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Effects of Fractures on Buildings and Road Construction: A Case Study of Area BZ, Ahmadu Bello University, Zaria, Nigeria

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Abstract

Structural collapse due to the absence of geophysical information has become a major concern in the construction and building industries today. In this research, we reported the effect of fracture on some selected buildings in Area BZ, Ahmadu Bello University, Zaria. Reflex W software was used to analyze the vertical and horizontal profiles of the subsurface features in two-dimensional (2D) tomography of seismically related regions. The data were collected using MK6 Terraloc seismograph. Seismic refraction method was used to obtain relevant information about the subsurface strata. The velocities of different layers were obtained from the distance-time graph to generate the tomography of the four profiles of 115 m distance each. Results revealed that there are fractures beneath the surface, starting from the depth of 10 m into the basement region as evident in the four (4) profiles with variations in the seismic velocities of 1652 to 2086 m/s and 2521 to 2955 m/s for given strata. The 2D tomography of the study area also revealed that the eastern parts of profiles 1-3 may not be safe for the erection of buildings and other structures without excavation, while profile 4 revealed high levels of structural deformation and it is recommended as a high-risk region that will not support engineering structure. We, however, recommend that further geophysical surveys should be carried out in the area, using Electrical Resistivity Tomography (ERT).

Keywords: 2D tomography; Fracture; Refraction; Tomography; Profiles.

I. INTRODUCTION

A fracture is simply a separation or gap in a geologic formation, such as a joint or fault that divides the rock into two or more pieces [1]. It sometimes develops into a deep fissure or crevice in the rocks [2]. Fractures are mainly caused by external forces greater than the cohesive force binding the particles of the rock [3]. This usually happens at the weakest planes. Some of the causes of such fractures are; the weight of the overburden [4] and its erosion as it becomes closer to the earth's surface, Folding, shock waves during rock blasting, human activities such as farming, and a host of others [5]. Fracture has a direct effect on engineering structures as it leads to the collapse of structures. According to [6] stress concentration controls structural deformation around the vicinity of the rock in the roadway.

In this study the effects of fractures on buildings and road construction within Area BZ, Ahmadu Bello University, Zaria is being investigated.

A. Study Area

The study area is located in area B.Z within the main campus of Ahmadu Bello University, Zaria. (Fig. 1). It is about 760 m above sea level. It is approximately bounded by Latitude 11° 10’ 46’’N and 11° 4’ 25’’ N, Longitude 7° 36’ 55’’ E and 7° 44' 12"E. It is underlain by Precambrian rocks typical of Nigeria basement complex, which bear the imprint of thermo tectonic event dating from Achaean to early Paleozoic times [7].

Fig. 1 Google map of the Study Area

B. Geological Setting of the Study Area

The study area forms part of the northern Nigeria basement complex and apart from an extensive superficial cover, the rocks in this area can be divided according to [7] into a crystalline complex of migmatite and gneisses probably of Dahomeyan age, including relicts of an ancient Birrimian meta-sedimentary sequence. A younger meta-sedimentary series of Katangan age occupying north-south trending synclinal belts in the crystalline complex, and a suite of intrusive syntectonic to late tectonic granites and granodiorites of the late Precambrian to low Paleozoic age associated with extensive aplite and pegmatite development.

These rocks have been variably metamorphosed and granitized through at least two tectonic-metamorphic cycles and folded during the Pan African orogeny resulting in tight isoclinal folding about an East-West, North-South axes, alternating and deformation of rocks from low-grade phyllites to high-grade gneisses [1].

The area is also covered by laterites and alluvium deposits, with a valley cutting across almost the middle of the area where measurements were taken. There is also a gigantic gully erosion in the portion largely covered by the laterites (i.e. around the site of profile 4).

II. MATERIALS AND METHODS

The 24-channel Terraloc Mk6 machine which is a multi-channelled seismograph for refraction and high-resolution reflection surveys, tomography, etc. was used for obtaining data for this research. $45 - 100\,Hz$ vertical geophones connected to a take-out on a cable feeding the twenty-four channels with an extra geophone acting as a trigger geophone were used. The Terraloc Mk6 seismograph was connected to a printer, mouse, external keyboard, and monitor. The Terraloc Mk6 has the capacities for velocity calculation, picking first arrivers times, spectrum analysis, analysis of ground noise, and digital filtering. However, data acquired from the field were transferred from the Terraloc Mk6 into a desktop personal computer with a programme for analyzing and interpreting the observed data.

Grids were made in straight lines using pegs and ranging poles. Profiles 1, 2, and 3 were first taken close to a security post; with profile 3 laid across profiles 1 and 2. Whereas, profile 4 was taken after a valley over profiles 1, 2, and 3. The entire profile cut across the survey area. Data was collected using the forward and reverse profiling methods and the split spread method. Due to the hardness of the ground in some places, an iron rod was first used to bore holes in the ground where necessary, after which the geophones were pushed into the holes, and care was taken to ensure that they remained vertical and maintained good contact with the ground. The receiver geophones were laid out at an interval of five meters, after which the reel of connection cable was rolled out, and the geophones were connected to the various takeout on the cable.

The position of the first geophone was noted based on the direction of the forward profile and its connection to the instrument. The Terraloc Mk6 was placed at the centre of the spread, and the cables were connected to their appropriate channels. The trigger geophone was placed close to the shot point and connected to the instrument with the aid of the trigger coil. The base plate was placed on the shot point. The battery was connected and the instrument was switched on. The instrument underwent some memory tests before getting to the main menu, after which the instrument was armed under the measure menu, ready to receive signals. Seismic energy was sent into the ground with the aid of a hammer blow on the base plate, which triggered the instrument and recorded the ground vibration.

There were three shots at each shot position. The data was saved, and the instrument was assembled and taken to the next profile. The direction of the profile was mainly North-South and East-West.

A. Data Processing and Interpretation

When results from seismic refraction surveys are applied to geotechnical engineering applications, the structure of the subsurface is usually visualized. Interpretation methods based on the refraction of the first portion of the seismic wave have been known for many years [8].

Data collected from the field was subjected to different stages of processing to enhance the signal-to-noise ratio. The first set of data collected for the preliminary survey was processed by the application of bandpass filtering using an upper cut-off frequency of 200 Hz and a lower cut-off frequency of 5 Hz to minimize noise and to get the required frequency. The application of this filtering process helped in improving the quality of the real signal after the noise has been filtered out. This was followed by picking of the first arrivals, which was later used to plot the forward and reversed travel time curve to determine the velocity and the depth to the overburden and to also ascertain if there are dipping layers. This particular survey and the result obtained were used to determine the direction and layout geometry of the seismic tomography.

The processing began with the downloading of the raw data collected from the Terraloc Mk6 into a computer system. The instrument was connected via a Local Area Network (LAN) cable to the computer, where the data was saved in the folder name. The raw data was then converted into the Reflex format and recognized by REFLEX W, the software used for the processing of the raw data.

The interpretation of seismic data involves its expression in geological terms. When competently carried out, it requires the fitting together of all pertinent geological and geophysical information into an integrated picture that is more complete and more reliable than either source is likely to give alone.

III. RESULTS AND DISCUSSION

The travel time curves of the profiles were plotted for the direct and refracted waves, to determine the velocities of the various layers. From the travel time plot, it was obvious that most of the profiles have a dipping layer based on the discrepancies observed in the intercept time and the slope of the refractor. This preliminary interpretation work was carried out to determine the thickness of the overburden and depth to the basement, which will act as a guide for the interpretation of the seismic refraction model generated. The tables below show the results of the preliminary work carried out.

Table I. Calculated value obtain from profile 1

Physical parameters measured	Velocity m/s
Overburden velocity	1167
Velocity of refractor up-dip	2000
Velocity of refractor down-dip	1471
Thickness of overburden up-dip	15.2 m
Thickness of overburden down-dip	6.5 m

Table II. Calculated value obtain from profile 2

Physical parameters measured	Velocity m/s
Overburden velocity	774
Velocity of refractor up-dip	2143
Velocity of refractor down-dip	1679
Thickness of overburden up-dip	13.2 m
Thickness of overburden down-dip	2.02 m

Table III. Calculated value obtain from profile 3

Physical parameters measured	Velocity m/s
Overburden velocity	757
Velocity of refractor up-dip	3200
Velocity of refractor down-dip	1920
Thickness of overburden up-dip	16 m
Thickness of overburden down-dip	14 m

Table IV. Calculated value obtain from profile 4

Physical parameters measured	Velocity m/s
Overburden velocity	1000
Velocity of refractor up-dip	2000
Velocity of refractor down-dip	1333
Thickness of overburden up-dip	17.7m
Thickness of overburden down-dip	11.4m

A. *Interpretation of Tomography Model*

The tomography sections were displayed in colours ranging from blue, light green, yellow, orange, red, and indigo to purple colour. Each of the colours was assigned a velocity range, corresponding with the velocities of the respective layers as shown in the colour bar.

Fig. 2 shows that the first section being dark blue has a velocity range of $621\ m/s - 1947\ m/s$. Comparing this velocity range with that of the standard velocities of the earth's materials given by [8], [9], [10] and [11], the section represents the overburden layer which comprises of alluvium deposit, sandy clay, silt and laterite.

From model 1, the depth of the overburden is about 20 m (20 m thick) from the beginning of the profile towards the middle, and14m thick towards the end of the profile, which gives an average overburden thickness of 16 m. The next layer has a tomography section with a velocity range of $1947\ m/s - 2609\ m/s$ which represents the weathered basement. Fig. 2 shows that the weathered basement increases from the beginning of the profile towards the end with an average thickness of 6.0m with an undulating surface. The last segment is shown on the tomography by a mixture of green, yellow, indigo, red and brown colours. The section is seen to concentrate along a particular direction (i.e. end of the profile) which shows a sign of outcrop to the surface. The last layer which represents the fractured basement has a velocity of about 2609 m/s and above which continued from the weathered layer downwards.

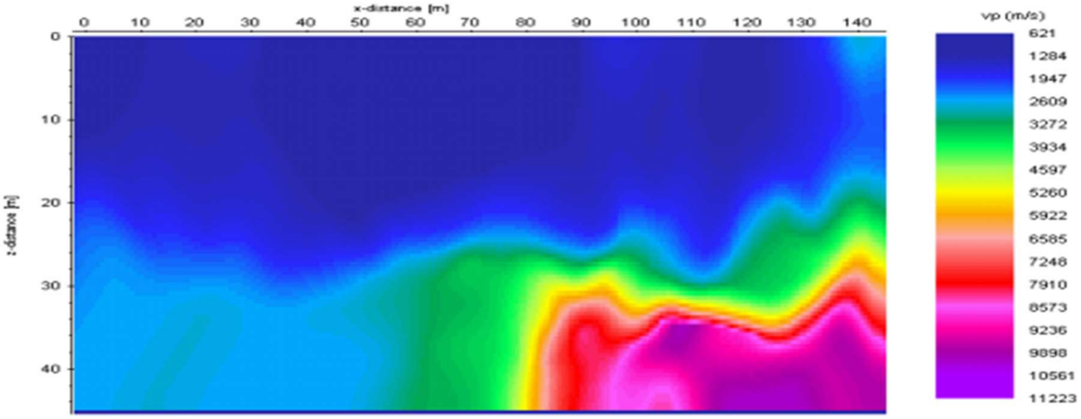

Fig. 2 Tomography model for Profile 1.

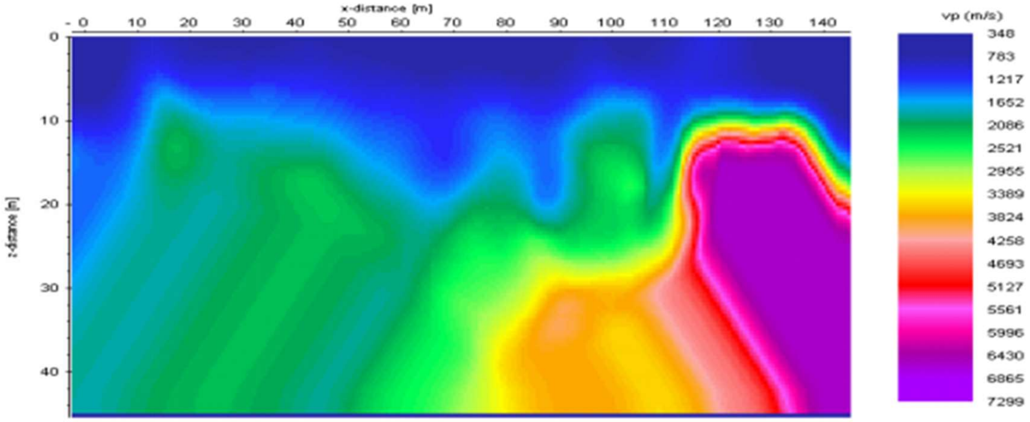

Fig. 3 Tomography model for Profile 2.

In profile 2, (see Fig. 3), the first section indicates a velocity range of 348 m/s to 1217 m/s (dark blue). Compared with the standard velocity table, the section represents the overburden segment of the region enclosed by the profile. Overburden constitutes alluvium, sand, sandy clay, and silt. As shown by the tomography section, the thickness of the overburden varies from portion to portion. At the beginning, 20 m, towards the middle, 16 m and 14 m respectively, and 8 m towards the end to give an average thickness of 14.5 m. The next section (light blue) has a velocity range of 1217 m/s to 2086 m/s which corresponds to the weathered basement when compared to standard velocity, with an average thickness of about 5.4 m. It is also seen that there are fractures in this section. The last section has a velocity range of 2086 m/s and above. Thus, it represents the basement which extends downward. On the tomography section, it is indicated by a mixture of green, yellow, orange, grey, red, and purple colours.

From the tomography model for profile three (see Fig. 4), the overburden has a velocity range of $467\ m/s - 1319\ m/s$. The thickness of this is 15.5 m with few variations as shown near west of the tomography. The weathered basement velocity ranges from $1319\ m/s - 2171\ m/s$. The average thickness is 5.0 m. This formation also extends laterally downwards. The basement is concentrated on a particular section of the tomography with a very high seismic velocity as shown from the tomography and extends downwards.

Profile 4 (see Fig. 5), consists of overburden which constitutes accumulated sediment formation with a velocity range of $466\ m/s - 1266\ m/s$ as shown on the tomography. The average thickness of the overburden is 17 m. The weathered layer has a velocity range of $1266\ m/s - 2066\ m/s$ with an average thickness of 8.7 m. The weathered basement undulates in a way that it is thicker at the edges and thinner at the middle as seen from the tomography. The last section is the basement with a velocity from 2066 m/s and above. This layer appears throughout the length of the profile unlike in the other profiles. It is also curved in the middle of the tomography, hence varying the thickness, making the centre of the tomography deeper and thicker than both edges of the model. It extends downward.

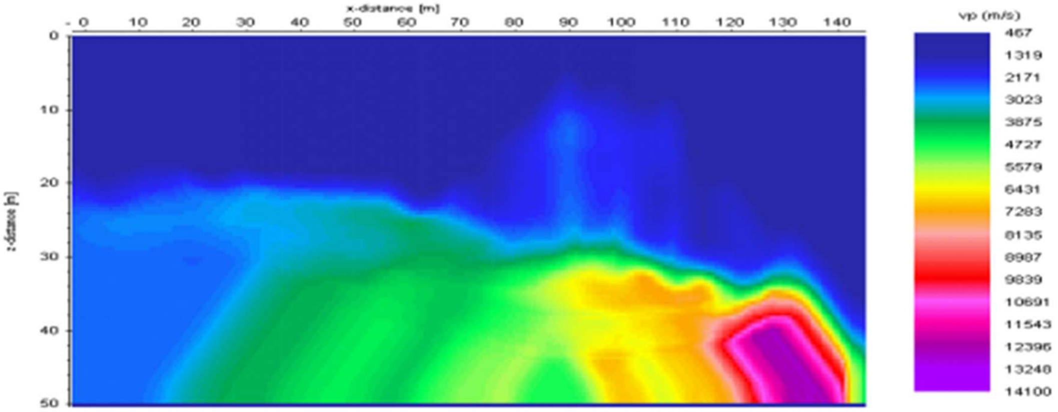

Fig. 4 Tomography model for Profile 3.

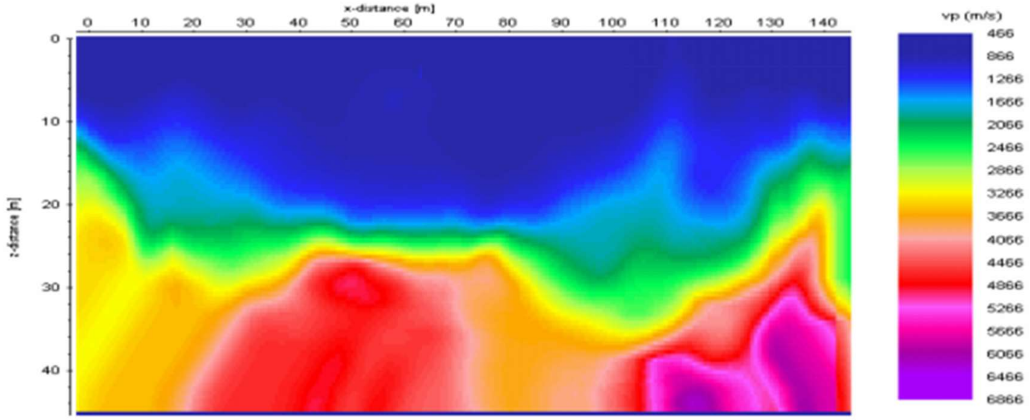

Fig. 5 Tomography model for Profile 4.

Near-surface seismic refraction tomography is a geophysical inversion technique designed for subsurface investigations where the number of units of interest is small (generally less than five) and seismic propagation velocity increases with depth. For regions with more substantial complexity, seismic reflection techniques are recommended [12].

The result of this study has revealed that the average thickness of the overburden within the survey area is 14 m while that of the weathered basement is estimated to be 6.3 m. The depth of the basement varies within the study area. The shallowest depth is 7.5 m at the profile 2 site. This confirms the outcrops that were physically seen in the area during the field survey. It also indicates that the overburden of the region where profile 2 was laid is shallow when compared to the other profiles. However, the deepest Profiles 1 and 2 which were laid parallel to each other have average overburden thicknesses of 11.0 m and 14.5 m, with an average weathered thickness of 6.0 m and 5.4 m respectively. Whereas, profile 3 has an average overburden thickness and weathered thickness of 15.5 m and 5.0 m respectively. Profile 4 which was taken at a distance further away from profiles 1, 2 and 3, where no outcrops were viewed at the surface, has an average overburden thickness of 17.0 m and a weathered thickness of 8.7 m. These depths correlate with what was observed in the region where the profiles were taken. The lower depths of profiles 1, 2, and 3 are attributed to the wearing away of the topsoil as well as the highly sloppy nature of the area enclosed by the profiles. Consequently, the thickness of the overburden in profiles 1, 2 and 3 revealed the variation of the thickness of the overburden as one moves from the regions of profiles 1, 2 and 3 towards profile 4. The tomography sections revealed that the area of profile 2 has fractures while the areas of the other profiles have undulating weathered layers. The tomography sections also showed that the thickness of the weathered layer of areas of profiles 1, 2 and 3 have an infinitesimal difference as compared to profile 4 whose thickness is a bit larger than theirs. The fresh basement of the regions where profiles 1 – 3 were taken is concentrated along a particular direction while that of profile 4 spreads. This indicates that in the region of profiles 1 – 3, the outcrops are concentrated along a particular side, unlike where profile 4 was taken.

IV. CONCLUSION

The results revealed that the survey area has obvious fractures in a few areas, mostly within the profile 2 region and the average thickness of the overburden within the survey area is consistent with the values obtained in areas within the basement complex of Nigeria such as Kaduna state, specifically Zaria. This average thickness is very low when compared to averages from areas within the sedimentary basins of Nigeria, such as the Niger Delta with an average of about $10{,}000\ m$. It also revealed that the area has been weathered to some extent. In addition, the results revealed that the fresh basement is concentrated along a particular direction and is made up of quartzite, probably also occurring with gneiss and some aplitic intrusions and extending downwards from the weathered layers in all profiles.

Based on the results obtained so far, it is thought that seismic refraction tomography is an accurate geophysical inversion technique that is ideally suited for subsurface investigation where the number of layers concerned is very small.

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