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A SEISMIC REFRACTION INVESTIGATION OF THE BEDROCK GEOMETRY OF THE NORTHERN SECTOR OF KUJAMA PRISON FARM, KADUNA

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Abstract

A seismic refraction study was carried out to investigate the bedrock configuration of the northern part of the Kujama Prison Farm, Kaduna. It was aimed at obtaining information on the subsurface layering of the area for civil works. The area covered was 200,000sqm having five (5) profiles with six (6) points on each profile and separated 100m apart. The Ras 24 seistronix seismogram in a forward and reverse shot method was used to acquire the field data and from the interpretation of the field data, the results suggests that the area is mainly underlain by two (2) layers namely overburden and basement bedrock. The velocity of the first layer was found to range from 478m/s to 1666m/s with average overburden thickness of 13.14m, the second layer velocity range from 1162mls to 7141m/s and the basement having an infinite thickness. The overburden material is found to be sandy, clayey and lateritic. From the study, it is suggestive that the bedrock topography has taken an irregular geometry over geological times.

***Keywords*:** Seismic refraction, bedrock geometry, overburden thickness, Kujama Prison Farm Kaduna

Introduction

Modern day man has continued to improve in thinking and technological development and application in an attempt to achieve the best of his environment. In the heart of this quest; Geophysics is playing a very significant role by providing an efficient and cost-effective means of collecting geologic information. Various techniques can be used to help determine the hydro stratigraphic framework, depth to bedrock, location of voids and faults or factures. Geophysics is simply investigating the Earth's interior structure using the principles of physics. Information from beneath the earth surface can be derived either by direct or indirect means [1]. Topographic map interpretation, aerial photography and the study of existing geological reports, maps, and soil surveys indirectly provide subsurface information. Direct methods include drilling of boreholes from which disturbed and undisturbed samples of the in situ materials may be collected and analysed, geotechnical field tests, such as the standard penetration test, which can be correlated with other engineering parameters, the use of modern geophysical techniques for mapping structures of the subsurface and geologic field reconnaissance, including the examination of in situ materials, man-made structures and groundwater level [1, 2]. Among these, geophysical methods with continuous measurement can provide copious information over a wide range of area.

Generally, collecting data without invading or non-destructively from a prefered area is a major concern in any geophysical exploration [3, 4]. To achieve the best in terms of planning and management of the environment, great knowledge of the subsurface environment has become very critical in construction engineering, resource exploitation and exploration. Poor knowledge of the subsurface site whether in construction engineering or resource exploration has often resulted in catastrophic consequences of seismic activities, disturbance of natural environmental phenomena, contamination and rupturing. Application of geophysical methods in geotechnical investigations has the capability of bringing out the subsurface image of a site which is very essential to the project decision and management [5]. It must be admitted that lack of knowledge about the subsurface strength distribution of a location either for erecting a structure or excavation is in disguise a risk to the inhabitants and people living in its environment. Normally, questions pertaining the foundation of buildings come to the fore when issues of buildings submerging under their load arise at a later time; or the collapse of deep wells, tunnels, dam walls, mining sites or caves have brought about questions on the available data or knowledge of the subsurface structures in such locations. Early detection of subsurface conditions that may pose potential danger to subsurface areas of interest can be accomplished with geophysical survey. Undetected cavities, fissures and other near surface features such as high clay content that serves as sources and risk to buildings and subsurface activities put up without any geotechnical investigations. Geological features and conditions beneath the surface such as voids, conduits, fractures, nearness of the water table to the surface, depth to bedrock are vital geophysical information that can enhance quality decision making with regards to subsurface impacts on projects intended in certain location so as to avoid possible catastrophe in the future [6]. In the light of the above this study, was set out to investigate the bedrock geometry of the northern part of the Kujama prison farm to provide information for civil works.

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Location of the Study Area, Geology and Method.

The Kujama prison farm is located in the heart of Kujama which is the capital of Chikun Local Government Area (Figure 1a) and its geographical coordinates of latitude and longitude lies between 10^0 26′23. 30″ N to 10^0 27′10. 30″ N and 7^0 34′02. 0″E to 7^0 36′52. 30″E (Figure 1b). Kujama is lying on a gentle undulating plain ranging from 450-650m above sea level underlined by the crystalline basement complex of the Precambrian age. The area and its environs are situated on a lowland area alike. In some parts of the area, there exist some outcrops of hard resistant granite rocks which are basically the result of weathering activities on the Precambrian rocks which were exposed by erosion through

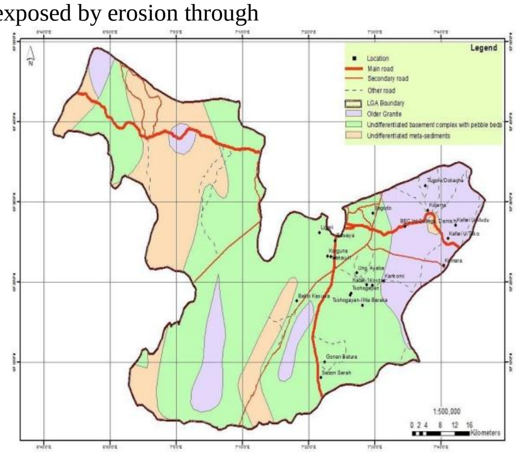

Figure1a: Geological Map of Chikun Local Government Area, Kaduna State

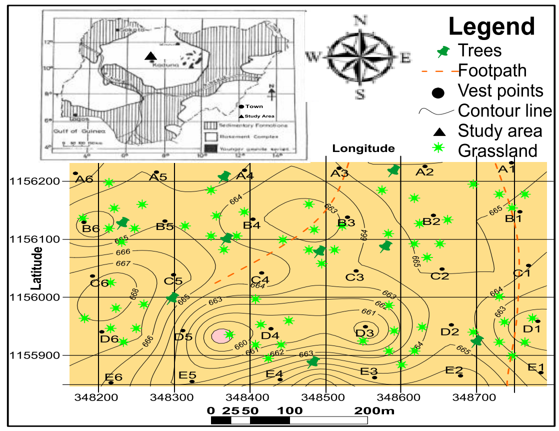

Figure 1b. Map of Study Area Showing the location of the profiles and its Elevation (Inset, Geological map of Nigeria)

Geophysical investigation involving the seismic refraction was conducted along profiles established at the northern sector of the Kujama prison Farm. Seismic refraction finds part of its application in the determination of rock competence for engineering purposes, depth to bedrock, groundwater exploration, crustal structure and tectonics [7, 8, 9, 10].

The seismic refraction method is based on the measurement of the travel time of seismic waves refracted at the interfaces between subsurface layers of different velocity [11]. The seismic refraction data was acquired using a 24-geophone channels seismograph called Ras 24 Seistronix. The area covered was 200,000m^2 having five (5) profiles, each profile is 400m long with six (6) points and each separated by 100m apart. The forward and reverse shot seismic refraction method was used. The technique consisted of laying out 12 geophones in a straight line and recording arrival times from shot points produced by striking a 10kg sledge hammer into a steel plate at a minimum of 2m offset distance of the geophone spread on a system control unit, the geophone – geophone spacing was 5m resulting in a spread of 50m. For noise level reduction and enhancement of the quality of the seismic signal, the steel plate was struck two times and the acquisition was done in an area that was free of unwanted seismic signal and traffic noise.

Theory of Seismic Refraction

A seismic refraction survey consists in deploying a line of seismic receivers (i.e. geophones) on the ground, and shooting a seismic source into the receivers, usually at multiple locations. The method of seismic refraction works when you have two or more layers of different rock materials in the subsurface, and the upper layer has a smaller Velocity (over burden) than the lower layer (refractor). When the incident angle of a seismic wave is the critical angle, the seismic wave travels through the interface with the Velocity of the lower layer, and then is refracted back to the surface. We measure the time it takes for the primary wave to travel from the seismic source to every receiver (geophones) in the profile.

Considering a two layered subsurface as shown in (Figure. 2) where x is the offset distance from the energy source S to the geophone G. Z_1 is the thickness of the first layer, V_1 is the signal velocity in the first layer and $V_2$is the signal velocity in the second layer. The path of the energy signal is defined as SABG Using (Figure 2), we consider the wave SA which hits the layer boundary at the critical angle θ_c.

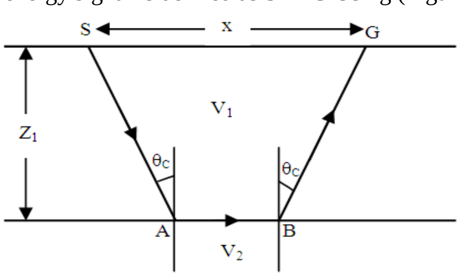

Figure 2. A two layer horizontal stratified substratum

The total travel time for the refraction signal to travel from the source 'S' to the geophone 'G' is expressed as

$$T_{SG} = T_{SA} + T_{AB} + T_{BG} \quad (1)$$

$$T_{SG} = \frac{SA}{V_1} + \frac{AB}{V_2} + \frac{BG}{V_1} \quad (2)$$

From (Figure 2), SA=BG= $\frac{Z_1}{\cos\Theta_C}$ and AB = $x - 2Z_1$ TanΘ_C

$$T_{SG} = \frac{Z_1}{V_1 \cos\Theta_C} + \frac{x - 2Z_1 \tan\Theta_C}{v_2} + \frac{Z_1}{V_1 \cos\Theta_C} \quad (3)$$

$$T_{SG} = \frac{2Z_1}{V_1 \cos\Theta_C} + \frac{x}{v_2} - \frac{2Z_1 \tan\Theta_C}{v_2} \quad (4)$$

$$T_{SG} = \frac{x}{v_2} + \frac{2Z_1}{V_1 \cos\Theta_C} - \frac{2Z_1 \sin\Theta_C}{v_2 \cos\Theta_C} \quad (5)$$

From Snell's law, $\sin\Theta_C = \frac{v_1}{v_2}$, while the relationship $sin^2\Theta + cos^2\Theta = 1$

Equation (5) can be expressed as

$$T_{SG} = \frac{x}{v_2} - \frac{2Z_1}{V_1 \cos\Theta_C}[1 - sin^2\Theta_C] \quad (6)$$

$$T_{SG} = \frac{x}{v_2} - \frac{2Z_1 \cos\Theta_C}{V_1} \quad (7)$$

Equation (7) gives the total time taken by the wave to travel from the bedrock back to the geophones.

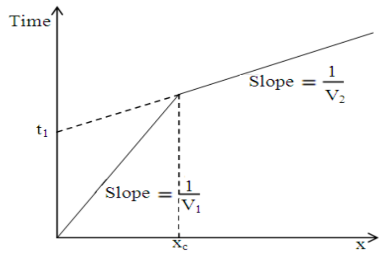

Figure 3. Travel-Time graph for two layer surface [11].

The time distance curve produces two segments with different slopes as shown in (Figure 3), it shows that it can be used to determine the velocities of the two layers. The slope of the first part gives $\frac{1}{V_1}$ and the slope of the second part gives $\frac{1}{V_2}$. The inverse of slopes gives us the velocities of the subsurface. The critical distance (x_c) is the point on the surface at which the direct wave and the head wave arrived simultaneously. Before the critical distance, the direct waves arrive first while beyond the critical distance, the head wave arrives first t_1 is the intercept of the second segment of the straight line graph. With all the necessary information obtained from the plot, the depth of the first layer is obtained to be

$$Z = \frac{t_1 V_1 V_2}{2\sqrt{V_2^2 - V_1^2}} \quad (8)$$

Data Processing and Interpretation

The first arrival breaks were picked using the Ras 24 seistronix seismograms software (Figures 4a and 4b) and after the picks a plot is then made showing the arrival times against distance between the shot and geophone positions for the Forward and Reverse Shots and this is called a time-distance graph (Figure 5). Distinctive segments on the time - distance graph were interpreted as representative of different subsurface layer [12]. The interpretation of the seismic signal is therefore set to determine the layer velocities of which layer velocities were determined from the inverse of the slopes of such segments and depth values to the different acoustic interfaces were determined using the intercept method and crossover distance method [12]. The time distance graph was plotted (using Excel package). (Figure 5) is a sample of the resulting time-distance graph plotted with data from the forward and reverse shot of Line A (3a_b). The graphs show a two-layer case. The slopes of the two layers were calculated, and the inverse of the slopes gives the values for V_1 and V_2. The depth to refractor was also calculated using the relation in equation 8. This was done for all the shot points.

Also, the Oasis montaj software was used to contour the layer velocity maps (Figures 6 and 7) and layer depth contour (Figure 8). The information produced on the maps were used to obtain other geological information as they relate to the study region.

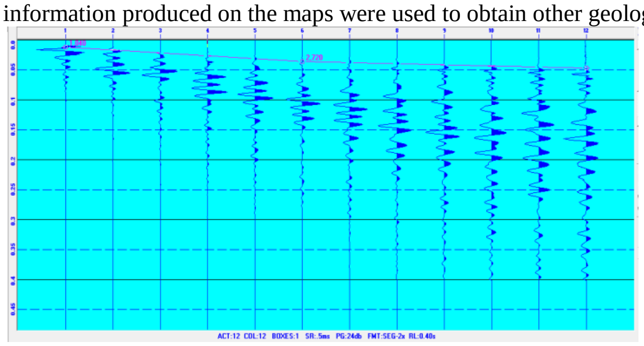

Figure 4a. Forward Seismic Shot (LNA_3a)

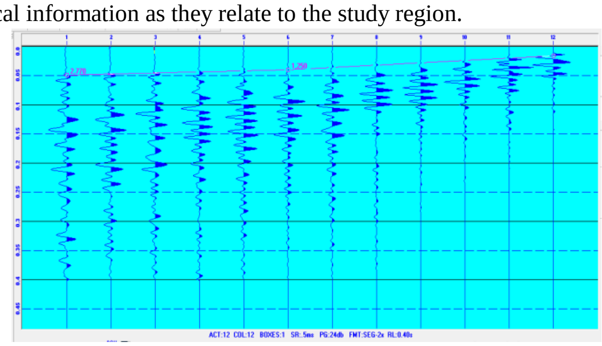

Figure 4b. Reverse Seismic Shot (LNA_3b)

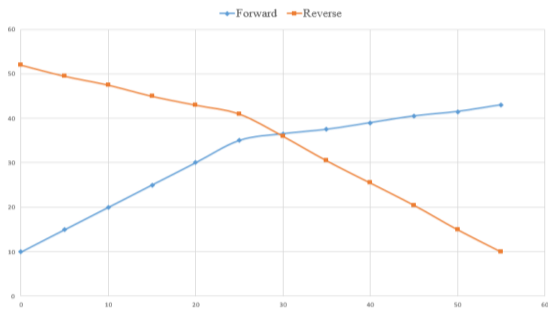

Figure 5. Forward and Reverse Travel Time-Distance Graph (LNA3a,b)

Results and Discussions

The main objective and end product of any seismic work is the ability to interpret seismic data in geological terms [13]. In most seismic refraction techniques, the assumption lies on the value of the velocity (V_1) of the section above the refractor. This is because of the heterogeneous composition of the superficial deposits which make the overburden velocity rarely constant [14]. In this interpretation, a combination of the general geology of the area and the use of standard tables that provide approximate range of velocities of longitudinal seismic waves through some earth materials was employed. A good attempt was made to obtain a reasonable geological structure for the surveyed area. This process was repeated for all the profiles.

Based on the values of the velocity obtained, the first layer velocity throughout the entire survey area varies between 478m/s to 1666 m/. The velocity values obtained for the first layer over the entire survey area was correlated with the materials found in the superficial layers. It was also observed on the field that this superficial layer is composed of clay, dry sand, coarse sand and gravel. The first layer velocity contour map showed lateral variation in velocities of the seismic waves through the different earth materials of the survey area (Figure 6). There is a significant rise in seismic velocity values towards the north south part of the survey area (point marked as, A1a,b, A2a, A6a,b B3a, B2a,b, D3a, E6a,b, E5a, E4a,b, E3a), it is marked with the red to violet colour on the contour map (Figure 6) . Low seismic velocity values were observed towards the North East section, and South West sections of the survey area, (points marked as A2b, A3b, A4a,b, A5a,b, B3b,B4a,b, B5a,b, B6a,b, C4b, C5a,b, C6a,b, C1a, D5a,b, D6a,b, E1b, E2a), it is marked with the blue to green colour on the contour map (Figure 6) which is characteristic of unconsolidated rock materials, chiefly weathered earth materials and dry sand (Table 1).

Table 1. Established Standard P – Wave Velocities of Soil and Rock types [Modified from 15, 16]

Rock Type	Standard P-Wave Velocity (m/s)
Sand with gravel (dry)	490 – 690
Sand/ Clay/gravel/coarse sand	690 -4200
Sand stone	1400 – 4300
Granite	5500 – 6000

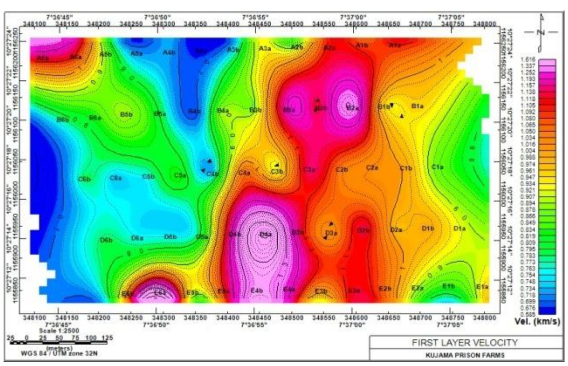

Figure 6. Map of the First Layer Seismic Velocity

The velocity values of the second layer throughout the survey area vary from 1162m/s to 7142m/s, and was used to obtain the contour map for V_2 (second layer) (Figure 7). The points marked A1a,b, A2a,b, A3a, A6a, B2a,b B3a,b, B5b, B6a,b, C6b, D1a,b, D2a,b, E1a,b, E3b, E5a,b, E6a,b on the contour map fig.8 are the areas having high velocities. The points marked A3b, A4a,b, A5a,b, B4a,b, B5b, C1a,b, C2b, C3a,b, C4a,C5a,b, C6a,b, D3a,b, D4a,b, D5a,b, D6a,b,E2b, E4b are the areas of low velocities. High concentrations of closures were also observed around some part of the north, west, south and east parts of the survey area. These are characteristics of lateritic rocks and granites. However, low seismic velocities were observed towards the north central portion of the survey area.

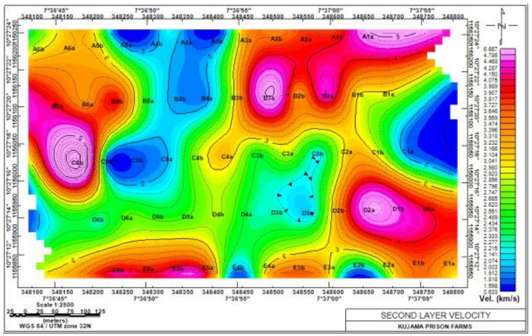

Figure7. Map of the Second Layer Seismic Velocity

The Refractor Depth

(Figure 8) shows variation in the thickness of the overburden layer across the survey area. This is an indication of the heterogeneous nature of the basement. The (Figure 8) shows that the bedrock topography is irregular with high depths around A6b, B2b, B2a,b, B6b, C4a, C6b, D1a,b, D2a,b, D6b, E3a,b, E4b, E5b, E6b and the basement is shallow around A2b to A6a down to around to D3a to D6a also around the north eastern part. Generally, the bedrock dips around the western, north eastern, and south eastern parts of the northern sector of the Kujama prison farm.

The low velocity associated with the regions of basement uplift may be as a result of intense weathering of the fresh basement over geological times.

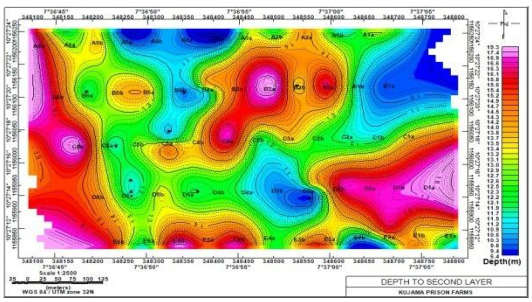

Figure 8. Map of the Depth to Second Layer

Conclusion

The interpretation of the results showed that two layers underlie the study area. The upper layer consists of sand, clay, sandy clay and laterite. The second layer is the basement. The basement revealed its composition to be chiefly, granites and undifferentiated basement complex rocks. The recommended zones for foundation design, engineering structural and other related works, are the regions where the basement materials, have a high velocity with a shallow depth to the top layer, these points are A1a,b, A2b, A3a, A5b, A6a, B1a,b, B6a, C2a, C6b, E1a, E4a and E6a. These are good zones for siting high rise buildings associated with minimal cost.

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