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Evaluation of Seismological Activity and Site Characterization Using Seismic Tomography

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ABSTRACT

Though major earthquake of large magnitude has not occurred in Nigeria from previous records, however, the incessant earth tremor currently being experienced within the central northern Nigeria basement complex whose cause is yet to be ascertained calls for concern. Hence, the need for site seismological evaluation and characterization becomes paramount before putting up structures. The aim of this research therefore is to carry out a detail seismic survey of the site under investigation, and determine among other factors, the velocity distribution, the overburden thickness, depth to aquifer, depth to weathered and fresh basement, which will be used to infer and evaluate the nature of Geological Hazards, Seismic shaking hazard, surface fault rupture hazard, ground lurching, liquefaction Hazard, water inundation and shrink swell potential of near-surface soil of the site. The results of the investigation revealed that the seismic wave velocity registered a general increase of velocity with depth, with velocity range of 990 m/s to 3340 m/s. The velocity distribution gave an indication that the site is majorly characterized by hard rocks which are of low elevation thereby ruling out the possibility of landslide in the event of seismic shaking from a remote earthquake. The seismic survey did not detect any obvious fracture or fault that will constitute geological hazard by acting as pathway for contaminant to move into the underground water, or that could engender major earthquake that will cause surface fault rupture hazard. The investigation also reveals that the soil is not predominantly loose sand and the groundwater is restricted to isolated aquifers, therefore the structure sited within this site will not heave or lurch in the event of any shaking because, the possibility of soil liquefaction is ruled out. It was also observed that since the near surface material is not predominantly clay but laterite, therefore the swell potential of the near surface soil will be infinitesimally small. The geological hazard analysis have revealed that the site under investigation is not prone to any geological hazards that could be induced by earthquake, faults, elevation depth to aquifer, and nature of soil.

Introduction

The aim of this research is to carry out a detail seismic survey to determine among other factors, the thickness of the overburden, the depth to the basement (Bed rock), and the depth to the aquifer. This will be used to infer and evaluate the nature of Geological Hazards, Seismic shaking hazard, surface fault rupture hazard, ground lurching, liquefaction Hazard, water inundation and shrink swell potential of near-surface soil within the site under investigation.

Several equipment was deployed for this survey, among which is Terraloc mark 6 digital seismograph, 13 geophones, reels of cables with takeout points, sledge hammer as energy source etc. Considering the previous work done by other researchers it was observed that, "Several earth tremors have been reported in northern Egypt before the 1990s" [1]. [4] in their review paper "has shown that virtually every region in the African continent has come under the threat of some form of seismic event with magnitudes and intensities resulting in a wide range of devastations". [3] stated in their work that "the deep comprehension of the Serghaya fault behavior allows a realistic evaluation of its seismic activity which could be used thereafter for an assessment of seismic hazard". [2] stated that "the average P-wave velocity of soil and bedrock layers were calculated by using the seismic refraction tomography (SRT) method and then the distribution maps of P-wave velocities were delineated".

Location of the Study Area

Figure 1. Image Map of the survey area showing the seismic profiles and boreholes.

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The study area is within the basement complex of the North Central Nigeria, bounded by Latitude 8° 56' 47.13''N Longitude 7° 17' 27.82''E, Latitude 8° 56' 39.18''N Longitude 7° 18' 10.68''E, Latitude 8° 56' 16.56''N Longitude 7° 18' 02.95''E with an average elevation of 305mabove mean sea level. The image map of the study area alongside the profile lines are shown in figure

Geology of the Study area

The study area is predominately underlain by high grade metamorphic and igneous rocks of Precambrian age. These rocks consist of gneiss, migmatites and granites. A schist belt outcrops along the eastern margin of the area. The belt broadens southwards and attains a maximum development to the southeastern sector of the area where the topography is rugged and the relief is high [5]. The Basement Complex rocks made up of igneous and metamorphic rocks cover about 48 % of the total area and in some places the land is occupied by hills and dissected terrain. [6].

Data acquisition

The data acquisition started with planting of the geophones in a straight line at an interval of 5 m, after which, the geophones were connected to the reels at their takeout points. The energy source was place at an offset distance of 30 m. The reels where connected to the seismograph, and shots were deployed at interval of 5 m, at an offset distance of 30 m before the first Geophone and 30 m after the last geophone. The generated seismogram was recorded for onward processing at the geophysical workstation.

Data processing

Data processing started with importing the raw seismic data (Fig. 2) generated in the field into dedicated seismic software. The band-pass filter was set to remove the effect of very low and very high frequency noise. The gain filter was applied to remove the effect of geometrical spreading. The first arrival travel time was picked from the processed data (Fig. 3). The inversion of the picked travel time, with the inculcation of static subroutine was carried out. The generated initial model was used to iteratively generate a tomography model that represents the distribution of seismic velocity within the subsurface. The overburden thickness was determine, alongside the depth to the aquifer zone and basement complex. These data was used to generate a 3D surfaces and contour maps.

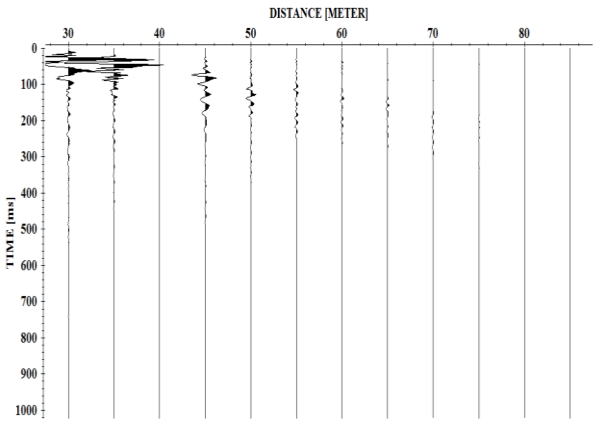

Figure 2. One of the raw seismic data generated in the Field.

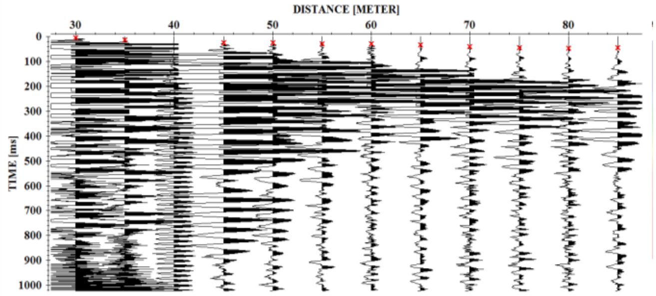

Figure 3. The equivalent processed data with picked arrival time.

Results

Four seismic profiles were generated at the site under investigation. Profile BH 7, which was generated across borehole BH 7 is shown in figure 4. Profile BH 6, which was generated across borehole BH 6 is shown in figure 5. Profile BH 1, which is a seismic profile generated across borehole BH 1 is shown in figure 6. Profile BH 4, which is a seismic profile generated across borehole BH 4 is shown in figure 7.

Profile BH 7 which was taken across borehole BH 7, have a range of velocity of 990 m/s to 3019 m/s. The velocity distribution shows a general increase of velocity with depth. The highly weathered basement showed up at the beginning of the profile, but tapered out at the end of the profile under a thick overburden cover. The average overburden thickness is 24 m. The depth to the bedrock (fresh basement) on this profile ranges between 19 to 34 m.

Profile BH 6 which was generated across borehole BH 6, has a velocity range 1161 m/s to 2832 m/s. It showed a general increase of velocity with depth with an undulation of the basement topography. It also has thick overburden cover, with an average overburden thickness of 29 m. it gave a clear indication of highly weathered basement, at the beginning of the profile. The depth to the bed rock ranges between 14 m to 39 m.

Profile BH 1 which was taken across borehole BH 1, started in the vicinity of an outcrop, has a range of velocity of 1212 m/s and 3340 m/s. Except for distance of 20 m along profile, the profile has thick overburden cover, with an average overburden thickness of 21 m. the depth to the bedrock within this profile ranges from 0 to 36 m.

Profile BH 4, which is a profile generated across borehole BH 4, has a range of velocity of 1185 m/s to 3172 m/s. It has a very thin overburden cover that is almost evenly distributed, with an average value of 11 m. The depth to the bedrock along this profile, ranges from 7 m to 27 m.

In addition to the 2D profiles of figure 4 to 7, 3D surfaces along with their equivalent contour maps were generated to cover the entire areas under investigation. The 3D surfaces along with their equivalent contour maps are shown in figure 8 to 14.

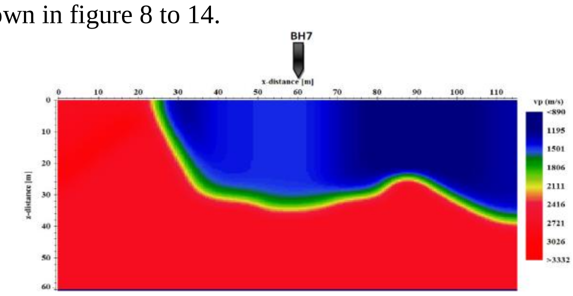

Figure 4. Profile BH 7, showing the borehole drilled point (BH 7), and distribution of seismic velocity within the subsurface, with a colour scale bar to infer the velocities represented by the various colours.

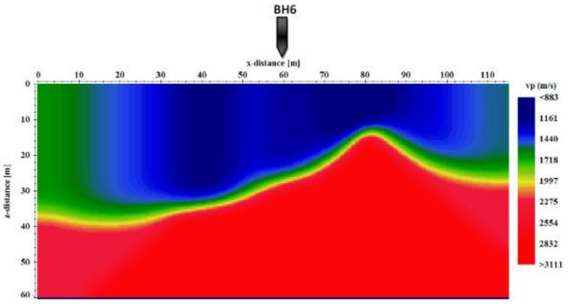

Figure 5. Profile BH 6, showing the borehole drilled point (BH 6), and distribution of seismic velocity within the subsurface, with a colour scale bar to infer the velocities represented by the various.

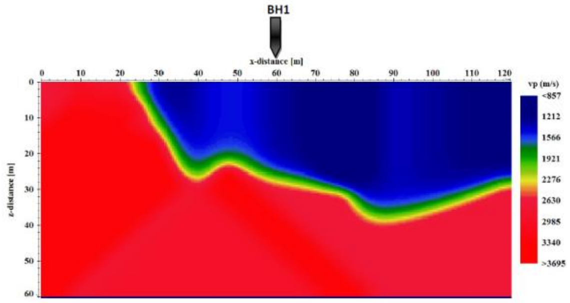

Figure 6. Profile BH 1, showing the borehole drilled point (BH 1), and distribution of seismic velocity within the subsurface, with a colour scale bar to infer the velocities represented by the various colours.

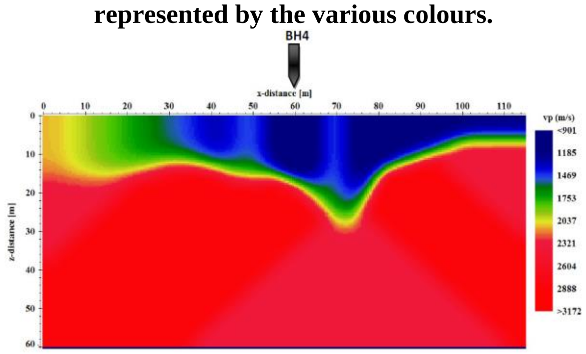

Figure 7. Profile BH 4, showing the borehole drilled point (BH 4), and distribution of seismic velocity within the subsurface, with a colour scale bar to infer the velocities represented by the various colours.

Figure 8, is a 3D surface of seismic velocity distribution at the surface, within the study area. Figure 9 is an equivalent contour map of surface distribution of seismic velocity within the study area. It has a velocity range of 900 m/s which is within the range of overburden velocity to 3000 m/s, which is within the range of fresh basement velocity. The surface velocity distribution in the survey area, taking reference point at the center of the 3D surface and contour map, is characterized with regions of highly weathered top soil material, that are flanked by basement rock in the North, and a fan of distribution of weathered top soil material in the South. It can be concluded that the site is characterize at the surface with rocks and weathered top soil material, with alternate regions of high velocity and regions of low velocity.

In figure 10 and 11, a representative depth of 25 m was chosen to ascertain the distribution of the seismic velocity at that depth. The range of velocity within this region is 1200 m/s to 3200 m/s, which falls within the velocity of the weathered and fresh basement. The velocity distribution at this depth is still not uniform. Taking the center of the contour as reference point, you have regions of low velocity in the North East flank by regions of high velocity.

The South West is also characterize with regions of high velocity, relative to the North East and South East.

Figure 12 and 13 were modeled to determine the overburden thickness, which also signifies depth to basement in the survey area. It was discovered that the range of overburden thickness is between 0 m in the vicinity of an outcrop, to 40 m, which falls within the regions of weathered material with low seismic velocity. Therefore one can rightly infer that the fresh basement rock occurred uniformly in the site under investigation at a depth of 40 m. This thick overburden covers are located within the vicinity of BH1, BH6 and BH7, but however, there are not sited at the thickest overburden points.

Figure 14 and 15 was analyzed to determine the depth to aquifer, and to ascertain the best points where boreholes that will be used for municipal purpose could be sited, for maximum yield. It was discovered that the aquifer depth ranges from 0 m at the vicinity of outcropping basement to 34 m at the points of highest overburden thickness. The direction of underground water flow was simulated (Fig. 14 and 15) base on the deferential depths to the aquifer using vector maps. On that basis, two points were selected that could habours boreholes that could be used for municipal purpose. The two points are indicated by red circle with an arrow. The points are on the seismic profiles taken across BH6 and BH7. The indicated point close to BH 6 has coordinate 8^{o} 56' 23.62''N, 7^{o} 17' 47.75'' E, and it is 40 m from BH6, Northward. The indicated point close to BH 7 has coordinate 8^{o} 56' 18.99''N, 7^{o} 17' 51.89''E, and it is 60 m from BH7, Southward.

Site Hazards Analysis

Base on the analysis and results stated so far, the site was also analyzed for geological hazards, seismic shaking hazard, Surface Fault Rupture Hazard, Ground Lurching, Liquefaction Hazards, water inundation and shrink Swell potential of near Surface soil. The results are state below:

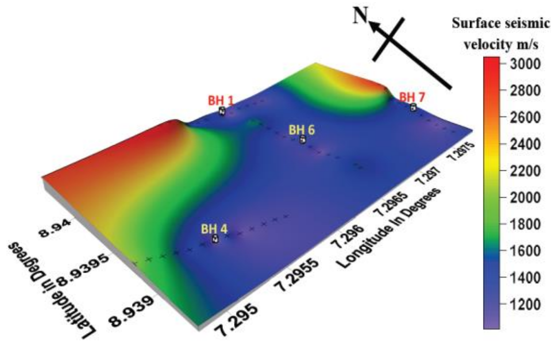

Figure 8. 3D Surface contour of Surface Seismic Velocity distribution in the survey area.

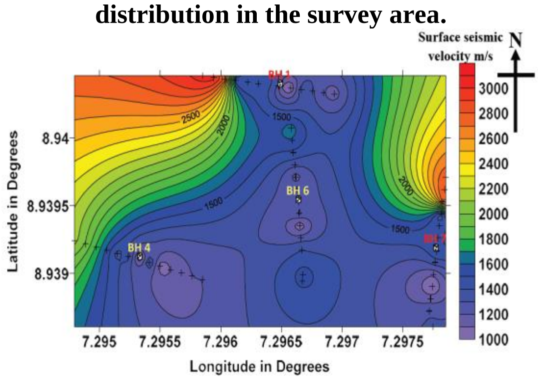

Figure 9. equivalent contour map of Surface Seismic Velocity distribution in the survey area.

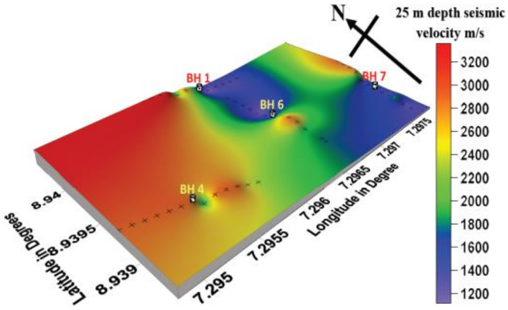

Figure 10. 3D surface of Velocity distribution at depth of 25 m in the survey area.

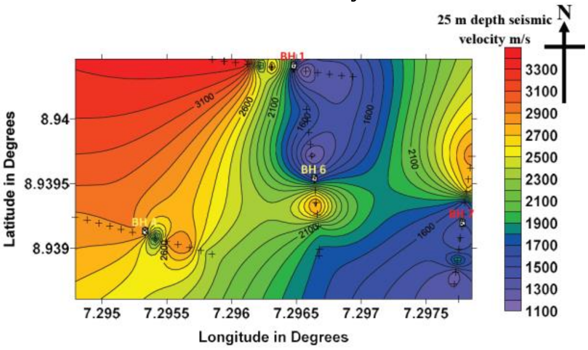

Figure 11. Equivalent contour Map of Velocity distribution at depth of 25 m in the survey area.

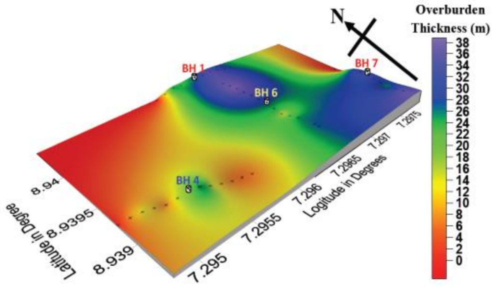

Figure 12. 3D Surface of Overburden thickness and depth to Bedrock.

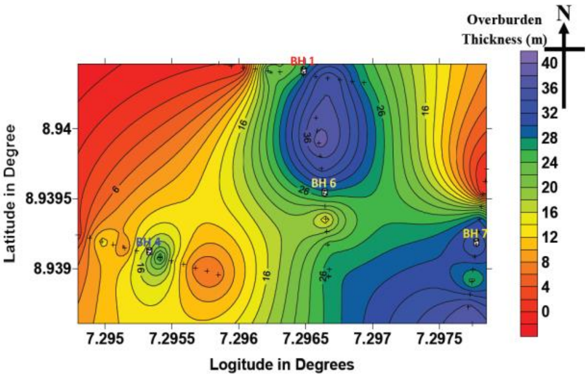

Figure 13. Equivalent contour map of Overburden thickness and depth to Bedrock.

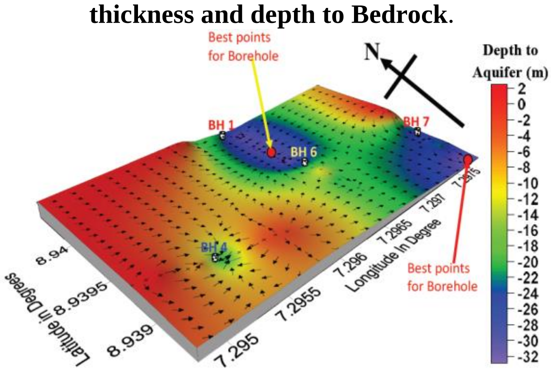

Figure 14. 3D Surface of Depth to aquifer.

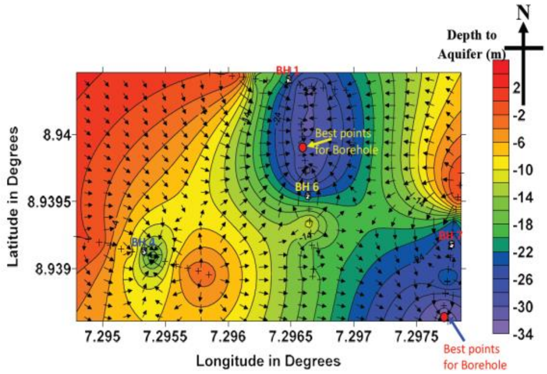

Figure 15. Equivalent contour map of Depth to aquifer.

Geological Hazards

The seismic survey result did not detect any obvious fracture or fault within the site under investigation that will constitute any geological hazards, by acting as a path way for contaminants to access the underground water, or that could favour the occurrence of an earthquake in the nearest future. The basement outcrops have very high velocity, within the neighborhood of 3000 m/s, and are of low elevation, and therefore does not pose any threat of landslide (Rock fall or Mud slides).

Seismic Shaking hazard

Seismic shaking hazard does not pose a serious threat to the site under investigation. In the first place no obvious fault that could lead to earthquake generation was detected. The geological condition at the site (the hard rock, based on their seismic velocity and gentle topography), will act as great attenuating soil to any seismic shaking that might result from far earthquake, and rule out the secondary effect like landslide.

Surface Fault Rupture Hazard

The effect of Surface Fault Rupture Hazard due to movement along the fault zone is completely ruled out, because no fault or major fracture of any orientation was detected by the seismic survey.

Ground Lurching and Liquefaction Hazards

The soil in the area under investigation is not predominately loose sand, and the groundwater is restricted to isolated aquifers, hence the water table is not evenly distributed and close to the surface. Therefore the structures place here will not heave or lurch in the event of any shaking, because the possibility of soil liquefaction is ruled out.

Water inundation

The topography of the landscape will encourage a good water runoff in the events of heavy rain. This will sink underground at the points where there is good overburden thickness. However the natural drainage pattern in the vicinity of the site should be studied in other to design a very good drainage pattern, and to avoid putting structure in waterways that could result to local flooding of the site.

Swell potential of near Surface soil

Physical observation at the surface and the distribution of seismic velocity both at the surface and at depth, have shown that the near surface material is predominantly laterite not clay, that will alternately swell or shrink in the vicinity of underground water. Hence, since the near surface material is not predominantly clay, therefore the swell potential of the near surface soil will be infinitesimally small.

Conclusion

The results obtained from the survey area have shown that the seismic velocity has a general increase of velocity with depth.

The range of seismic velocity is between 990 m/s to 3340 m/s. the site is characterize with regions of thick overburden and regions where the granitic outcrops are visibly exposed at the surface. The aquifer at this site is localize, with depth to aquifer highest at the point where the overburden is thickest and least in the vicinity of an outcrop. It can be concluded therefore, that the geological hazard analysis have revealed that the site under investigation is not prone to any geological hazards that could be induced by earthquake, faults, elevation depth to aquifer, and nature of soil.

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