0.077111	73
17 18	1884.9556	0.053673	101
18 19	3298.6723	0.043151	142
13 14 15 16	94.2478	0.72319	68
16 17	376.9911	0.16589	63
17 18	942.4778	0.087615	83
18 19	1884.9556	0.063142	119
19 20	3298.6723	0.039343	130
14 15 16 17	94.2478	0.67862	64
17 18	376.9911	0.18749	71
18 19	942.4778	0.10817	102
19 20	1884.9556	0.060088	113
20 21	3298.6723		
15 16 17 18	94.2478	0.71850	68
18 19	376.9911	0.19061	72
19 20	942.4778	0.089627	84
20 21	1884.9556		
21 22	3298.6723		
16 17 18 19	94.2478	0.91152	86
19 20	376.9911	0.20725	78
20 21	942.4778		
21 22	1884.9556		
22 23	3298.6723		
17 18 19 20	94.2478	1.3760	130
20 21	376.9911		
21 22	942.4778		
22 23	1884.9556		
23 24	3298.6723		

Table 2: Table showing Second Dipole-Dipole Array Field Data

TRAVERSE TWO RESISTIVITY FIELD RECORD (DIPOLE-DIPOLE ARRAY)			
Date:			Observer:
Instrument Used: ABEM SAS 1000 terrameter			Traverse Azimuth
Traverse No. Two (2)			Electrode Spacing: 5
Site Description:			Number of n = 5
Electrode Position C1 C2 P1 P2	Geometric Factor (G)	Resistance R (Ω ohm)	Apparent Resistivity (Ω ohm)
0 1 2 3	94.2478	0.69290	65
3 4	376.9911	0.22664	85
4 5	942.4778	0.014776	14
5 6	1884.9556	0.061431	116
6 7	3298.6723	0.050204	167
1 2 3 4	94.2478	0.45880	43
4 5	376.9911	0.13538	51
5 6	942.4778	0.087540	83
6 7	1884.9556	0.063269	119
7 8	3298.6723	0.088032	290
2 3 4 5	94.2478	0.51966	49
5 6	376.9911	0.16736	63
6 7	942.4778	0.12739	120
7 8	1884.9556	0.15163	286
8 9	3298.6723	0.13716	452
3 4 5 6	94.2478	0.39549	37
6 7	376.9911	0.26276	99
7 8	942.4778	0.25160	237
8 9	1884.9556	0.25199	475
9 10	3298.6723	0.52869	1744
4 5 6 7	94.2478	1.0900	103
7 8	376.9911	5.2541	1981
8 9	942.4778	0.34672	327
9 10	1884.9556	2.8150	5306
10 11	3298.6723	0.13563	447
5 6 7 8	94.2478	1.0305	97.1
8 9	376.9911	0.37437	141
9 10	942.4778	1.2457	1174
10 11	1884.9556	0.096081	181
11 12	3298.6723	0.066031	218
6 7 8 9	94.2478	1.2515	118
9 10	376.9911	3.6771	1386
10 11	942.4778	0.29211	275
11 12	1884.9556	0.18016	339.6
12 13	3298.6723	0.045060	149
7 8 9 10	94.2478	0.014504	1.41
10 11	376.9911	0.88606	334
11 12	942.4778	0.43357	409
12 13	1884.9556	0.12729	239.9
13 14	3298.6723	0.10456	345
8 9 10 11	94.2478	1.9173	181
11 12	376.9911	0.68693	259
12 13	942.4778	5.6166	5294
13 14	1884.9556	0.097445	184
14 15	3298.6723	0.088045	290
9 10 11 12	94.2478	7.5819	715
12 13	376.9911	1.5697	592
13 14	942.4778	0.60218	568
14 15	1884.9556	0.51181	965
15 16	3298.6723	0.39240	1294
10 11 12 13	94.2478	1.1978	113
13 14	376.9911	0.17760	67
14 15	942.4778	0.11088	105
15 16	1884.9556	0.079292	149

16 17	3298.6723	0.074019	244
1112 13 14	94.2478	0.34964	113
14 15	376.9911	0.17750	67
15 16	942.4778	0.098327	93
16 17	1884.9556	0.068025	128
17 18	3298.6723	0.058611	193
1213 14 15	94.2478	1.1306	107
15 16	376.9911	0.19492	73.5
16 17	942.4778	0.083223	78
17 18	1884.9556	0.077026	145
18 19	3298.6723	0.044675	147
1314 15 16	94.2478	0.49428	47
16 17	376.9911	0.11667	44
17 18	942.4778	0.085506	81
18 19	1884.9556	0.046120	87
19 20	3298.6723	0.043888	145
1415 16 17	94.2478	0.38620	36
17 18	376.9911	0.20279	76
18 19	942.4778	0.10907	103
19 20	1884.9556	0.10323	195
20 21	3298.6723		
1516 17 18	94.2478	0.45114	43
18 19	376.9911	0.17232	65
19 20	942.4778	0.15002	141
20 21	1884.9556		
21 22	3298.6723		
1617 18 19	94.2478	0.44504	42
19 20	376.9911	0.23666	89
20 21	942.4778		
21 22	1884.9556		
22 23	3298.6723		
1718 19 20	94.2478	0.60064	57
20 21	376.9911		
21 22	942.4778		
22 23	1884.9556		
23 24	3298.6723		

Highway structures constructed on top of subgrade soils are supposed to be strong enough to support heavy loads on them. (Momoh, *et. al.,* 2008) observed that subgrade soils underlying a stable highway should possess highly resistive and sufficient geotechnical strength to withstand stress. Such soil must have good drainage and permeability characteristics and not shrink or swell excessively (Adeleye, 2005, Oladapo, 1998).

However, the result obtained from this work does not conform to the ideal due to the fact that the soil underlying the study area has been affected by the presence of water such that they could shrink and swell at any time. Probably, the study area is underlain by typical expansive clay materials. The stable segment which also falls within the earlier part within the first pseudo-section is underlain by weathered basement that is not waterlogged.

Hence, there exist no failure in this segment and this segment is devoid of any geological features or structures that could aid and abet failure. The top soil and the subgrade soil here is purely lateritic with a significant thickness of about 20 meters. This means this area is thick enough to support any impose wheel load. As the traverse progresses, failure begin to be noticeable due to the presence of water level located closer to the surface, coupled with the fact that the section is made up of weathered incompetent layers made up of mud/clay materials.

5.0 Conclusion and Recommendation

This research has been carried out in order to investigate the cause of road failure at Idominasi, along Ilesha-Osogbo expressway using an integrated approach that combines the use of the dipole-dipole technique of electrical resistivity method with the electromagnetic ground penetrating radar (GPR) method.

The cause of the road failure was found to be the presence of a low resistivity (weak and incompetent) lithology localized and sandwiched between two competent layers. The water level was observed to be located very close to the surface. The combination of these two has been the root cause of the failed portion of the road. In order to proffer a solution to the problem on ground, the depth to water table and the depth to mud were extracted from the GPR radargrams for each profile of the radargram carried out in the study area.

From the results obtained, since the clay is localized within a small portion of the road sandwiched within competent lateritic layers, towards the north western side and towards the south eastern part, the possible solution to the problem is to excavate the entire clayey layer in the study area, and replace with landfill material which can resist and withstand imposed wheel load. Excavation would be done to a depth of about 6 m to 7 m deep. Landfill materials to be used should be composed of homogenous and highly resistive lateritic material which is devoid of any significant geological features that could aid the development of swells and shrinking. This will go a long way to resuscitate the road and support heavy wheel load imposed on it.

6. Acknowledgement

The authors would like to say that this work was funded by research grant award by the TETFund. We wish to appreciate the effort of members of staff of Geological Sciences of Osun State University, Osogbo during the field work as well as the University NEEDS Assessment Fund for the purchase of the GSSI SIR 3000 machine. We also wish to appreciate all the anonymous reviewers for their contribution towards the review of the manuscript. We are highly indebted to all.

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