Seismic Refraction and Electrical Resistivity Investigation of Building Failure: A Case Study

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Abstract- Geophysical methods involving electrical resistivity and seismic refraction were adopted to investigate the cause(s) of failure of main library complex of the Olabisi Onabanjo University, Ago-Iwoye, South-Western Nigeria. The geoelectric section generated from geosounding data revealed four geologic layers. The topsoil has resistivity values varying from 128Ωm to 220Ωm and thickness between 0.9m and 2.4m. The second layer is composed of lateritic clay with resistivity values varying from 238Ωm to 410Ωm and thickness between 2.5m and 5m. The third layer is composed of weathered basement with resistivity values ranging from 56Ω-m to 88Ω-m with thickness between 9.1m and 13.5m. The fourth layer is fresh basement with resistivity values between 1110Ωm and 1200Ωm. The depth to the rock head is between 14.1m and 18.6m. The 2-D subsurface imaging revealed that the foundation soil is composed of clayey materials with resistivity values ranging from 4.3Ωm to 80Ωm, between 0.7m to 5m which correlate well with the geoelectric section. The geovelocity layers' characteristics substantiate the electrical resistivity imaging and vertical electrical sounding results as it revealed a 4-layer model namely: topsoil, laterite and basement bedrock as the weathered layer is blinded. The topsoil has average velocity 486m/s which is diagnostic of weak/unconsolidated materials presumably clayey materials and average thickness of 2.2m. The sub-weathering/ laterite has average velocity of 1506m/s and average thickness of 7m. The third layer is the bedrock with average velocity of 2292m/s and characterized with a displaced parallel time segment indicating fault within the bedrock. Geotechnical analysis of the subsoil sample revealed that the soils have plasticity index and strength values that are typical of clay. From the result, the building failure observed as cracks and foundation subsidence may have been caused by incompetent foundation soils. It is noteworthy that such faulted zone delineated within the bedrock is also inimical to the building foundation.

Keywords: foundation, resistivity, velocity and refraction

1 INTRODUCTION

Foundation failure of structures has resulted to many casualties of lives and loss of properties in Nigeria and the whole world. Foundation is meant to transfer the load of the superstructures such as dams, skyscrapers, mansions, bridges, among others, to the ground without causing the ground to respond in uneven and excessive moment. The incessant building collapse in Nigeria has reached an alarming rate to the extent now that Government is coming up with measures to ensure safety in the building or civil construction industry. The causes of this collapse can be attributed to many factors among which are poor/inadequate construction materials and incompetent foundation soils (Oyedele et al, 2009).

Building foundation may also experience failure due to presence of concealed geologic features such as sinkhole/cavity and shear zones which can actually lead to subsidence. The satisfactory design and construction of any building foundation can be accomplished only when the characteristics of the soil or rock on which it is to be built is ascertained. Therefore, it is often necessary prior to building construction to investigate the physical properties of subsoil/foundation soils and determine its suitability for design and construction of building structures. Geotechnical and geophysical methods are most suitable for this purpose as they provide information about the engineering properties of the foundation soils in relatively cost-effective and rapid manner (Olorunfemi et al, 2005).

Of all the geophysical methods, the electrical resistivity and the seismic refraction methods have proved very useful in foundation investigation (Whiteley et al, 2006). This paper presents the results of the investigation of the foundation failure of the Library complex of Olabisi Onabanjo University, Ago-Iwoye, Ogun state, Nigeria. The failure which occurred inform of cracks and structure settlement was observed at the back of the library complex.

2 DESCRIPTION OF THE ENVIRONMENT OF THE INVESTIGATED SITE.

The study area is located within Olabisi Onabanjo University, Ago-Iwoye, Ogun state, Southwestern Nigeria. The area is located between Latitudes 6° 55′ and 6° 58′ N and Longitude 3° 54′ and 3° 56′ E (Fig 1).

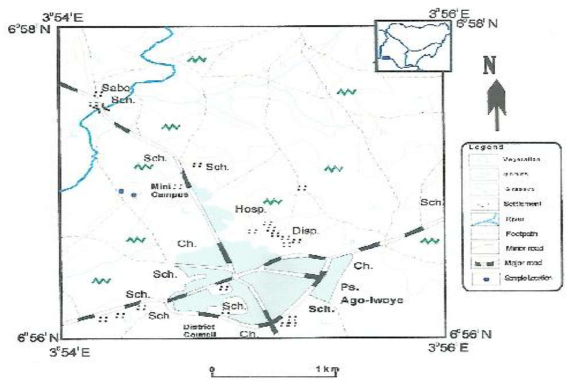

Fig 1: Location and accessibility map of the study area

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The area is underlain by granidioritic porphyroblastic granite, gneisses, migmatite gneiss, biotite gneiss and biotite, hornblende gneisses. The gneisses constitute the major rocks intruded by the other group of rocks. The minor rock types include; pegmatite and quartz veins (Fig 2).

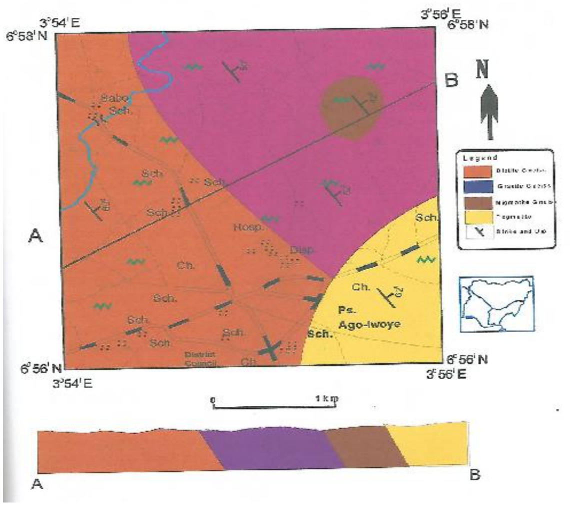

Fig 2: Geological map of the study area

3 METHODOLOGY

Geophysical investigation involving the electrical resistivity survey (1-D and 2-D) and seismic refraction were conducted along the profile established at the failed side of the Library Building complex. The electrical resistivity survey includes five Vertical Electrical Soundings (VES) using the Schlumberger array and 2-D imaging using Dipole – Dipole array with inter electrode spacing of 5.0 m and inter-dipole separation factor (n) which varied from 1m to 5m. The Dipole-Dipole data were inverted with the Dipro software (Fig 3).

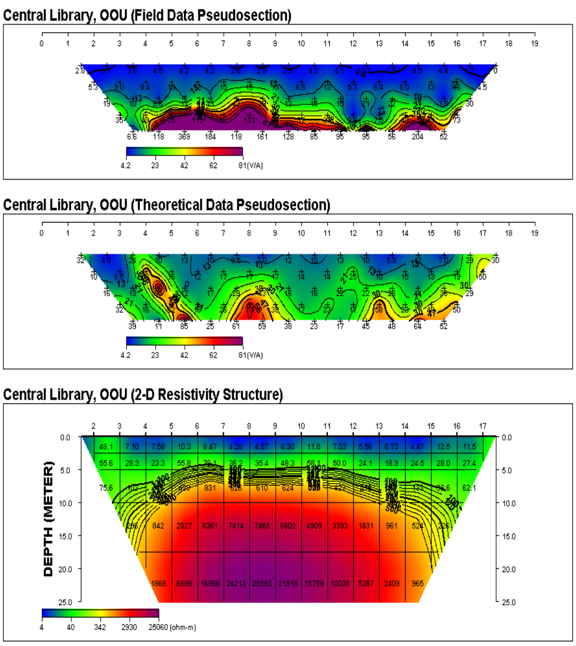

Fig 3: The 2-D subsurface imaging of profile 2

The electrode spacing (AB/2) of the VES varied from 1 m to 100 m. The VES curves were interpreted by partial curve matching and computer assisted 1-D forward modeling. The results of the interpretation were presented as geoelectric section. The seismic refraction data were acquired with 24-geophone channels seismograph. The seismic waves were generated through 50kg weight drop mechanism. The geophone – geophone spacing of 2 m and minimum offset of 4.0 m were adopted for the survey.

The first arrival times were picked from the seismograms and plotted as time – distance (T-X) graph (Fig 4). Distinctive segments on a T –X graph were interpreted as representative of different subsurface layer (Walker et al, 1991). Layer velocities were determined from the inverse of the slopes of such segments. Depth values to the different acoustic (Velocity) interfaces were determined using the intercept method (Sharma, 1967). Two (2) trial pits were dug along the established profile and soil samples were collected at different depths for laboratory analysis. Methods of testing soils for engineering parameters were conducted in accordance with BS 1377 (1990) for all soil samples collected. The tests include Atterberg Limit test (Liquid limit and Plastic limit) as shown in Table 1 as well as natural moisture content, grain size analysis (mechanical), consolidation test and triaxal test shown in Table 1.

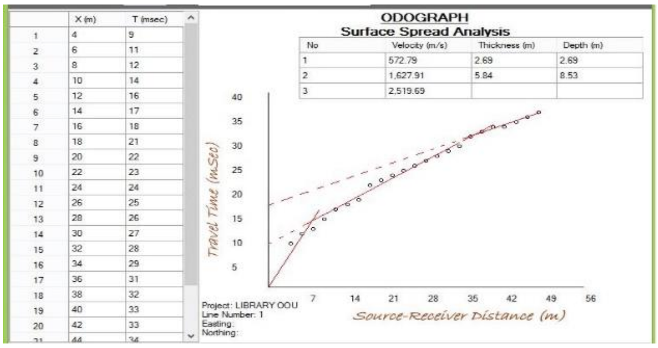

Fig 4: Time- Distance Graph from Seismograms

Table 1: Atterberg Limit Data Sheet

Location 1

Sample no	PL%	LL%	PI%	PLASTICITY
A	2.29	6.29	4.00	LOW
B	1.84	6.34	4.50	LOW
C	3.22	10.40	7.18	LOW

Location 2

Sample no	PL%	LL%	PI%	PLASTICITY
A	2.25	9.50	7.25	LOW
B	1.81	8.40	6.59	LOW
C	5.64	12.50	6.86	LOW

Table 2: Consolidation Test Result

Location 1

Sample no	Cv	Mv
1	14	0.139
2	10	0.121
3	6	0.094
4	4	0.066

Location 2

Sample no	Cv	Mv
1	16	0.141
2	13	0.136
3	9	0.086
4	6	0.045

4 RESULTS AND DISCUSSION

The geoelectric sections generated from the results of the VES revealed four geoelectric layers. The topsoil has resistivity values vary from 128Ω-m to 222Ω-m and its thickness is between 0.9m and 2.4m. The third layer is weathered basement with resistivity values ranging from 56Ω-m to 88Ω-m. The thickness of the layer is between 9.1 m and 13.5 m. The low resistivity values of the layer are diagnostic of its high clay content. The last layer delineated is the fresh basement, which has resistivity values of between 1110 Ω-m and 1200 Ω-m. The depth to the rock head is between 14.1m and 18.6m. From the results of the geoelectric survey the foundation soils are made up of incompetent materials which could compress on imposing loads. The 2-D subsurface imaging (Fig. 3) revealed that the foundation soils (blue colour) is composed of clayey materials with resistivity values ranging from 4.3Ωm to 80Ωm. This material is not suitable as foundation soil. The results of the 2-D imaging strongly correlate with the geoelectric section.

Moreover Seismic refraction survey results are presented as geovelocity section (Fig 6), geoelectric section (Fig 7), T-X graph (Fig 5a and Fig 5b) and the geovelocity layers' characteristics (Table 3) substantiate the electrical resistivity imaging and vertical electrical sounding results as it revealed a 4 layers model namely: Topsoil, Laterite and fresh basement layer while the weathered layer is blinded. The first layer(topsoil) having velocity of ranging from 400m/s to 573m/s which is diagnostic of weak/unconsolidated materials presumably clayey materials. The thickness of the layer ranges from 1.56 m to 2.7 m.The second layer (Laterite) has velocity ranging from 1389m/s to 1628m/s and thickness ranging from 4.8 m to 8.5 m. The third layer is the basement bedrock (consolidated layer) with average velocity of 2292m/s. T-X graph displayed displaced parallel time segment indicating fractured zone within the bedrock.

Table 3: Geovelocity Layers' Characteristics in Summary

Layer No.	1	2	3
Layer Description	Topsoil	Laterite	Basement
Velocity (m/s)	400 - 573 Mean = 486 ± 10.5	1386 - 1627 Mean = 1505.5 ± 20.8	2064 – 2519 Mean = 2292 ± 57.4
Depth (m)	1.56 – 2.69 Mean = 2.1± 0.7	3.24 – 5.84 Mean = 4.5 ± 1.3	-
Thickness (m)	1.56 – 2.69 Mean = 2.1± 0.7	4.8 – 8.53 Mean = 6.7 ± 2.3	-
Probable Lithology	Topsoil	Laterite	Basement
Probable Soil Condition	Unsaturated	Unsaturated	

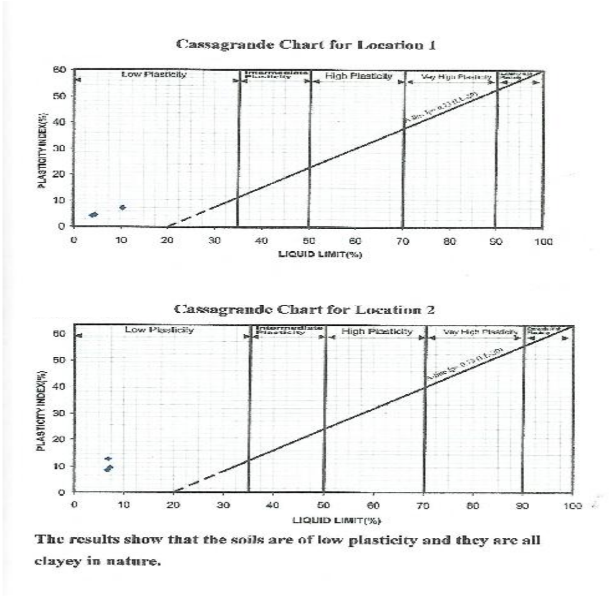

Fig 5: Cassagrande chart for location 1 and 2 from the study area

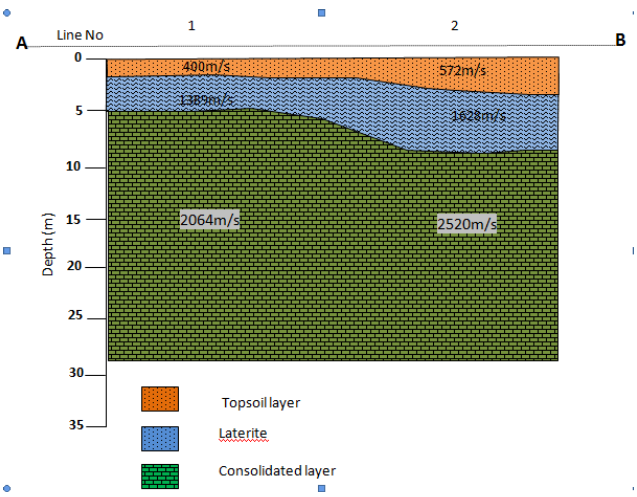

Fig 6: Geovelocity section of line 1 and 2 along profile A-B

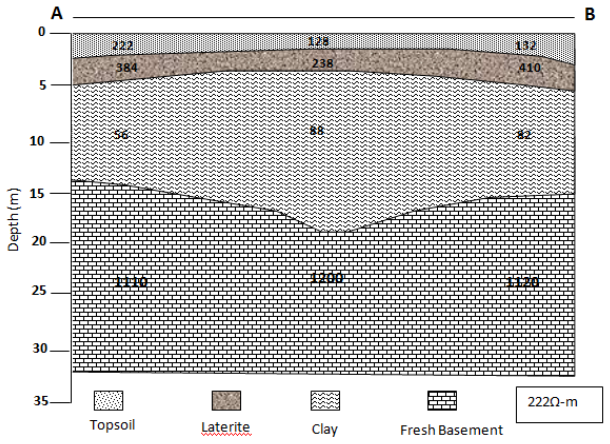

Fig 7: Geoelectric section along profile A-B

It is noteworthy that such fractured zone is inimical to the building foundation. There is significant correlation between the geoelectric section, 2-D resistivity imaging and T-X graph results. Atterberg limit test carried out on soil samples from two (2) locations in the surveyed area (Table 1); the result showed that the soils are of low plasticity and they are all clayey in nature. Moreover, a consolidation test was also carried out (Table 2) with the result showing that the load undergoes a primary compression due to reduction in volume which is accomplished through the expulsion of water and air from the sample. The soil is highly comprehensible by the building which is imposed on it and the soil the building is underlain by an incompetent material which is susceptible to settlement. The ultimate bearing values (Table 4) from the surveyed area indicate a cohesive soil category and a clayey soil type which corroborate the geophysical investigations.

Table 4: Bearing values from surveyed area (Location 2)

Sample no	Cohesion (c)	Angle of internal Friction ϕ (0)	Presumed bearing capacity qu (KN/m2)	Allowable bearing capacity qu (KN/m2
1	33	25	411.6	208.3
2	35	23	376.0	202.3

5 CONCLUSION

The geoelectric section and the 2-D resistivity imaging revealed that the investigated area is underlain by clayey material (which constitutes the foundation soils) to the depth of about 18.6m. These materials are incompetent foundation soils because it normally compressed on imposing loads and leads to settlement. The seismic refraction results corroborate well with the results of resistivity survey thus affirming clay material as the foundation subsoil. The seismic result also revealed faulted zone within the basement bedrock which has negative effect on building foundation. Thus, the failures expressed on the building are due to incompetent subsurface materials and presumably the presence of fractured zone within the underlain basement bedrock.

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