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Investigation of the Cause of Failure of Building Structures in Damaturu, Northeastern Nigeria, Using Electrical Resistivity Method

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Abstract
In this study, building failures were investigated in Damaturu metropolis, using Electrical resistivity method which involves, both Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT). The study reveal that the area is composed of five geologic layers, which are the topsoil, clay, sand, sandy-clay, and sand. The topsoil thickness ranged from 0.7 to 1.9 m and has resistivity values which ranged from 127.6 to 171.5 Ωm. The second layer which is a clay formation has a thickness which ranged from 6.9 to 12.6 m. The topsoil is thin in most parts of the study area and it is mostly excavated during the building process for foundation laying and thereby leading to a situation where the foundation of the buildings are footed on the second layer which is a clay formation. The study reveal that the foundation of most buildings in the study area are underlain by clay. Clay soils often swell during rainy season and shrink during the dry season. Considering the appreciable thickness of clay in the study area, the swelling and shrinking behavior of clay is responsible for the failure and collapse of buildings in the study area. The resultant swelling and shrinkage of the clay under the foundation, subjects the buildings to shear stress which culminate in cracking of walls and deformation of the buildings. The study revealed that the materials underlying the building foundations in the study area are incompetent and they deserved to be compensated during building construction by using appropriate foundation types or by engineering reinforcement, using concretes to enhance the load bearing capacity of proposed building sites in the study area.

Keywords: Building, foundation, failure, geophysics, electrical resistivity.

Introduction
The rising trend in building failure in Damaturu and Nigeria at large is worrisome as it has led to loss of lives and properties. This ugly development needs to be curtailed through research and extensive public enlightenments. Geologic features such as faults, folds, sinkholes, voids, cavities, fractures, and geologic contacts due to subsurface inhomogeneities are detrimental to building foundations, as they can easily initiate differential settlement of

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the subsurface or subsidence which in most cases lead to building failures and eventual collapse.

Aderoju and Adebayo, (2017) conducted a geophysical foundation studies at Ogun river valley estate in Lagos State, southwestern Nigeria, and they observed that the area investigated was composed of peat, clay, sandy clay and sand. They concluded that the layer upon which the buildings were sited were generally inappropriate for the buildings and suggested that future building development in the area should be based on foundations that will suite the geologic nature of the area. Adiat, (2017) noted that encountering anomalous conditions, during site development and construction can lead to truncation, interruption and an abandonment of the entire project or perhaps the project might attracts additional cost in terms of labor and materials. Fatoba *et al*. (2013) in their study of structural failure reported that the increase in the rate of building failure in Nigeria depend on a number of factors which includes inadequate information about the soil upon which buildings are sited, poor foundation design and the use of substandard materials for building construction. In view of these observations the role of geophysics in building construction is highly important as it helps to reveal the subsurface lithology of any given area designated for building development.

Ozegin *et al.* (2011) observed that preliminary studies of a designated construction site will help to avert problems associated with soil expansivity and the effects of naturally occurring geologic structures such as voids and cavities which might initiate deformation and subsidence. Therefore, the geophysical investigation of any designated site for civil engineering construction, such as dams, roads, stadia, houses or high rise buildings, petroleum stations and bridges is very important. It is pivotal to a building design and the type of foundation to be used. Proper understanding of the subsurface lithology of any designated area for construction will help to inform the load bearing capacity of the area or soil competency and the type of foundation to be adopted. Electrical resistivity method has been adjudged by many researchers as efficient and cost effective tool for subsurface geotechnical studies (Adepelumi and Olorunfemi, 2000; Soupios *et al.,* 2006; Ibitoye, 2013; Aderoju and Adebayo, 2017). Adebowale *et al*.(2016) reported that the increase in the number of building collapse in Nigeria are due to several factors which includes derailment from the approved plan to minimize cost, lack of monitoring from approving authorities, and the execution of building projects by un-professionals.

Failed buildings are common in Pompomari area of Damaturu, northeastern Nigeria. They are also easily seen in the other parts of Damaturu metropolis. Most of the affected buildings had cracks and deformations on their walls even down to their foundations (Figure 1). Considering the importance of geophysical investigation to building construction, this study investigated the cause of building failures in Pompomari area of Damaturu and its environs. It is also focused on delineating the subsurface stratigraphic sequence and the evaluation of the geoelectric parameters of the subsurface layers and their implications on the integrity of the foundations of the buildings in the study area and its environs.

Figure 1: A typical failed building with cracks down to the foundation in the study area.

Methodology

The Study Area

Pompomari is a district in Damaturu, and Damaturu is located within the Chad Basin in the semi-arid region of Nigeria. It is situated on latitude 11° 39'N and longitude 11° 54'E (Figure 2). It is located in the Chad Basin, and it has a semi-arid climate characterized by a long dry season and short rainy season. The duration for the rainfall last for about three to four months, the annual rainfall ranges from 500-1000mm and the rainy season is from June to September (Agada *et al.*, 2011). Chad Basin is the largest area of inland drainage in Africa (Barber, 1960). It occupies an area of about 2,335,000km^2 and extend into Nigeria, Cameroon, Niger Republic, Chad, Sudan, Libya and Algeria (Okosun, 1992). The Basin is divided into three aquifer zones which are the upper, middle and the lower. The Upper Aquifer is composed mainly of fine sand, clay and silts partly inter-stratified with fluvial sands. The formation increases in thickness towards Maiduguri axis and thins out towards Potiskum. Damaturu is at the fringe of the Chad Basin.

Field Measurements

An Electrical Resistivity Tomography (ERT) survey was carried out in the study area to elucidate the nature of the subsurface lithology. A Wenner-Schlumberger configuration using 42 electrodes separated by 2 m was used to obtain a 2-D image of the subsurface. The 2-D ERT data was acquired with an ABEM SAS 1000 Terrameter provided by the National Centre for Geodesy and Geodynamics, Toro. The acquired 2-D data were processed to generate 2-D resistivity models using RESIST2DINV Software. The software discretized the surface model into a finite element model (Loke, 1999). The finite element model was automatically modified by an iterative process to enable it converge to the measured data.

Ten (10) vertical electrical resistivity soundings were also carried out in the study area with the aim to determine the various subsurface layer resistivities and thicknesses in the study area. A Schlumberger array was adopted to obtain a 1-D resistivity data of the study area. An ABEM SAS 1000 was used to acquire the data. The acquired data was interpreted by plotting the apparent resistivity values against the current electrode separation ($\frac{AB}{2}$) m. The apparent resistivity curves were partially curve matched with theoretical curves to obtain the input data for an iteration process. The data were further processed using WINRESIT Software version 1.0. The results from the graphs drawn by the processing Software shows the thickness, depth, and the true resistivity values of the various subsurface layers. The results obtained were correlated with an existing bore logs and the various subsurface layers were identified based on their true resistivity values after Palacky, 1987 (Figure 2)

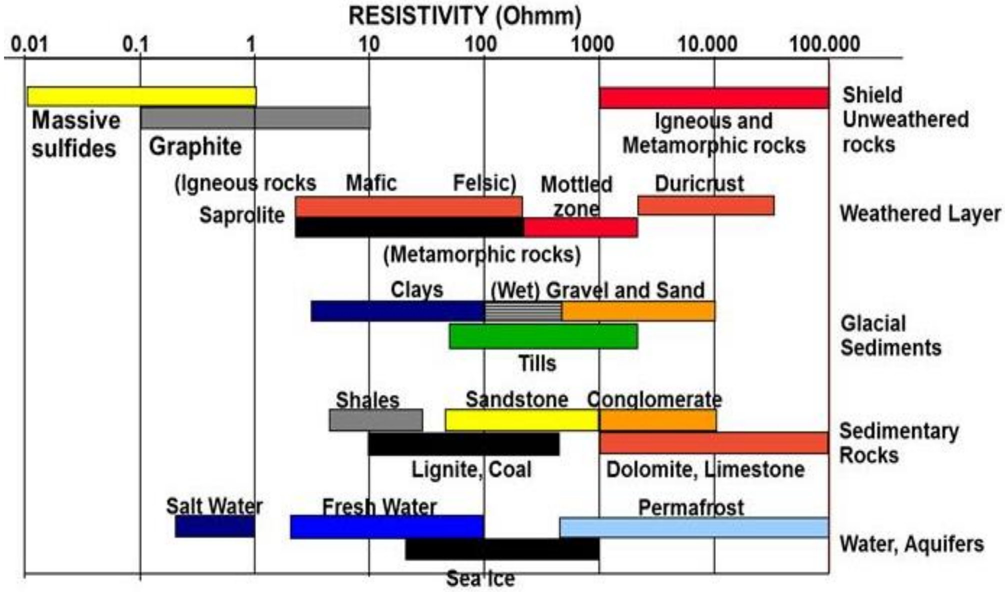

Figure 2: Soil resistivity values (After Palacky, 1987)

Results and Discussion

Five geoelectric layers were delineated as shown by the resistivity curves in the study area (Figure 3). The subsurface is composed of topsoil, clay, sand, sandy clay and sand (Figures 4 and 5).

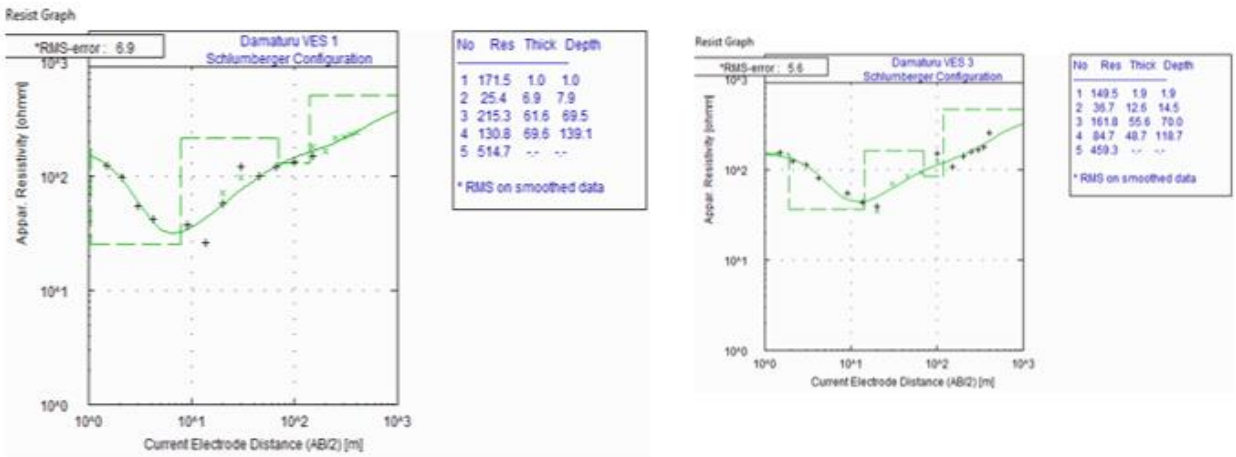

Figure 3: Typical curves obtained from the study area.

The thickness of the topsoil ranged from 0.7 to 1.9 m and has resistivity which ranged from 127 .6 to 171.5 Ωm (Figures 4 and 5). It is composed of a mixture of sand and clay materials. The topsoil is relatively thin. The varying thickness and resistivity of the first layer is an indication that the topsoil is heterogeneous in nature (Table 1). The second layer has resistivity values which ranged from 25.4 to 82.6 Ωm (Table 1). The low resistivity values of the second layer clearly indicates that it is a clay formation. Its thickness ranged from 6.9 to 12.6 m (Figures 4 and 5). The third layer is a sand formation whose thickness ranged from 38 to 61.6 m, and it has resistivity values which ranged from 130 to 409 Ωm (Table 1).

The 2- dimensional imaging results (Figure 6a, b, and c) showed that the study area is underlain by very low resistivity materials which is composed of dead organic matters (peat) and clay soil. These materials are known to possess poor geotechnical properties and exhibit low shear strength and high compressibility potential.

Table 1. Geoelctric parameters of the study area.

VES No.	Coordinates		Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
	Latitude (°N)	Longitude (°E)					
			1	171.5	1.0	1.0	Topsoil
			2	25.4	6.9	7.9	Clay
VES 1	11.732798	11.973459	3	215.3	61.6	69.5	Sand
			4	130.8	69.6	139.1	Sandy clay
			5	514.7	------	----	Sand
			1	127.6	1.6	1.6	Topsoil
			2	34.8	11.1	12.7	Clay
VES 2	11.736790	11.969553	3	185.0	41.2	53.9	Sand
			4	117.1	40.9	94.8	Sandy clay
			5	639.2	-------	---	Sand
			1	149.5	1.9	1.9	Topsoil
			2	36.7	12.6	14.5	Clay
VES 3	11.730099	11.964339	3	161.8	55.6	70.0	Sand
			4	84.7	48.7	118.7	Clay
			5	459.3	------	----	Sand
			1	241.9	0.8	0.8	Topsoil
			2	65.7	7.6	8.4	Clay
VES 4	11.731706	11.966120	3	193.5	49.7	58.1	Sand
			4	179.0	44.2	102.3	Sandy clay
			5	312.0	------	----	Clay
			1	149.9	0.7	0.7	Topsoil
			2	57.2	8.6	9.3	Clay
VES 5	11.735593	11.966474	3	211.3	38.0	47.3	Sand
			4	130.0	52.0	99.3	Sandy clay
			5	289.0	------	----	Sand
			1	130.5	1.1	1.1	Topsoil
VES 6	11.731097	11.973534	2	82.6	7.9	9.0	Clay
			3	290.2	40.0	49.0	Sand
			4	118.1	59.6	108.6	Sandy clay
			5	245.0	------	----	Sand
			1	139.2	0.9	0.9	Topsoil
VES 7	11.729616	11.970266	2	55.7	11.7	12.6	Clay
			3	219.5	52.6	65.2	Sand
			4	117.3	34.8	100.0	Sandy clay
			5	420.6	-----	----	Sand
			1	140.0	0.8	0.8	Topsoil

VES 8	11.727332	11.961376	2	51.1	10.7	11.5	Clay
			3	409.4	40.1	51.6	Sand
			4	123.8	56.3	107.9	Sandy clay
			5	324.0	------	----	Sand
			1	131.2	0.7	0.7	Topsoil
VES 9	11.7247375	11.960462	2	55.6	7.5	8.2	Clay
			3	317.5	54.6	62.8	Sand
			4	86.7	67.2	130.0	clay
			5	296.0	-----	----	Sand
			1	146.7	1.2	1.2	Topsoil
VES 10	11.730365	11.963337	2	65.4	10.7	11.9	Clay
			3	235.0	61.0	72.9	Sand
			4	123.8	59.7	132.6	Sandy clay
			5	247.0	-----	----	Sand

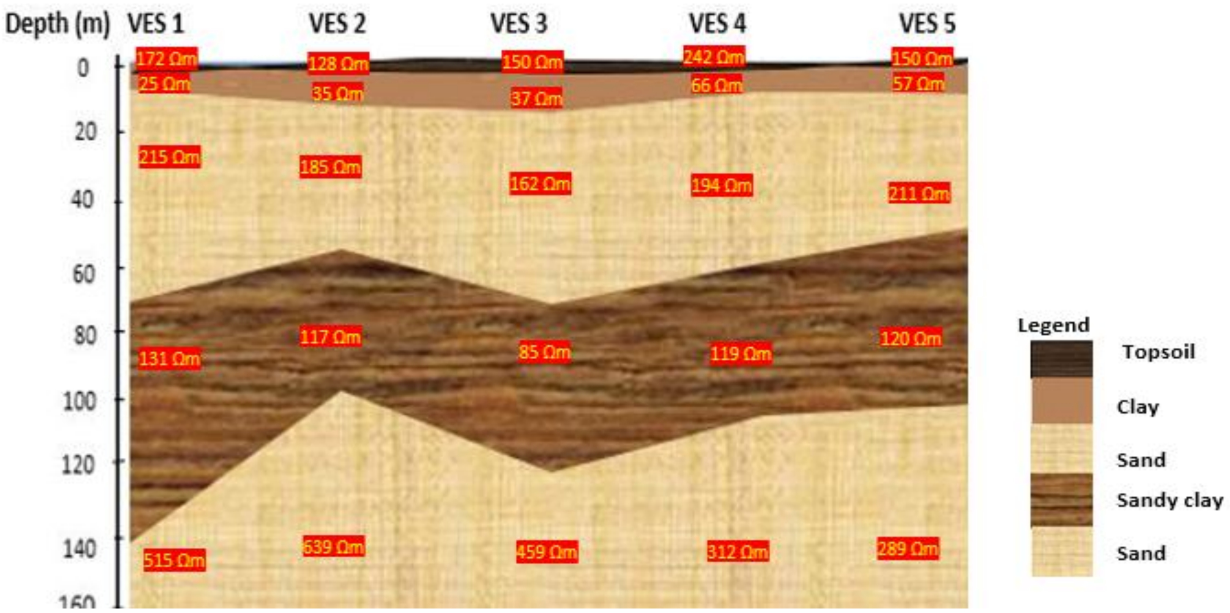

Figure 4. Geoelectric section of VES 1-5.

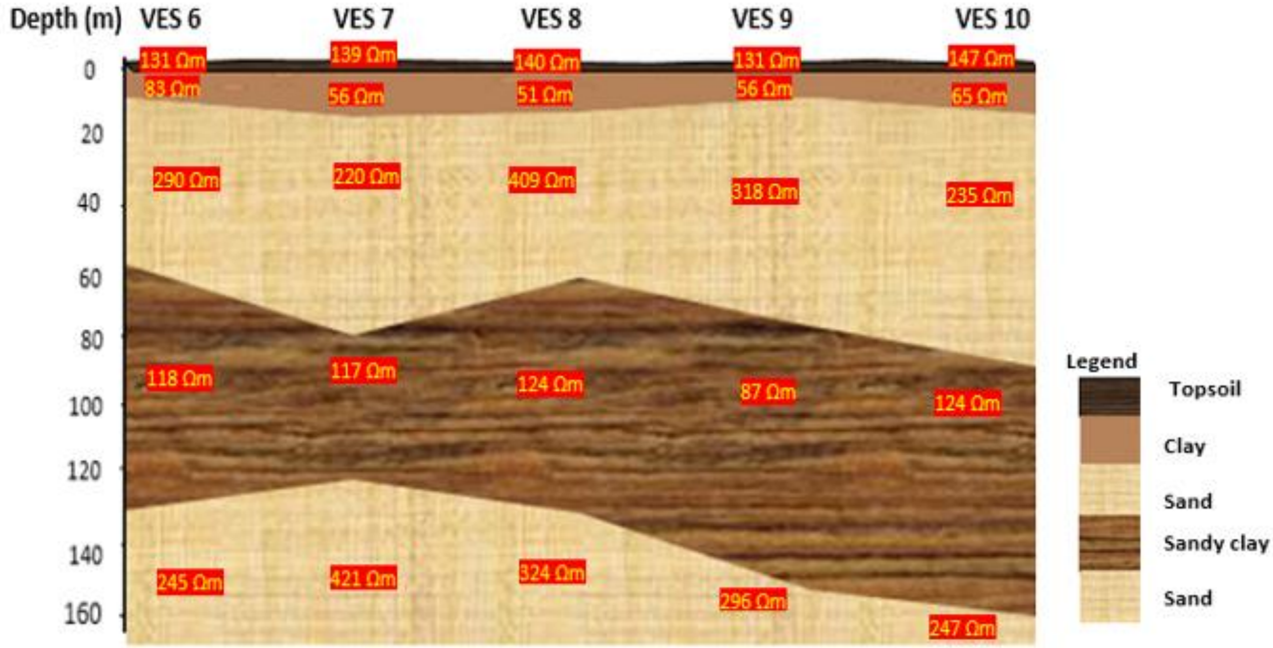

Figure 5. Geoelectric section of VES 6-10.

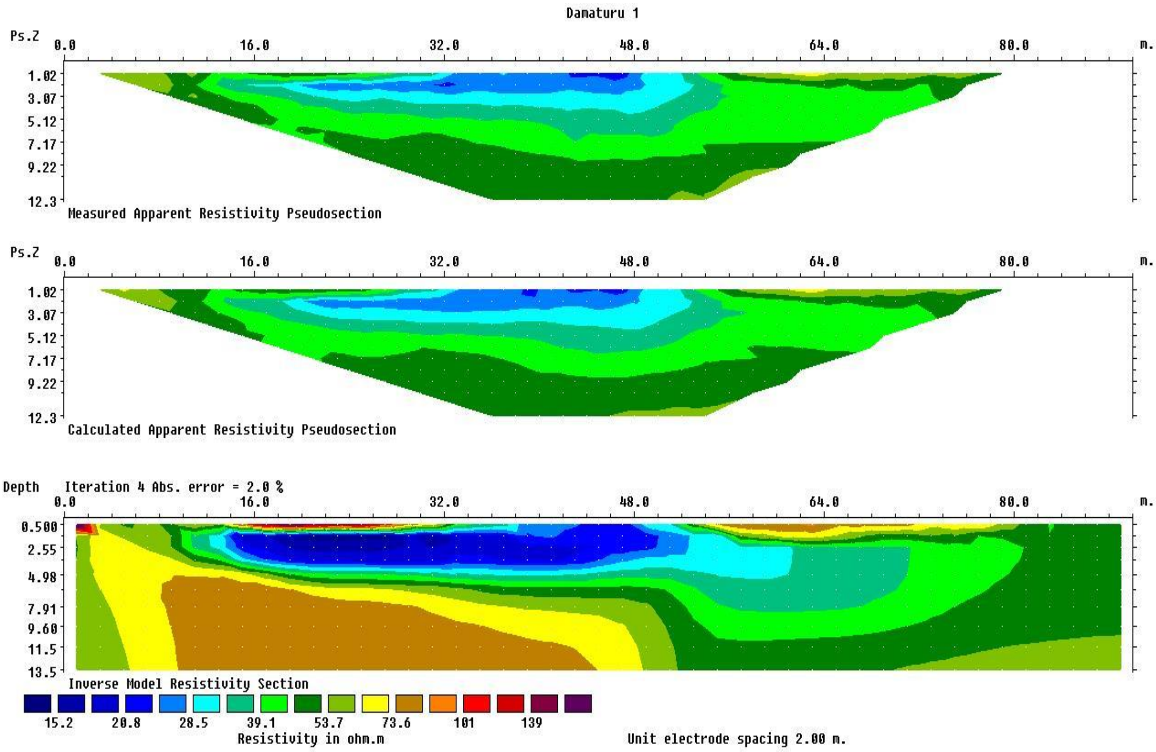

Figure 6 a.

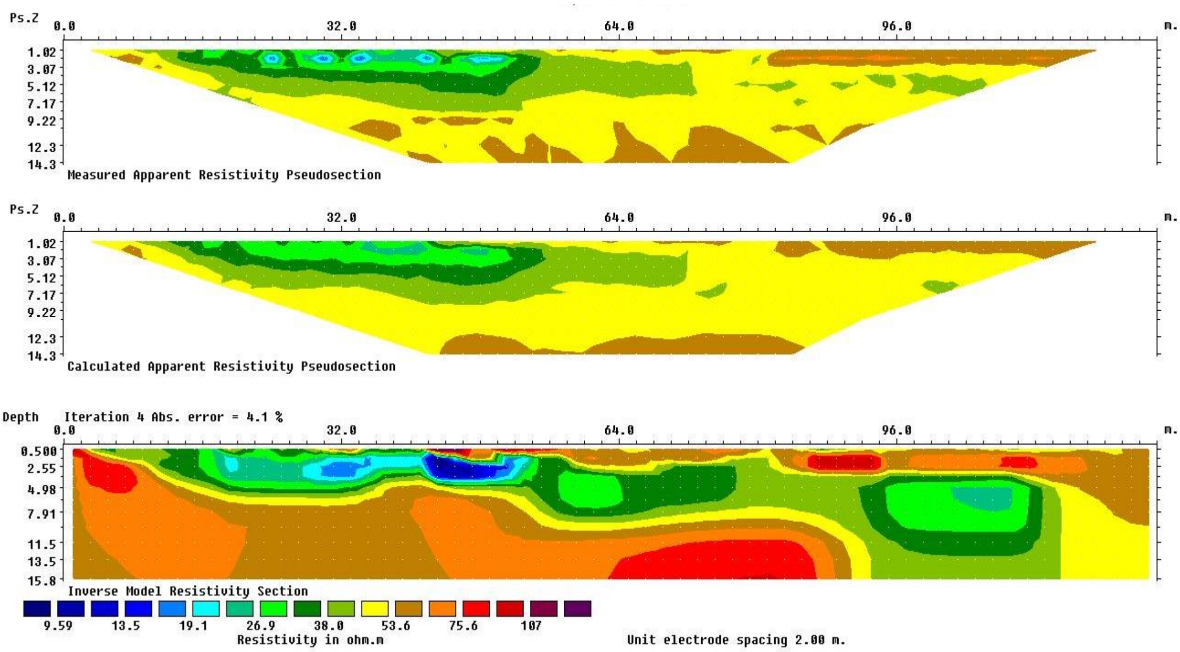

Figure 6b.

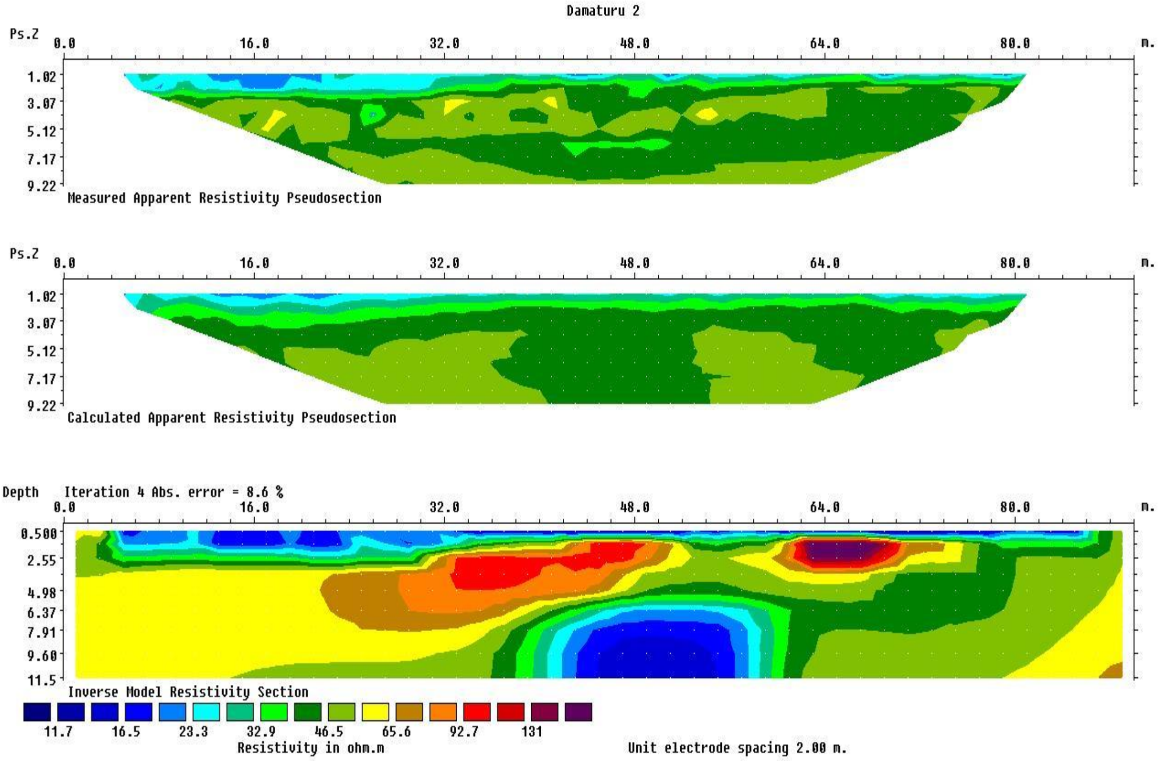

Figure 6c.

Figures 6a-c: Inverted resistivity models showing the distribution of clay and other incompetent materials in the subsurface of the study area. These materials area responsible for building failures.

The 2-D imaging sections showed that the underlying clay layer has low resistivities which varies from 9.59 to 92.7 Ωm (Figure 6a, b, and c). The VES results correlated well with the 2-D ERT results. Both results showed that the subsurface underlying the buildings in the study area is generally incompetent. The inhomogeneous nature of the topsoil by the virtue of its varying resistivities and thin sizes which varies from one location to another (Figures 4 and

5) made the topsoil incapable of providing the necessary footing for the foundation. During construction, the topsoil is mostly excavated, thereby making the building to rest much on the second layer which is incompetent. The clay soils are expansive and they contain smectite minerals. The smectites shrink upon drying and swell upon wetting.

These shrinking and swelling properties of clay leads to the cracking and failure problems associated with buildings built in the study area. Some parts of the study area have pockets of sand units (Figure 6a) which have competency for building foundation, but they are not continuous. The results of the study clearly showed that the cracking and failure of buildings in the study area were caused by the expansion and contraction of the materials underlying the building foundations. The soil layer underlying the foundation is incompetent to bear the buildings. The results are in agreement with the reports of Aderoju and Adebayo (2017). Aderoju and Adebayo (2017) in their study in Lagos State, observed that buildings in Ogun river valley estate were sited on incompetent soil formation which led to their failure and eventual collapse.

The role of geophysical investigation of a proposed site for civil engineering construction cannot be over-emphasized since it helps to provide vital information on the suitability of the soil for building purpose and the type of foundation to be adopted. It also reveals some hidden geological features which might constitute a serious problem to the buildings in the future. The results of this study showed that the area needs significant improvement of the foundation soil through both mechanical and engineering reinforcements, in the form of pile foundation and soil replacement with highly compacted materials such as gravel and crushed concrete.

Conclusion

This study investigated the cause of building failures in Damaturu, Yobe State. Both the Vertical Electrical Sounding (VES) and the Electrical Resistivity Tomography (ERT) results showed that the buildings in the study area were sited on incompetent clay soil. The absence of compensation for the weak soil layer underlying the foundation of the affected buildings are responsible for their failures and the subsequent collapse. Most of the buildings whose foundations are footed on the clay formation might have undergone differential settlement which led to their failure. The incorporation of geophysical investigation in any building construction project in the study area will help to avert the issue of building failures in Damaturu and its environs.

Based on the findings of this study, we therefore recommend that geophysical investigation should be carried out to ascertain the nature of the subsurface layers underlying building proposed sites in the study area. The results of such geophysical investigation will help in determining the type of foundations that could be adopted for buildings in the study area to avoid the occurrence of building failures.

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