

RESEARCH ARTICLE

SUBSURFACE GEOPHYSICAL EVALUATION OF ROAD FAILURE MECHANISMS IN A ROAD SEGMENT AT EKITI STATE UNIVERSITY CAMPUS

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ABSTRACT

This study investigates the causes of recurring road failures at Ekiti State University, Ado-Ekiti, Nigeria, using geophysical methods. The research aims to identify subsurface conditions contributing to these failures, assess the geological and geotechnical properties of the soil and rock, and recommend sustainable construction practices. Electrical resistivity using dipole-dipole configuration and two-dimensional (2D) electrical imaging were used. Data were collected through Ohmega Resistivity Meter, electrodes, and connecting cables, with measurements processed using Dipro-Win software. The results revealed four geological formations: topsoil with resistivity values ranging from 22 – 128 Ωm, a weathered layer (128 – 737 Ωm), a partly weathered basement (737 – 4232 Ωm), and fresh basement rock (>4232 Ωm). Weak zones with low resistivity, suspected as clayey material, were found between stations 3 and 7, with a thickness of less than 2.5 meters. These zones are associated with road cracks and failures. Moderate resistivity zones (likely laterite) between 7 and 10 meters demonstrated field competence. Below these layers, partly weathered and fractured zones were identified above fresh basement rock, with signs of weathering toward the east of the study area. According to the findings, the electrical resistivity approach was a useful tool for identifying the reasons behind road failures along Ekiti State University's Management Science Road to college of medicine. For road rehabilitation projects, the discovered subsurface anomalies such as inadequately compacted soil and underground water channels offer important insights. The study shows how geophysical techniques can be used to solve problems with road infrastructure and shows how they can be used more widely in road engineering and maintenance projects.

KEYWORDS

Electrical resistivity, subsurface characterization, dipole-dipole, horizontal profiling, road challenges

1. INTRODUCTION

Application of physics concepts to the study of the Earth is known as geophysics (Keller and Dehler, 1999). By examining physical phenomena related to the Earth, such as the geomagnetic field, heat flow, seismic wave propagation, gravitational force, and more, pure geophysics seeks to deduce the Earth's physical characteristics and interior structure (Telford et al., 1990). On the other hand, applied geophysics seeks to examine particular characteristics of the Earth's crust at a shallow and relatively small scale (Brooks et al., 2002). Synclines, anticlines, geological faults, salt domes, undulations of the crystalline bedrock beneath a moraine cover, ore bodies, clay deposits, and other features are examples of these characteristics (Brooks et al., 2002). It is widely recognized that exploring such features often has practical implications for challenges related to oil exploration, identifying water-bearing layers, mineral exploration, highway construction, and civil engineering (Reynolds, 2011). In many cases, combining physics with geological information is the most effective approach for solving these problems (Reynolds, 2011). When it comes to investigating the shallow features of the Earth's crust, geophysicists employ various methods that depend on the physical properties of the rocks constituting these features (Geldart et al., 1995). Broadly speaking, these methods can be classified into different categories. One class of methods is known as static methods, which involve the accurate detection and measurement of distortions in a static physical field. These distortions

help in delineating the features responsible for them. The static field can be a natural field like the geomagnetic field, the gravitational field, or the thermal gradient field. Alternatively, it can be an artificially applied field, such as an electric potential gradient (Geldart et al., 1995). Sending signals into the ground and then detecting and evaluating the strength and arrival times of the returning signals at appropriate locations constitutes another class of techniques known as dynamic methods. Time is always a factor in these dynamic methods, either directly as the wave arrival time (as in the seismic method) or indirectly as variation in frequency or phase (as in the electromagnetic method) (Geldart et al., 1995). Moreover, electrical resistivity techniques have been widely employed for groundwater exploration and have also shown promise in resolving other groundwater-related problems (Loke, 2011). Numerous applications in mapping geophysical features, including contacts, faults, shear zones, and basement relief, are made possible by these techniques (Loke, 2011). The electrical resistivity method can also assist in investigations related to civil and military engineering. In the Electrical resistivity method, electric currents generated artificially are introduced into the ground, and the resulting potential differences are measured at the surface. Deviations from the expected pattern of potential differences, assuming a homogeneous ground, provide valuable information about the shape and electrical properties of subsurface irregularities (Loke, 2011). The electrical resistivity method finds significant application in road construction and road failure assessment by assisting in the delineation of geological

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structures, as well as the characterization of soil and subsurface layers beneath the area under investigation or proposed for road development (Binley, 2003).

The primary objective of employing the electrical resistivity method in road construction and road failure assessment is to assess the properties of near-surface geologic materials, including their type, nature, and the presence of bedrock structures. By utilizing the electrical resistivity method, potential issues that could lead to road failures post-construction can be identified and addressed. One crucial aspect of using the electrical resistivity method in road construction and road failure assessment is the detection and mapping of geological features that may render the road susceptible to failure. These features encompass fractures, faults, geological contacts, joint zones, and other weak zones. The method enables the determination of the lateral and vertical extents of such local subsurface geological features. Furthermore, it facilitates the calculation of geophysical parameters for the proposed area, including the thickness of subsurface layers and electrical resistivity.

In a broader context, applied geophysics, as a discipline, is predominantly employed to obtain valuable information for a variety of purposes. This includes determining the depth to bedrock, locating sinkholes or buried objects, tracking the movement and transport of contaminant plumes, assessing the properties of soil and rock, and studying underground water and salt movements (Reynolds, 2011). The specific objectives of an investigation dictate the particular applications of applied geophysics, allowing for the acquisition of essential data pertinent to the given context (Reynolds, 2011). Electrical resistivity techniques will be used in this study to determine the causes of failures along a recently constructed road inside Ekiti State University, Ado-Ekiti. Investigating the conductive zones that can show the clayey formation, badly weathered zone, and fractured zone of the underlying bedrock is the aim of the study.

2. PROBLEM STATEMENT

Road infrastructure plays a critical role in the social and economic development of any community, particularly within institutions like universities where accessibility and transportation are vital for daily activities. In Ekiti State University campus, recurring road failures have become a significant challenge, disrupting mobility, increasing maintenance costs, and negatively impacting the overall user experience. The causes of road failures are often multifaceted, involving poor construction practices, substandard materials, and inadequate design. However, underlying geological and geophysical factors, such as soil composition, groundwater conditions, and subsurface structural anomalies, are frequently overlooked during road construction and rehabilitation.

These hidden factors can exacerbate the degradation of road surfaces, leading to cracks, potholes, and subsidence. In the affected areas of the Ekiti State University campus, the persistence of road failures raises concerns about the suitability of the subsurface materials and their bearing capacity. Preliminary observations suggest that issues such as expansive clay, weak subsoil layers, and fluctuating groundwater tables may be contributing to the problem. Without a comprehensive geophysical investigation, these issues cannot be accurately diagnosed or addressed, resulting in repeated road failures despite rehabilitation efforts.

3. LOCATION AND GEOLOGY OF THE STUDY AREA

Ado-Ekiti is located between latitudes $7^{\circ} 33.44' N$ and $7^{\circ} 43.26' N$ and longitudes $5^{\circ} 8.35' E$ and $5^{\circ} 18.05' E$. Both main and local highways lead to the location. (Figure 1) The research area's terrain has a generally mild slope. Large hills that are encircled by populated areas define the region. According to a study, the majority of the rocks are up to 250 meters above mean sea level. Generally speaking, it is an upland region (Talabi et al., 2014). There are distinct wet and dry seasons in this lowland tropical rain forest climate. The wet season lasts from May to October, whereas the dry season occurs from November to April. Ekiti State, located in southwestern Nigeria, lies within the basement complex region of Nigeria, part of the West African Craton. The geology of this area is predominantly composed of Precambrian crystalline rocks, which are among the oldest rocks in the world. These basement rocks are characterized by their high-grade metamorphic and igneous origins, with lithological units including migmatites, gneisses, schists, granites, and quartzites (Rahaman, 1988). The migmatite-gneiss complex forms the dominant lithology in Ekiti State. These rocks are highly deformed and display a combination of igneous and metamorphic characteristics, resulting from partial melting and recrystallization processes. Their mineralogical composition includes feldspar, quartz, biotite, and amphibole (Figure 2).

The study area, located within the Ekiti State University campus in Ado-Ekiti, southwestern Nigeria, is part of the Nigerian Basement Complex. The local geology of the area is predominantly influenced by the broader regional geology, which is composed of Precambrian crystalline rocks that have undergone significant deformation and metamorphism. These geological characteristics play a crucial role in determining the geotechnical properties of the subsurface materials, which, in turn, affect the stability and performance of infrastructure such as roads. The lithology of the study area comprises a variety of rock types typical of the basement complex. These include: Migmatites and gneisses, granites, schists, laterite and residual soil.

The study area is influenced by structural features such as faults, fractures, and joints (Figure 3). These features, aligned predominantly in the NE-SW direction, are a result of tectonic activities during the Pan-African Orogeny (Rahaman, 1988). The presence of these structures can facilitate the infiltration of water, leading to the weakening of subgrade materials and contributing to road failures.

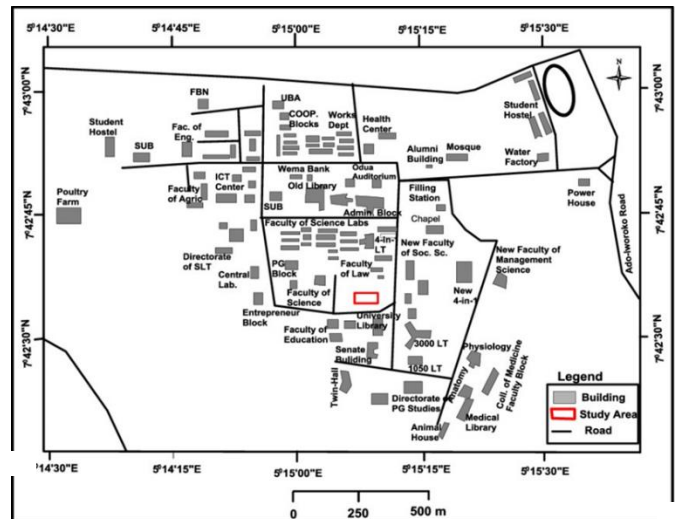


Figure 1: Map of Ekiti State University showing the Location of the Study Area (After Ajayi et al., 2022).

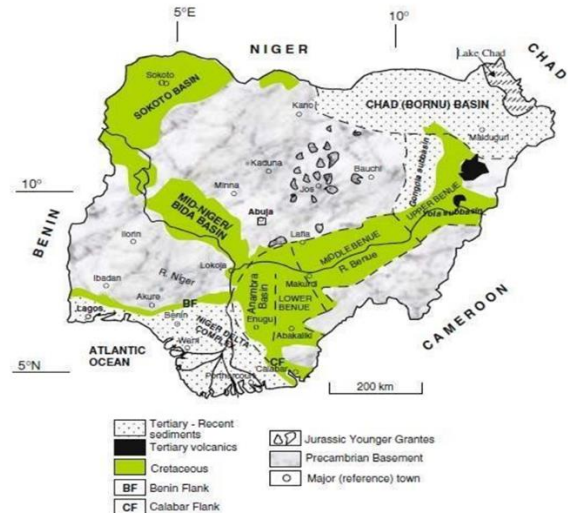


Figure 2: Geological map of Nigeria showing the Basement Complex (Modified after Obaje, 2009).

4. MATERIALS AND METHODOLOGY

4.1 Materials

The materials used for the geophysical survey for the road failure investigation of the study area include; measuring tape, Ohmega Resistivity Meter from Allied geophysical associates, battery, electrodes, hammer, connecting cables/ cable reels and crocodile clips.

- Measuring tape: The measuring tape was used to determine the length of the traverses and also determine the meter points for the electrodes.

- **Ohmega Resistivity Meter:** The Ohmega Resistivity Meter is a high-quality portable earth resistance meter capable of accurate measurement over a wide range of conditions. It was used to transmit electrical current into the subsurface via the current electrodes, and to determine the potential difference arising from the subsurface.
- **Electrodes:** Two pairs of electrodes were used during the course of the survey (two current and two potential electrodes).
- **Geological hammer:** Geological hammer was used to drive the electrodes into the ground to enable good contacts.
- **Connecting cables:** Connecting cables were used to connect the electrodes to the resistivity meter for sending electrical current into the subsurface and also for measuring the potential difference.
- **Crocodile clips:** the clips were used to secure the cables to the electrodes for smooth transmission.

four electrodes. Imaging depth of electrical resistivity method is dependent on the spacing between electrodes. Greater depth is achieved by increasing the electrode spacing. The total length of electrode array also plays role in resulting greater imaging depth.

To create the base map and ascertain the local geology, outcrops, and drainage pattern of the research area, a reconnaissance survey was conducted. The traverse was set up perpendicular to the direction of the strike. A 200-meter traverse that was set up parallel to the road was the subject of the geophysical study employing the electrical resistivity method. Data was collected using an omega resistivity meter, vertical electrical sounding (VES) employing a dipole-dipole array, and two-dimensional (2D) electrical imaging. First, the single traverse set up parallel to the road was used for the 2D electrical imaging. The subsurface's lateral and vertical resistivity variations are simultaneously provided by the 2D imaging. One VES point was recorded in Universal Traverse Mercator (UTM) coordinates with the help of the Global Positioning System (GPS), and Dipro Software was used for 2D modeling. This technique was used as reconnaissance to identify potential weak zones along the road; the inner electrode spacing was 5 m and the inter dipole expansion factor (n) ranges. The theoretical pseudo-section provides high-resolution color images of the field data used for quantitative interpretation.

Vertical electrical sounding was adopted to investigate electrical resistivity changes with depth. With this technique, vertical variations in the ground apparent resistivity were measured with respect to a fixed array centered by gradually increasing the electrode spacing. Dipro-Win software was used to process the resultant data acquired using this approach (Dipro for Windows 2000).

$$J = E/\rho \tag{2}$$

Imagine that the source is located at the centre of a spherical body of radius 'r'. The current density at the spherical surface is:

$$J = \frac{I}{A} \tag{3}$$

Where A = area of the spherical surface is:

Given; $4\pi r^2$

$$J = \frac{I}{4\pi r^2} \tag{4}$$

Substitute equation (4) into (2)

$$E = \frac{\rho I}{4\pi r^2} \tag{5}$$

But E is the gradient of scalar potential i.e

$$E = -\nabla V = \frac{-\partial V}{\partial r} \tag{6}$$

Equate equations (5) and (6)

$$\frac{\rho I}{4\pi r^2} = \frac{-\delta V}{\delta r}$$

Therefore,

$$\delta V = \frac{-\rho I \delta r}{4\pi r^2} \tag{7}$$

Taking the integral of both sides

$$\int \delta V = \int -\rho I \delta r / 4\pi r^2$$

$$\int \delta V = \frac{-\rho I}{4\pi} \int \frac{1}{r^2} \delta r$$

Therefore,

$$V = \frac{\rho I}{4\pi r} \tag{8}$$

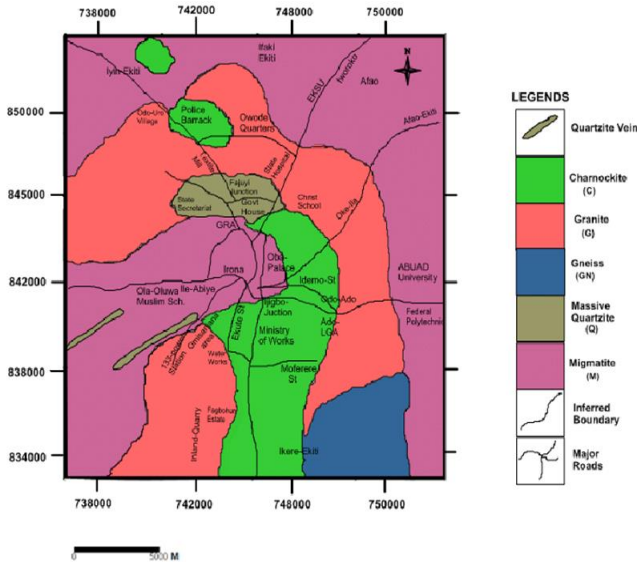


Figure 3: Geological Map of Ado Ekiti (After Ademilua et al., 2020).

4.2 Methodology

Electrical Resistivity Method (ERM) is basically conducted to measure and map the resistivity of subsurface materials. It also refers as survey that carried out to present the image of electrical properties of the subsurface by passing an electrical current along many different paths and measuring the associated voltage. Electrical Resistivity Method (ERM) is based on the response between the earth and the flow of electrical current. It's sensitive to variations in the electrical resistivity of the subsurface measured in Ohm meters. Resistivity measurements are conducted by inducing an electric current into the earth through two current (C1 and C2) electrodes and measuring the resulting voltage at two potential electrodes (P1 and P2) (Figure 4). The apparent resistivity (pa) value can be calculated based on the current (I) and voltage (V).

$$pa = kV/I \tag{1}$$

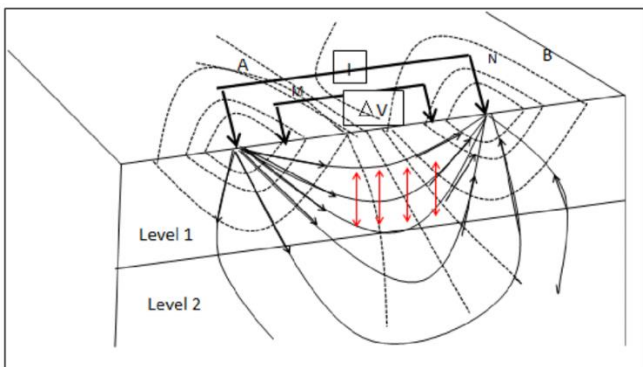


Figure 4: Working principle of Electrical Resistivity Method (Bozkurt et al., 2019).

k represented the geometric factor that depends on the arrangement of

In practice, the earth surface structure is taken as an approximate hemisphere. The current density (j) is defined as:

$$j = I/A \tag{9}$$

The area of a hemisphere is $2\pi r^2$ Equation (9) becomes

$$j = \frac{1}{2\pi r^2} \tag{10}$$

$$E = \frac{I\rho}{2\pi r^2} \tag{11}$$

But $E = -\nabla V = \frac{-\delta V}{\delta r}$

$$\frac{\delta V}{\delta r} = \frac{-I\rho}{2\pi r^2} \tag{12}$$

Taking the integral of both sides:

$$\int \frac{\delta V}{\delta r} = \int \frac{-I\rho}{2\pi r^2}$$

$$\int \frac{\delta V}{\delta r} = \frac{-I\rho}{2\pi} \int \frac{1}{r^2}$$

$$\int \delta V = \frac{1\rho}{2\pi} \int \frac{1\delta r}{r^2}$$

$$V = \frac{-I\rho \left(-\frac{1}{r}\right)}{2\pi r^2}$$

$$V = \frac{-I\rho}{2\pi r} \tag{13}$$

This is the potential at point P due to current at point C on the surface of the earth.

5. RESULT AND DISCUSSION

5.1 Electrical Resistivity Pseudo-section

The 2D-Electrical Pseudo-Section representing the apparent resistivity of the subsurface (Figure 5) was obtained from the dipole - dipole arrangement of the electrical resistivity method conducted along the single traverse of the existing road (Table 1).

The study produced four geologic formations: partly weathered basement (yellow and reddish color) with resistivity values ranging from 737 to 4232 Ωm; fresh basement, represented by a dome shape structure indicated by red to purple color with resistivity value > 4232 Ωm; weathered layer (green to greenish yellow color) with resistivity values ranging from 128 to 737 Ωm; and top soil (blue to green color) with resistivity values ranging from 22 to 128 Ωm. The study region could be delineated down to a depth of 15 meters using the Dipole-Dipole method. The worn layer often absorbed the topsoil layer because of its thinness.

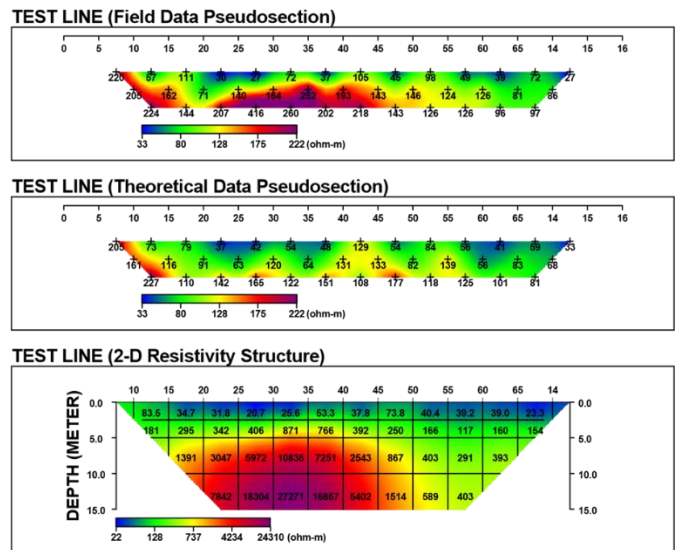


Figure 5: 2D Electrical Resistivity Structure of the Study Area.

Table 1: Dipole - Dipole Data Acquired Along the Road

Electrode C ₁ C ₂	Position P ₁ P ₂	Geometric Factor	Resistance	Apparent Resistivity (Ohm-m)
0 1	2 3	94.26	0.429	220
	3 4	377.04	0.544	205
	4 5	942.60	0.238	224
1 2	3 4	94.26	0.605	57
	4 5	377.04	0.429	162
	5 6	942.60	0.153	144
2 3	4 5	94.26	1.178	111
	5 6	377.04	0.188	71
	6 7	942.60	0.220	207
3 4	5 6	94.26	0.350	33
	6 7	377.04	0.371	140
	7 8	942.60	0.441	416
4 5	6 7	94.26	0.246	27
	7 8	377.04	0.286	164
	8 9	942.60	0.276	260
5 6	7 8	94.26	0.764	72
	8 9	377.04	0.668	252
	9 10	942.60	0.214	202

Table 1 (Cont): Dipole - Dipole Data Acquired Along the Road

Electrode C ₁ C ₂	Position P ₁ P ₂	Geometric Factor	Resistance	Apparent Resistivity (Ohm-m)
6 7	8 9	94.26	0.393	37
	9 10	377.04	0.512	193
	10 11	942.60	0.111	105
7 8	9 10	94.26	1.517	143
	10 11	377.04	0.379	143
	11 12	942.60	0.048	45
8 9	10 11	94.26	1.337	126
	11 12	377.04	1.040	98
	12 13	942.60	0.329	124
9 10	11 12	94.26	0.134	126
	12 13	377.04	0.520	49
	13 14	942.26	0.334	126
10 11	12 13	94.26	1.037	96
	13 14	377.04	0.859	81
	14 15	942.60	0.257	97
11 12	13 14	94.26	0.076	72
	14 15	377.04	0.912	86
	15 16	942.26	0.000	0
12 13	14 15	94.26	0.029	27

5.2 Interpretation of Result

One profile was established along the faculty of management science and college of medicine road at EKSU Campus, and the results is shown in Figure 4.1. From the result, we could see that the lateral extent is 200 m. From Station 3 to 7 has relatively low resistivity value which is suspected to be a clay material having a thickness less than 2.5 m. Similar findings have been reported in other parts of Southwestern Nigeria where low resistivity clay materials were linked to pavement instability and failure (Adenika et al., 2018; Aderemi and Adeola, 2021). At 7 to 10 occurs a moderately high resistivity zone with patches of low resistivity, this zone can be characterized by laterite with some level of competence and has no crack, while on the zone with cracks and low resistivity, there are evidence of road failure. In contrast, the moderately high resistivity zone observed between Stations 7–10 at EKSU, interpreted as lateritic material with better competence, agrees with studies that found laterite to provide stable subgrade support for road pavements (Aderemi and Adeola, 2021).

Under these zones we have a moderate resistivity which is suspected to be a partly weathered/fractured layer which is above the relatively high resistivity zone typical of fresh basement. This also agreed with a study in Ado-Ekiti who delineated low resistivity zones (clay intercalated with laterite), overlying fractured/weathered basement down to 25 m, with fresh high-resistivity basement beneath using electrical tomography (Ewumi et al., 2025). The bed rock has a hilly structure and the continuous resistivity shows that there is no fracture. But to the east, the resistivity value of the bed rock reduces suggesting some element of weathering.

6. CONCLUSION

For the geotechnical study of the area surrounding the failed sections of the Management Science to College of Medicine-road at Ekiti State University, Ado-Ekiti, vertical electrical sounding electrical geophysical methods were used. The demarcation of incompetent zones in the area that are detrimental to engineering projects was demonstrated by the interpretation of these methodologies. The road is vulnerable to future failure and complete collapse due to these recognized weak zones. The outcome demonstrates that the subsurface formation is mostly thought to be composed of clayey material and weathered formations that extend down to a depth of roughly 5 to 10 meters. Clay, though highly porous but less permeable owing to poor connectivity of its pores, retains water without releasing it thus making it swell up and collapse at the exertion of

pressure. Also, the presence of geologic features such as fractured zones within the subsurface structure in the area creates structurally weak foundation for the constructed road.

RECOMMENDATION

According to the fact that the road was built because the civil engineers and other professionals were unaware of the geologic issues related to the environment, a thorough geophysical study of roads is necessary before any construction work is done. In order to obtain appropriate depth and information about the subsurface during the planning stage, the traditional engineering investigations should be combined with the geophysical methods. The route under investigation would require a complete refurbishment. Any further road construction within the investigated area should be place on competent materials with a well-constructed piled foundation or excavation of non-competent layers (clay, weathered zones, and crack zones) to ensure adequate stability of the road within the study area.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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