Site characterization of Ayetoro Housing Scheme, Oyo, Nigeria

T.A. Adagunodo¹, L.A. Sunmonu², O.P. Oladejo³, O.S. Hammed⁴, K.D. Oyeyemi¹, O.T. Kayode¹

¹Department of Physics, Covenant University, Ota, Ogun State, Nigeria
²Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomosho, Oyo State, Nigeria
³Department of Physics, Emmanuel Alayande College of Education, Oyo, Oyo State, Nigeria
⁴Department of Physics, Federal University of Oye-Ekiti, Oye-Ekiti, Ekiti State, Nigeria

theophilus.adagunodo@covenantuniversity.edu.ng; taadagunodo@gmail.com

Abstract. Detail knowledge about the subsurface properties and its engineering implications is crucial in pre-foundational studies. Geophysical investigation has been found relevant in probing the subsurface for the purpose of deducing its characteristics before any engineering construction activities would commence because of its non-invasiveness. The deduced soil characteristics are used as preliminary information to determine the suitability of the site under investigation. When the results from such study are properly utilized, it prevents prospective structural failure and loss of valuable asset. Ground magnetic technique and Vertical Electrical Sounding (VES) was used to characterize the subsurface layers of Ayetoro Housing Scheme, Ojongbodu, Oyo West Local Government Area, with a view to determining the competency of the subsurface and hydrogeological prospect of the study area. A total of six traverses were established in the E-W direction and N-S direction in order to map the magnetic signatures in the study area. Thirty VES stations were occupied across the study area using the Schlumberger electrode array configuration with current electrode spacing varying from 130 to 200 m. The data acquired was interpreted qualitatively and quantitatively. The magnetic highs and lows were observed in all traverses. The magnetic highs represent regions of magnetic minerals such as metamorphic or igneous rocks while magnetic lows represent regions with linear geologic features. Power spectrum and analytical signal filtering techniques were used for the ground magnetic interpretation. Depth to magnetic sources from power spectrum analysis (local field) ranged from 5 to 62 m. However, depth to magnetic sources from analytical signal varied from 20 to 160 m with an average variation from 38.3 to 77.6 m. The western part, some part of the northwestern zone, base of the northeastern zone and some part (probably base) of the southern region of the study area were interpreted as regions of magnetic highs while others belong to average and low magnetic distribution. Twelve of the thirty modeled curves were H-type, eight were QH-type, three were HA-type, one was Q-type, two were A-type, two were HK-type and two were KH-type. The overburden thickness ranges from 1.8 m to 44.8 m, the geoelectrical sections obtained from the Sounding curves showed both 3-layer and 4-layer earth model. Nine of the VES stations show fresh bedrock while the remaining twenty one showed fractured basement. The models showed that the subsurface layers categorized into topsoil, weathered/clay layer, and fractured/fresh basement. It was concluded that the subsurface is incompetent for high-rise buildings since the lithology of the
area showed that clayey zones, thick overburden and fractured bedrocks constitute two-third of the study area. However, groundwater exploration (hand dug wells and boreholes) for domestic uses would not be problematic in the study area.

**Keywords**: Site characterization, Structural failure, Competent zone, Incompetent zone, Basement complex.

1. Introduction

Investigation of the subsurface properties for its engineering worthiness by geologists and geophysicists provide vital information that aid the building engineers the choice and design of civil engineering structures to adopt. A civil engineering construction without consideration of geological structures may result to differential settlements which could finally lead to collapse of such building. Linear features such as voids, fracture, and increase in water table are treats to the foundation of buildings. Geophysical methods suitable to provide subsurface information about the nature of the underground strata are quite available. These methods are however not to serve as replacement for geotechnical investigations, but the beauty in adopting these geophysical techniques is that they render cheap and quick preliminary approach to harvesting subsurface information for man’s utility [1].

Unceasing rate of structural failure in Nigeria has been so alarming such that both Federal and State Government are perturbed about the ugly incidence. This has led government to instruct the town planning unit to come up with regulatory code for any building above a storey. Oyo state government has not been left out in this instruction too since the quest to make life easy for the masses has been her watchword always. The causes of this collapse can be attributed to many factors among which are poor or inadequate construction materials and incompetent foundation soils. Incautiously, one particular major point that has always not been given serious attention in this part of the world is lack of inadequate information on the nature of subsurface conditions prior to construction exercise. Building foundation may experience failure due to presence of concealed geologic features such as sinkhole/cavity and shear zones which can actually lead to subsurface subsidence. The satisfactory design and construction of any building foundation can be accomplished only when the character 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 [2].

Geophysical investigation is one of the methods used in probing the soil/subsoil and subsurface for any engineering construction activities. This is because of its non-intrusive approach to civil engineering site investigation, relatively low and time saving advantage [3]. Geophysical methods or techniques are often used in site investigation to determine depths to the basement and map subsurface characterization prior to excavation and construction. Geophysical techniques have also been found very useful in geologic characterization [4 – 6], aquifer characterization [7 – 8], identification of gamma doses emanating from subsurface [9 – 11], contaminant plume identification [12 – 13] and location of buried wastes and other anthropogenic features [14]. Meaningful characterization of the earth’s subsurface using geophysics often requires an integrated approach [15].

In this study, ground magnetic method and Electrical resistivity employing Schulumberger electrode array also known as Vertical Electrical Sounding (VES) were used in order to know the geophysical characteristics of Ayetoro Housing Scheme. The purpose of using the two methods is to affirm a convincing result. This study is aimed at determining the characteristics of the subsurface at Ayetoro Housing Scheme in order to assess the stability of the subsurface for residential purpose and its hydrogeological prospects. Ground magnetic method or VES has been successfully used by several authors in order to evaluate the subsurface competency hence the adoption of the integrated techniques. Among the authors are Yusuf et al. [3], Macleod et al. [16], Jeffrey [17], Babu et al. [18], Kasidi and Ndatuwong [19], Adagunodo and Sunmonu [20], Adagunodo and Sunmonu [21], Jatau et
al. [22], Fatoba et al. [23], Ibitoye et al. [24], Ibeneme et al. [25] and Ojo et al. [26]. Adewoyin et al. [27] posited that geophysical technique safes cost and time for private residential building developers when the area of consideration is large.

2. The study area and its Geology

Ayetoro is an area in Oyo town, Oyo West LGA of Oyo state, Southwest Nigeria (Figure 1). It is situated about 10 km west of Emmanuel Alayande College of Education and lies within Latitude N07° 50’ 00” to N07° 53’ 00” and Longitude E003° 52’ 00” to E003° 55’ 00” approximately with an average elevation range of about 292 m. The study area is one of the major towns in Southwestern Nigeria. It has gained influx of citizens since the establishment of St. Andrew’s College, Oyo (now Emmanuel Alayande College of Education, Oyo) in 1896. Presently, Oyo has up to five tertiary institutions which has made the town to be part of urban renewal project for the government of Oyo state. Hence, the study area (Ayetoro Housing Scheme) is one of the new areas in the state undergoing positive turn around.

The geology of study area is crystalline rocks, which is of Precambrian in age. These rocks are composed of metamorphic and igneous rocks, which are found even beyond the study area. Some metasediments that are found in the surrounding environments of the study area such as Kajola, Ifedapo and Ifeloju local government area are: quartzofelds pathic biotite schists, quartzites and marble. Larger quantities of quartzites are found in Oyo town (Figure 2). Laterites are also found visible in some parts of Oyo, Oyo state, Nigeria.

![Figure 1: Map of Oyo State Indicating the Study Area](image URL)
3. Materials and Methods
The study area was divided into six traverses (Figure 3), on which the inter station spacing was chosen to be ten meters, then the magnetic field of the area was measured using a proton precession magnetometer. The total magnetic intensity (TMI) was recorded from the field, the regional field was removed from the TMI during data processing. After the removal of the regional field, the residual data was further enhanced using analytic signal [28 – 30] and power spectrum [31, 32] filtering techniques. The reason for using this two enhancement techniques is to compare their depth to magnetic sources results whether there are variations in the results or not. The geostructural maps of the study area were generated from the analytic signal data.

A total of thirty VES data (Figure 3) were acquired using PZ-02 Earth resistivity meter. The apparent resistivity was calculated from the resistance and the geometric factor of VES as presented by Koefoed [33]. The apparent resistivity was then plotted against the inter-current electrode spacing on a bi-logarithmic paper. The partial curve matching was applied to the curves in order to get the layers parameters (i.e. the layers’ resistivity and thickness). The curve types gotten from the partial curve matching were then classified according to Koefoed [33] method of VES curves classifications.

Figure 2: Geological map of Oyo
4. Results and Discussion

The results of the ground magnetic data were presented in log power spectrum and analytic signal profiles. The depths to magnetic sources were however calculated from the features on these profiles. VES results were presented as curves and geoelectrical sections.

The observed power spectrum curves were obtained from plotting the log power against the frequency for the six magnetic traverses (figures 4.1 to 4.12). It is divided into two parts the regional field (figures 4.1, 4.3, 4.5, 4.7, 4.9, 4.11) and the local field (figures 4.2, 4.4, 4.6, 4.8, 4.10, 4.12).

4.1 Log Power Spectrum

Based on the models of Spector and Grant [31], depths to magnetic basement or sources were calculated and presented in Table 1. The depth from regional field ranged from 0.0620 to 0.1500 km, the depth from local field ranged from 0.0050 to 0.0620 km while the total depth ranged from 0.0695 to 0.1935 km. Traverses 2 and 4 showed thin overburden (i.e. 5 and 12 m) while, traverses 1, 3, 5 and
6 overburden are relatively thick (i.e. 62, 43.5, 43.5, and 43.5 m) for construction of high rise buildings as reported by Adagunodo [15].

Figure 4.1: Regional field for traverse 1

Figure 4.2: Local field for traverse 1

Figure 4.3: Regional field for traverse 2

Figure 4.4: Local field for traverse 2
Figure 4.5: Regional field for traverse 3

\[ y = -0.3x + 13.58 \]

Figure 4.6: Local field for traverse 3

\[ y = 0.087x - 2.199 \]

Figure 4.7: Regional field for traverse 4

\[ y = -0.239x + 11.97 \]

Figure 4.8: Local field for traverse 4

\[ y = -0.024x + 4.455 \]
Figure 4.9: Regional field for traverse 5

\[ y = -0.200x + 11.92 \]

![Graph of Figure 4.9](image)

Figure 4.10: Local field for traverse 5

\[ y = 0.087x - 2.818 \]

![Graph of Figure 4.10](image)

Figure 4.11: Regional field for traverse 6

\[ y = -0.124x + 12.66 \]

![Graph of Figure 4.11](image)

Figure 4.12: Local field for traverse 6

\[ y = 0.087x - 3.999 \]

![Graph of Figure 4.12](image)
Table 1: Depth to magnetic sources at different traverses from the power spectrum curves.

| Regional (km) | Local (km) | Total (km) | Thickness of the basement (km) |
|---------------|------------|------------|-------------------------------|
| Traverse 1    | 0.0685     | 0.0620     | 0.1305                        | 0.0065           |
| Traverse 2    | 0.0645     | 0.0050     | 0.0695                        | 0.0595           |
| Traverse 3    | 0.1500     | 0.0435     | 0.1935                        | 0.1065           |
| Traverse 4    | 0.1195     | 0.0120     | 0.1315                        | 0.1075           |
| Traverse 5    | 0.1000     | 0.0435     | 0.1435                        | 0.0565           |
| Traverse 6    | 0.0620     | 0.0435     | 0.1055                        | 0.0185           |
| Average       | 0.0941     | 0.0349     | 0.1290                        | 0.0592           |

4.2 Analytical Signal Curves

Analytic signal is the second enhancement technique used for this study and its principles have been reported by Nabighian [28] and [29]. The depth to the anomaly was calculated using half-width method and the results were presented in Table 2. The analytic signal curves are presented in Figures 5.1 to 5.6. The magnetic highs and lows were observed in all the traverses. Generally, the magnetic highs represent regions of magnetic minerals such as metamorphic or igneous rocks while magnetic lows represent regions with linear geologic features. The total distance covered by each traverse is 1.7, 1.6, 0.72, 0.84, 0.72, and 1.6 km respectively.

Table 2: Depth to Magnetic Sources for Analytic Signal.

| Traverse | Depth to magnetic sources for the different peaks in each traverse (m) | Mean (m) |
|----------|-----------------------------------------------------------------------|----------|
| 1        | 40  30  20  100  40  30  60  160                                     | 60       |
| 2        | 60  40  40  40  120 - - -                                           | 60       |
| 3        | 35  35  20  45  55  40 - -                                          | 38.33333 |
| 4        | 50  55  40 - - - -                                                | 48.33333 |
| 5        | 90  68  75 - - - -                                                | 77.66667 |
| 6        | 40  25  30  30  90  80 - -                                         | 49.16667 |
| Mean of all depth to magnetic sources (m) | 55.58333 |
Figure 5.2: Analytic Signal curve for traverse 2

Figure 5.3: Analytic Signal curve for traverse 3

Figure 5.4: Analytic Signal curve for traverse 4

Figure 5.5: Analytic Signal curve for traverse 5

Figure 5.6: Analytic Signal curve for traverse 6
4.3 Geomagnetic Imaging of Ayetoro Housing Scheme

The contour map generated by surfer software showed areas with magnetic highs as well as areas with magnetic lows. Areas with magnetic highs are said to be competent for high-rise buildings while areas with magnetic lows are said to be incompetent. Magnetic values greater than 150 nT were experienced at the Western part, some part of the Northwest zone, base of the Northeast zone and some part (probably base) of the Southern region of the study area (Figure 6). These zones are considered to be competent for civil engineering activities irrespective of the shape and size. Since the magnetic signatures are not evenly distributed, it might not necessarily be confirmed that the study area is suitable for the construction of high-rise buildings.

The surface map further enhances the points made by the contour map because the thickness of the magnetic signatures are revealed (Figure 7) unlike the 2-D map that was only represented by contour lines. If high-rise building foundations were laid on this terrain, variations in the zones of the basement depressions (subsurface heterogeneity) might result into failed foundations which shall give rise to cracks in the columns of the building. This might further result to structural failure in the future.

Figure 6: The 2-D map of the study area.
4.4 Vertical Electrical Sounding

Thirty VES stations were occupied in the study area. The overburden thickness ranged from 1.8 to 44.8 m. Seven curve types were identified in the study area which are 12 H-type (VES 2, 3, 10, 12, 16, 17, 19, 21, 23, 28, 29, and 30), 8 QH-type (VES 1, 4, 5, 6, 9, 11, 18, and 24), 3 HA-type (VES 14, 15, and 22), 1 Q-type (VES 7), 2 A-type (VES 13 and 20), 2 HK-type (VES 25 and 26) and 2 KH-type (VES 8 and 27). Nine of the VES stations showed fresh bedrock while the remaining twenty one showed fractured bedrock. The VES interpretation reveals that the study area is not competent for high-rise building due to its fracture distribution and thick overburden present in some parts of the study area. The VES curves are grouped into six profiles as shown in Figure 3. Profile 1 has VES 1, 2, 3, 4 and 5 which runs in the E-W direction, profile 2 has VES 11, 10, 9, 8 and 6 in the E-W direction, profile 3 has VES 16, 15, 14, 13, 12 and 7 in the E-W direction, profile 4 has VES 17, 18, 22 and 23 also in the E-W direction, profile 5 has VES 19, 20 and 21 in the E-W direction, profile 6 has VES 29, 28, 27, 26, 25, 24 and 30 also in the E-W direction. Seven different curve types experienced in the study area were presented in Figures 8.1 to 8.7. The VES curves’ summary is presented in Table 3.
Figure 8.3: Modeled curve for VES 7 (Q).

Figure 8.4: Modeled curve for VES 8 (KH).

Figure 8.5: Modeled curve for VES 13 (A).

Figure 8.6: Modeled curve for VES 14 (HA).

Figure 8.7: Modeled curve for VES 25 (HK).
4.5  **Geoelectrical Section.**

The 30 VES stations were grouped into 6 profiles according to how they could be located on a straight line, the result of the VES station in each profile were then interpreted to see a 2-D representation of the subsurface.

4.5.1  **Profile 1.** From the geoelectric section of profile one it was revealed that the topsoil which is less than 2 m contains lateritic formation (Figure 9.1). The second layer which was interpreted as weathered layer i.e. mixture of clay and sand which extends up to the depth of about 25 m towards the western region of the profile, also noticed on the profile was clayey zone which was present at the eastern and central part of the profile. Directly under this formation lies fractured bedrocks with the shoot-out of fresh bedrock or basement towards the western region of the profile. This profile is incompetent for high-rise buildings.

| VES Number | Curve Type | Overburden Thickness (m) | Basement Nature |
|------------|------------|--------------------------|-----------------|
| 1          | QH         | 12.0                     | Fractured       |
| 2          | H          | 5.7                      | Fractured       |
| 3          | H          | 8.8                      | Fractured       |
| 4          | QH         | 27.1                     | Fresh           |
| 5          | QH         | 29.1                     | Fractured       |
| 6          | QH         | 25.3                     | Fractured       |
| 7          | Q          | 2.7                      | Fractured       |
| 8          | KH         | 15.5                     | Fractured       |
| 9          | QH         | 22.3                     | Fresh           |
| 10         | H          | 7.1                      | Fresh           |
| 11         | QH         | 12.1                     | Fresh           |
| 12         | H          | 18.8                     | Fractured       |
| 13         | A          | 7.3                      | Fractured       |
| 14         | HA         | 8.5                      | Fresh           |
| 15         | HA         | 5.1                      | Fractured       |
| 16         | H          | 11.5                     | Fresh           |
| 17         | H          | 6.4                      | Fractured       |
| 18         | QH         | 17.8                     | Fractured       |
| 19         | H          | 9.2                      | Fractured       |
| 20         | A          | 15.7                     | Fractured       |
| 21         | H          | 1.8                      | Fractured       |
| 22         | HA         | 30.0                     | Fractured       |
| 23         | H          | 8.1                      | Fractured       |
| 24         | QH         | 44.8                     | Fresh           |
| 25         | HK         | 4.1                      | Fractured       |
| 26         | HK         | 4.9                      | Fractured       |
| 27         | KH         | 7.9                      | Fresh           |
| 28         | H          | 5.9                      | Fresh           |
| 29         | H          | 7.3                      | Fractured       |
| 30         | H          | 5.8                      | Fractured       |
4.5.2 **Profile 2.** It was revealed from the geoelectric section that it has topsoil that extends to a depth of about 2 m in the eastern part, 5 m in the central part, and 2 m in the western region (Figure 9.2). The western part of the topsoil was also found to contain lateritic formation. The second layer was found to be made up of clayey layer on the eastern and west central region up to depth of about 15 m. Weathered layer was found in the central and part of the western region of the profile. The profile was found to be underlain by fractured basement on the eastern and western part while the central part is underlain with fresh basement. Only the central part of this profile is competent for high-rise building constructions.

4.5.3 **Profile 3.** The topsoil extends to a depth of about 2 m on the eastern part, and 5 m on the western part (Figure 9.3). The topsoil is mostly made up of lateritic formations from about a distance
of 100 m to the western end of the profile. The second layer was found to contain clayey zone in the eastern to central part of the profile ranging from a depth of about 7 to 15 m, weathered layer was also found in the central to western part of the profile with a depth ranging from 2 to 25 m. The basement was found to contain majorly fractured basement with fresh basement only appearing in the western part of the profile. Due to the thick overburden of the fresh bedrock in this profile, the entire profile will be good for low-rise building construction.

4.5.4 Profile 4. The topsoil has a depth of less than 2 m throughout the profile and contains laterite for about 200 m between the eastern and central region of the profile. The second layer was found to contain weathered layer in the eastern and west central part of the profile with a depth of about 6 m in the eastern region and 28 m in the west central part, the second layer was also found to contain clayey layer to a depth of 15 m in the central and western part of the profile (Figure 9.4). The profile is majorly underlain with fractured basement with fresh basement shooting up in the eastern part of the profile. The profile would be prosperous for borehole drilling and incompetent for high-rise building.
4.5.5 **Profile 5.** This profile has a topsoil of about 2 m, the second layer contains majorly clayey zone which ranges in depth from 5 m in the western part to 10 m in the eastern part. It also contains weathered layer in the central part of the profile with a depth of about 15 m, the profile showed fractured bedrock throughout (Figure 9.5). Hence, it is incompetent for civil engineering activities.

![Figure 9.5: Geoelectric section of profile 5.](image)

4.5.6 **Profile 6.** It has a topsoil of about 2 m deep and shows lateritic formation on the eastern part. The second layer has a depth of about 6 m and is made up of weathered layer on the eastern and western end of the profile. It also consists lateritic formation in the central part of the profile and a clayey layer of about 400 m wide above the lateritic layer (Figure 9.6). The basement is majorly intercalations of fractured and fresh bedrocks. Inhomogeneity in this profile makes it incompetent for civil engineering purposes but fractured bedrocks would be productive for groundwater if explored properly.

![Figure 9.6: Geoelectric section of profile 6](image)

4.6 **Site Characterization**

In a complex terrain such as crystalline bedrock, it is unadvisable to delineate the subsurface features via single geophysical technique. An integrated approach is recommended as the information lost in one technique would be revealed through the other method. Figure 10 shows the subsurface
characterization of Ayetoro Housing Scheme. The weighted averages of all the parameters considered in this study (geoelectrical and geomagnetic features) were used to classify the study area into competent, moderate, and incompetent zones. Competent and moderately competent zones are recommended for high-rise ‘residential buildings’, moderate zone needs an experts’ advice in order to choose the most suitable design for the intended high-rise structures while incompetent zone should be avoided for such task. Incompetent zone trends in NW – SE direction with a digression towards the south. If the building developers that would be employed in this study area keenly follow the outcome of this study and make use of appropriate building materials, it would greatly avert any form of structural failure that might occur in this allocate expanse of land by Oyo State government, Nigeria.

5. Conclusion

The study has been able to affirm that justifiable conclusion needs an integrated approach. From the qualitative and quantitative characterization of Ayetoro Housing Scheme using ground magnetic and vertical electrical sounding techniques, it is concluded that the study area is generally not suitable for the construction of high-rise buildings, and such structures should be avoided. However, the study area is suitable for low-rise buildings' constructions. Drilling of boreholes instead of wells is also recommended in this terrain due to the nature of the bedrock. This would also reduce water scarcity in the study area during dry season. It is further recommended that building constructions in the study area should strictly be handled by professionals.
Acknowledgement
We appreciate the management of Covenant University, Nigeria for the publication support received from them.

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