SHALLOW 2D SEISMIC REFRACTION TOMOGRAPHY (SRT) INVESTIGATION AROUND URUAGU-NNEWI GULLY SITE, ANAMBRA STATE, SOUTH-EASTERN NIGERIA

[1]Egwuonwu, G. N., [1]Nwaka, E. G. and [2]Orji, O.
[1]Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka
[2]Department of Physics, Clifford University, Owerrinta, Abia State

Abstract
Shallow surface geophysical survey using two-dimensional Seismic Refraction Tomography (*2DSRT*) survey has been conducted at the vicinity of a gully erosion site located at Uruagu Nnewi in Anambra State, Southeastern Nigeria. Uruagu Nnewi is located in Anambra basin and lies within latitudes $06°01.122'N$ and $06°01.145'N$ and, longitudes $006°54.690'E$ and $006°54.683'E$. The *2DSRT* survey was aimed at delineating the near surface lithological formations and seismic refraction interface topography at the gully site. Seven survey lines were laid parallel to straight roads surrounding the gully site for the investigation. Three of the survey lines were oriented NS which are perpendicular direction whereas the other four were oriented EW which are parallel to the strike of the gully. With the aid of a 24 channel Seismograph namely *ES3000*, p-wave velocity data were registered in SEG-2 format. Geophone spacing along the survey lines were limited to 2 m and 3 m to give total of 48 m and 52 m profile lengths owing the built-up nature of the environment. Data obtained were processed using *Seisimager/2D^{TM}* to obtain a 2D p-wave velocity tomography models. Interpretation results of the model tomograms showed that the p-wave velocity range in the range of 300 to 670 ms^{-1} encompasses the ranges for sand and sandy clay predominantly. Results also showed that refraction interface topography delineated at the gully site is predominantly characterized by undulating refractors and landslide slip surfaces at shallow depths. It is therefore inferred based on the interpreted lithology, that the gully's vicinity is relatively weak being clayey. The rugged topography of the refraction interfaces suggests that differential settlement and runoff during erosion which probably is causative to formation of the active gully in Uruagu Nnewi Nigeria.

Keywords: seismic, tomography, refracting interface, clayey, undulations,

Introduction
Gully erosion is a highly visible form of soil erosion or an antecedent of the removal of soil by running water which affects soil productivity. It is a linear deep erosion feature with active head cut, unstable side wall, subject to mass movement, and non-graded longitudinal profile with temporal water flow (Sidorchuk, 2001). Gully erosion is a notable natural disaster causing global environmental deterioration and poverty in many parts of the world due to its unpredictable occurrence (Beijing, 2002). Gullies at their initial stages grow rapidly to large dimensions making effective control and prohibition technically difficult and expensive. Gully erosion is commonly trigged or accelerated by land use changes (Chaplot *et al.,* 2005a) and / or extreme climate events. It is observed that various anthropogenic activities on the soil consequently lead to the degradation of the soil forming gullies and landslides. Land use changes lead to infiltration, increase in sediment detachment and connectivity (Kepperler *et al.,* 1994). According to Tamene and Vleck (2007), the socioeconomic impacts of on-site gully erosion include loss of land and decreased in water holding capacity of the soils while the off-

site impact of gully erosion is the sedimentation of lakes and reservoirs, hindering their functions (Tebebu *et al.,* 2010; Gebreyohannis, 2009).
In south-eastern Nigeria, gully erosion is an endemic environmental problem and this outstanding in Anambra State (Okoyeh *et al.,* 2014). Of all the states in the south-eastern zone, Anambra state has been identified as one of the worst hits having about 1,000 active erosion sites in its domain (Egboka, 1993). The gully erosion/landslide site at Uruagu-Nnewi which is centred in the middle of the city is located in a built-up environment being surrounded by many residential and commercial houses. The gully's development in the recent years is alarmingly increasing posing danger to lives and property. It is therefore noted that the destructive geo-hazard has caused a significant threat to the community settlers.

Seismic survey survey could be practically applied for determination of lithology, subsurface geometry and the distribution of materials within topsoil a slope, identification sliding, water effect on slopes, physical properties of landslide materials and mass movement. Seismic tomography technique consists of inverting first arrival times to get an image of p-wave velocity distribution. Tomographic models play a critical role in the analysis of the subsurface – lithology and fracturing. Refraction tomography usually produces a good lateral velocity change representation of the near surface which has complex velocity structures. It performs well in many situations where traditional refraction techniques fail, such as velocity structure with both lateral and vertical velocity gradient (Carpenter *et al.,* 2003; Cramer and Hiltunen, 2004; Bery and Saad, 2012; Hiltunen and Cramer, 2006; Sheehan *et al.,* 2005). Thus, SRT technique is applied in this survey in order to delineate the shallow surface lithological models and delineate the seismic refraction topography layer(s) at the gully site.

Location and Geology of the Study Area
The study area is located lies within latitudes $06°01.122'N$ and $06°01.145'N$ and, longitudes $006°54.690'E$ and $006°54.683'E$. Figure 1 shows the base map of the study area. The area is in rain forest vegetation zone which has a tropical climate influenced by two major trade winds per annum: the warm moist south trade wind during the rainy season which occurs between April and October and the north-east trade winds which occur during the dry and dusty harmattan seasons between November and March of each subsequent year. The gully site is within the area underlain by Ameki formation in Anambra basin. The basin is a synclinal mega structure located structurally between Cretaceous Benue trough and Niger Delta (Ogala, 2011; Murat, 1972). The basin was platforms during Albian–Santonian period with reduced sedimentation; hence the basin has about 6,000 m sedimentary rocks. Major folding episode which occurred in the Benue trough during late Cretaceous is Santonian (Benkhelil, 1989). The stratigraphy of the basin shows that it contains six separate and distinct formations namely: Mamu formation (lower coal measure), Ajali Sandstone, Nsukka formation (upper coal measure), Imo formation, Ogwashi–Asaba formation and Ameki formation. The Ameki formation consists of Nanka sand, Nsugbe and Ameki sands as lateral equivalents (Reyment, 1965). The Ameki formation consists predominantly of alternating shales, clayey sandstone and fine–grained fossiliferous sandstone with thin limestone bands.

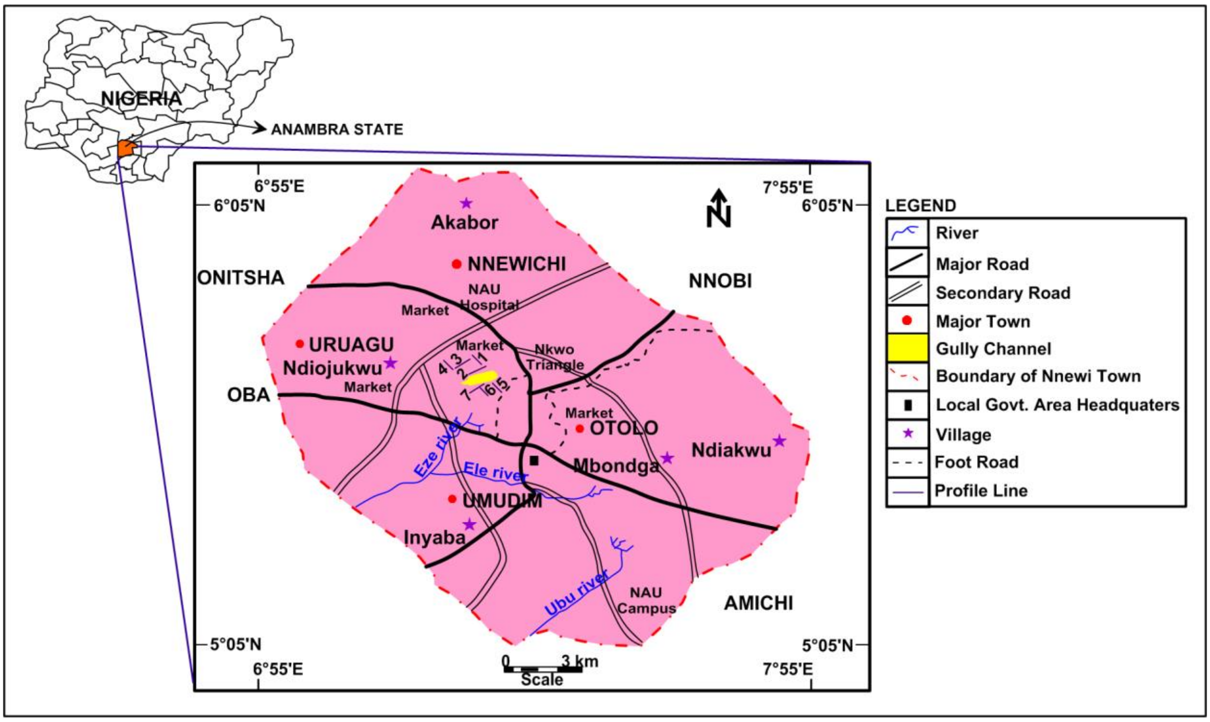

Figure 1: The base map of the study area.

Methodology

The field work was carried out with the aid of 24 channel seismograph namely *ES3000*. Aided by 24 p-wave velocity geophones for spread cable of 24 takeouts, 50kg sledge hammer used as seismic source, powered by 75AH 12volts battery and networked with field laptop computer for recording and global positioning system (GPS) for field geometry definition. In the field, seven profile lines namely; P1to P7 were laid at the gully site (figure 1). Three of the survey lines were laid perpendicular to the strike of the gulley while the other three were laid parallel to it. Due to the limited space owing to the buit-up nature of the site, the spacing of each survey line was varied between 2.0 meters and 3.0 meters depending on the length of the profile. At the ends of each profile, two-meter offset shots were taken available space left in order to take care of edde effect during the tomography modelling. Shot were taken around the positions of each geophone aligned for adequate scanning of the subsurface. It was ensured that there was a good electrical contact between the geophones, the cable wire and the seismograph and the electrical timing device was properly taped to the sledge hammer for effective transmission of energy triggering. Data acquisition of p-wave velocity signals generated were made and recorded in wiggle mode of *SEG-2* format. Signal enhancement of the registered data was ensured for adequate signal to noise ratio for all the shooting before onward processing and tomography modelling with the aid of software.

A total of 184 *SEG-2* data files were registered for processing. A seismic processor software namely, *SeisImager/2D^{TM}* comprising of *pickwin version 3.14* and *plotrefa* ee *version 2.73* was used for processing seismic refraction data signals. The raw data in SEG-2 format were processed after reasonable editing and filtering aided by changes of the display gain, adjustment of distance-time scales, trace style and correction of the record time errors. The appearance of the data was enhanced to enable easy picking of the first breaks. The first breaks were manually picked on the optimized data signals in the wiggle mode for each shot made.

The picked first breaks were saved after adjustments and the process was repeated until all the profile data were picked and saved. Figure 2 shows the pick first arrival status view of the first breaks on the seismic signals in wiggle mode made for the 24th shot taken along survey line P1. Finally, in the *plotrefa* module of the software, tomography modelling technique was applied to obtain 2D SRT tomogram for each survey line.

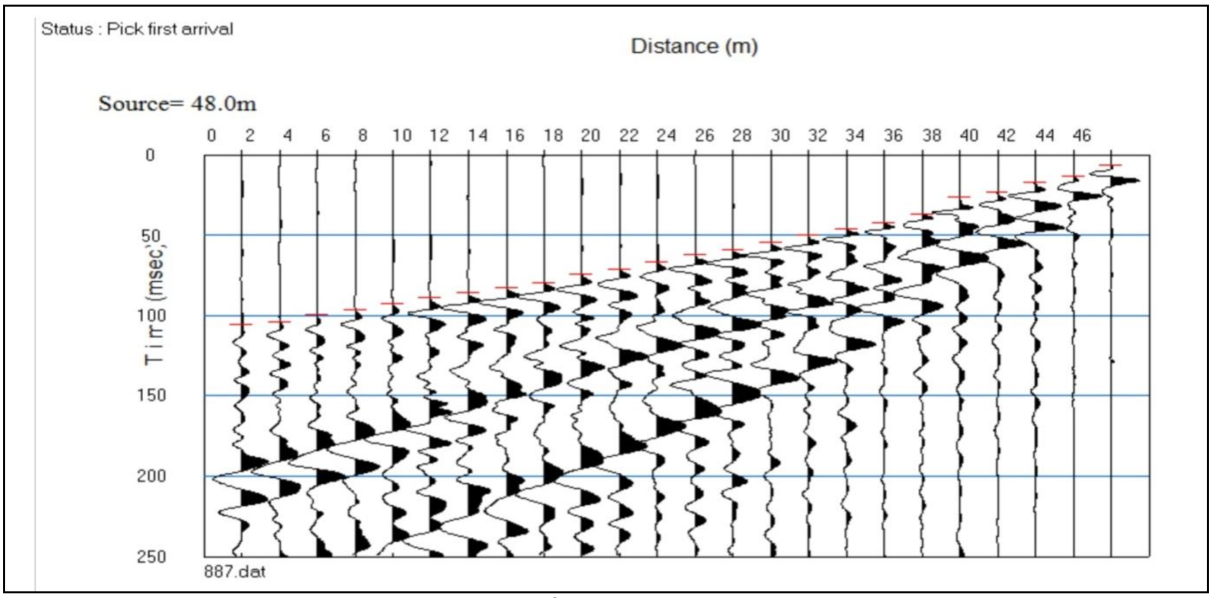

Figure 2: Pick first arrival status for the 24th shot taken along survey line P1

Results and Discussion

The pseudo plots of 2D seismic refraction tomograms (Figure 3 to 9) in colours ranging from purple to blue represent the p-wave velocity models for each profile from least value to maximum. The purple colour which is at the topmost represents the least p-wave value while the blue colour at its base represents the maximum p-wave value in the column. Other colours define certain ranges of p-wave velocity between the minimum and the maximum values. The depth of probe at profile lines of length 46 m is about 18 m while the depths of probe of profiles of length 69m is about 26m.

The ranges of p-wave velocity obtained from the models were in the range of about 300 to 700 m/s) The results were interpreted as guided by the geology of the survey area and some published p-wave velocity values. According to Kearey *et al.* (2002); Nwosu and Emujakporue (2016) and, Osemeikhain and Asokhia (1994), the ranges of p-wave velocity are given as; air filled column (300 – 330 ms^{-1}), dry sand (200 – 1000 ms^{-1}), clay (1000 – 4200 ms^{-1}), sandy clay (360 – 430 ms^{-1}), sandstone (975 – 6000 ms^{-1}), water saturated sand (1200 – 2000 ms^{-1}), sand (350 – 900 ms^{-1}) and loose sand (1800 ms^{-1}). The interpretations made on the survey results obtained from the survey were based on the standard p-wave velocity ranges published and the ranges obtained by some previous researchers.

2D Tomography Model of Profile P1: This model (Figure 3) is oriented south-northwards (SN) which is also approximately perpendicular to the direction of the gully's trend. The tomogram shows p-wave velocity range of 444 ms^{-1} to 473 ms^{-1} predominantly. The 2D seismic tomography model shows five layers of gradational downward increment of p-wave velocity at shallow depths. The interpreted tomogram shows that the model p-wave velocity range encompasses those for sand and dry sand predominantly. The refracting layers at shallow depths in this tomography model occur in the range of 0.1m to 6.0 m and these are characterized by landslide slip surface at depth range of 2.0 m to 4.0 m and lateral extent between 20.0 m and 27.0 m.

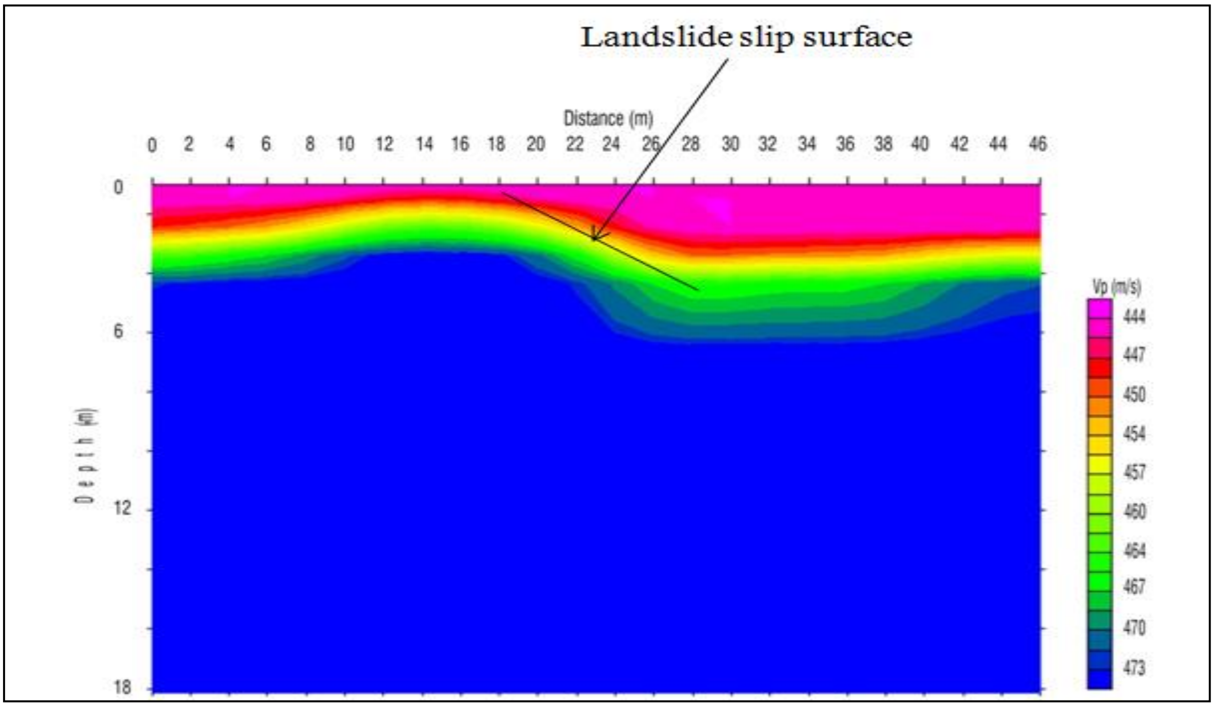

Figure 3: 2D refraction tomography model section of profile one

2D Tomography Model of Profile P2: Figure 4 is a 2D seismic refraction tomogram trending EW and parallel to direction of the gully. The tomogram encompasses p-wave velocity range 403 ms^{-1} to 467 ms^{-1} predominantly. The 2D seismic tomography model shows six layers of gradational downward increment of p-wave velocity at shallow depths. The interpreted tomogram also shows that the model p-wave velocity range encompasses those for Sand, dry sand and sandy clay predominantly. The refracting layers at shallow depths of this profile are undulating at depth range of 1m to 6m.

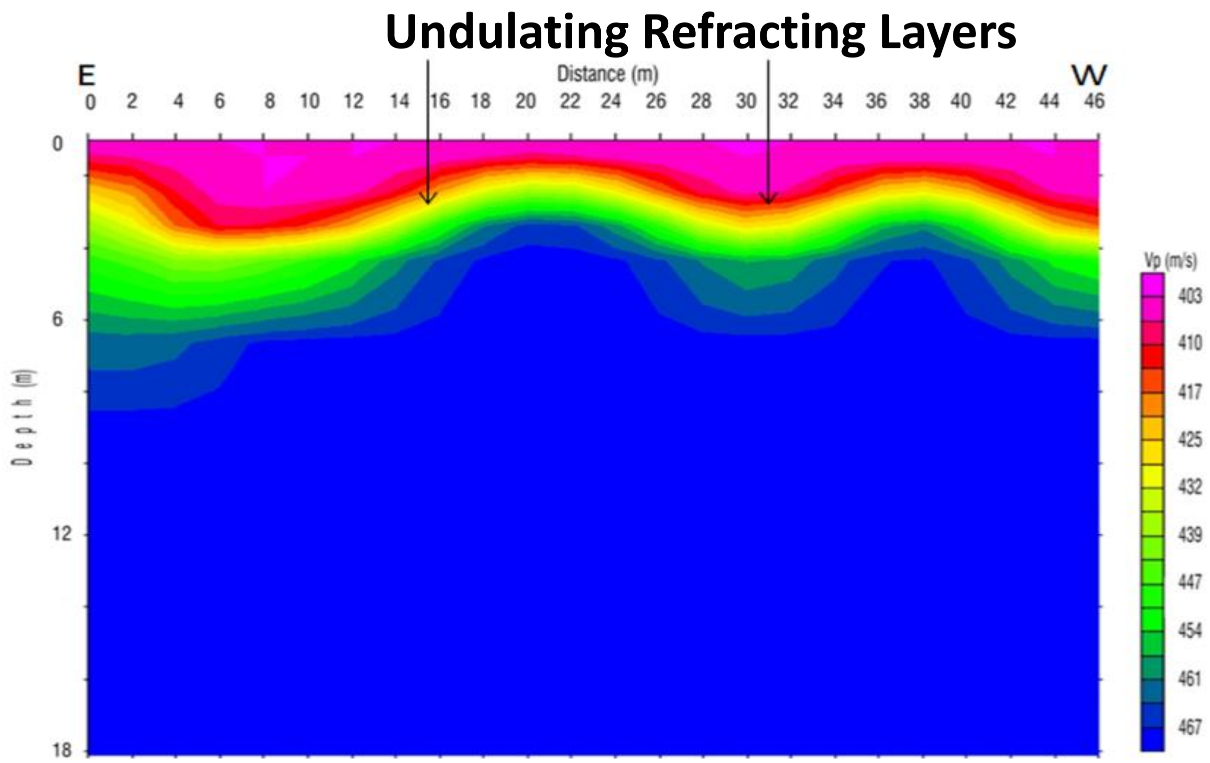

Figure 4: 2D refraction tomography model section of profile two

2D Tomography Model of Profile P3: The model shown in Figure 5 is an east-west (EW) trending tomography model which is also parallel to the direction of the gully's trend. The tomogram shows p-wave velocity range of 487 ms^{-1} to 668 ms^{-1} predominantly. The 2D seismic tomography model shows five layers of gradational downward increment of p-wave velocity at shallow depths. The interpreted tomogram also shows that the model p-wave velocity range encompasses those for sand and dry sand predominantly. The refracting layers of this tomography models occur at shallow depths in the range of 1.8m to 8m are shown to be relatively flat.

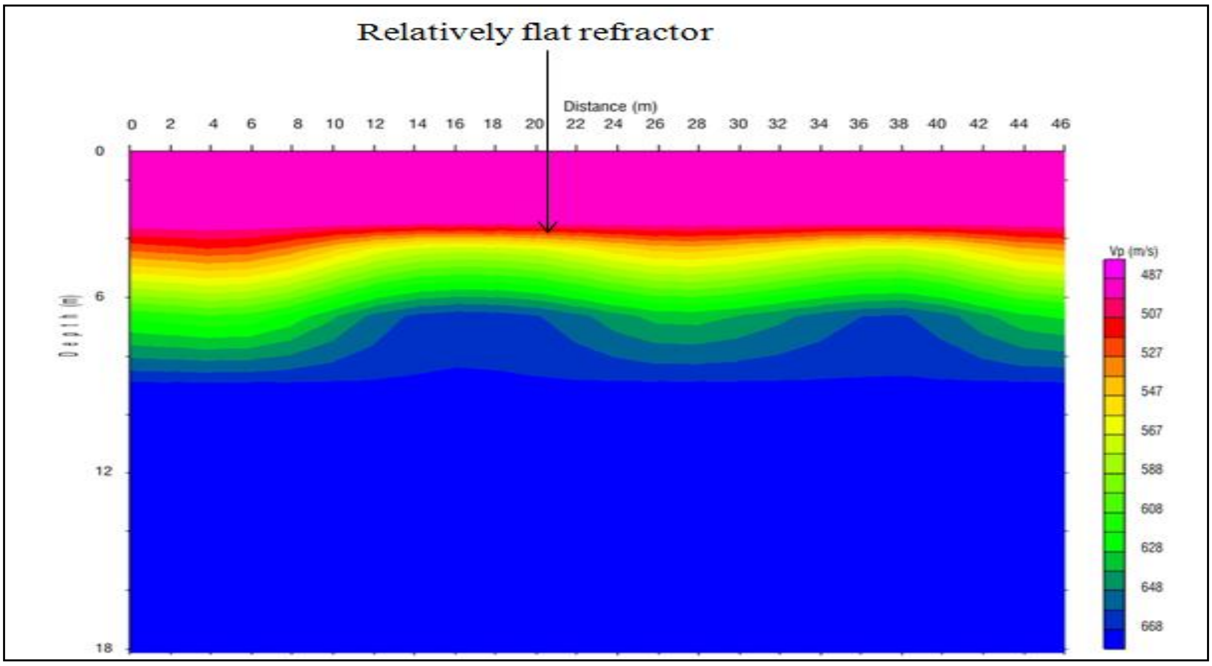

Figure 6: 2D refraction tomography model section of profile three

2D Tomography Model of Profile P4: Seismic refraction tomogram of line P4 (Figure 7) is a 2D tomogram trending south-northwards (SN) and is perpendicular to the direction of the gully's trend. It is dimensioned 46m long and 18m deep. The tomogram encompasses p-wave velocity range 356 ms^{-1} to 426 ms^{-1} predominantly. The tomogram features five layers model of gradational downward increase in p-wave velocity at shallow depths. Interpretation shows that the tomogram encompasses p-wave velocity range for sand, dry sand and sandy clay. The tomography model's refracting layer shows an obvious occurrence of landslide slip subsurface which are within the depth range of 1.8 m to 6.0 m and between lateral distances of extent of 24.0 and 34.0 in the horizontal scale.

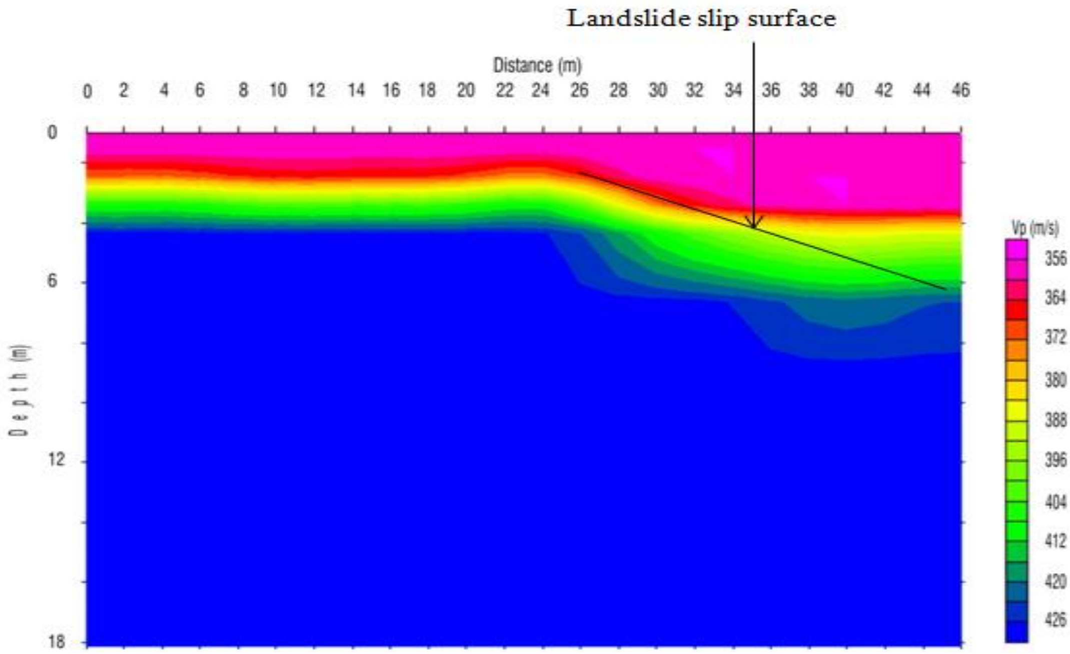

Figure 6: 2D refraction tomography model section of profile four

This model (Figure 3) is oriented south-northwards (SN) which is also approximately perpendicular to the direction of the gully's trend. The tomogram shows p-wave velocity range of 444 ms^{-1} to 473 ms^{-1} predominantly. The 2D seismic tomography model shows five layers of gradational downward increment of p-wave velocity at shallow depths. The interpreted tomogram shows that the model p-wave velocity range encompasses those for sand and dry sand predominantly. The refracting layers at shallow depths in this tomography model occur in the range of 0.1m to 6.0 m and these are characterized by landslide slip surface at depth range of 2.0 m to 4.0 m and lateral extent between 20.0 m and 27.0 m.

2D Tomography Model of Profile P5: From survey profile line P5 trending NS perpendicular to the direction of the gully was obtained a 2D seismic refraction tomography model shown in Figure 7. The tomogram, dimensioned 46m long and 18m deep encompasses p-wave velocity range of from 318 ms^{-1} to 360 ms^{-1} which is observed to be predominant. Gradational increment of the p-wave velocity with depth at shallow depths is observed to be smooth. However, the model could be characterized by six layers of increasing consolidation owing to rise in density down the depths. The interpreted lithology, based reference standard p-wave velocity, suggests suspected air-filled column, sand (dry and wet) and, sandy clay. The refracting layers in this tomography model at shallow depths show occurrence of anticline shaped feature spiked between the depths of about 2.0 m and 8.5 m. Also, flanking the anticline shaped refractor by its two sides suggest landslide slip subsurface mapped at this profile line P5.

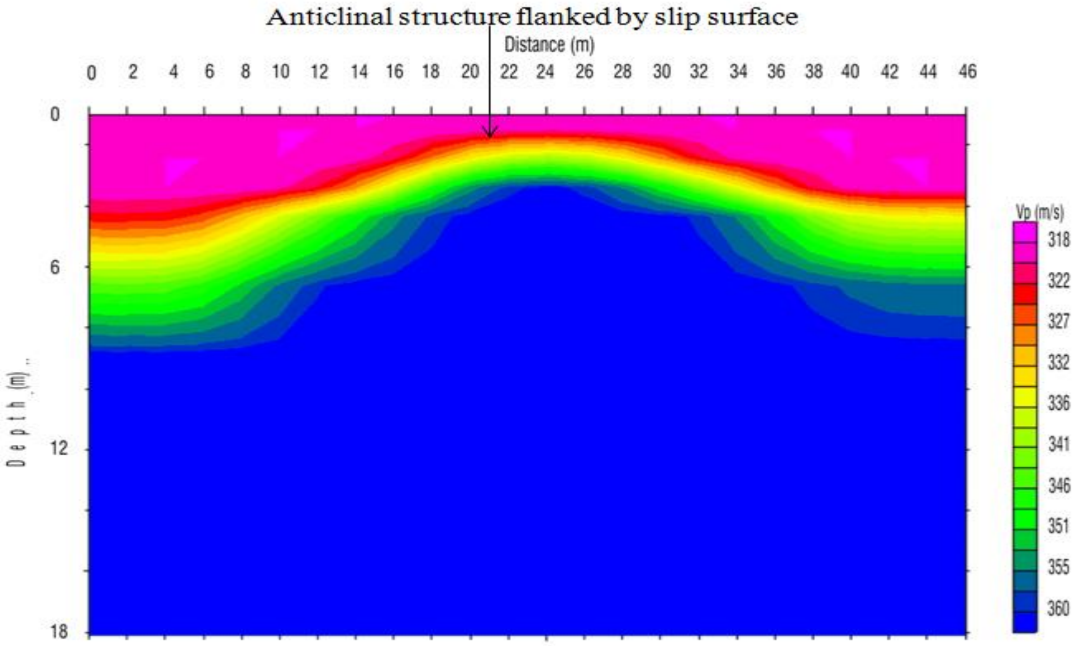

Figure 7: 2D refraction tomography model section of profile five

2D Tomography Model of Profile P6: From survey line P6 was obtained a 2DSRT model dimensioned 69m long by 26m deep (Figure 8). The tomogram is characterized by relatively flat refracting layers at shallow depths trending north-southwards (NS) and laid perpendicular to the direction of the gully's length. Predominantly, the tomogram encompasses p-wave velocity range 469 ms^{-1} to 513 ms^{-1} showing five layers model of increasing grades of density and consolidation down the depths. The interpreted lithology delineated by the registered p-wave velocity range in the model is solely sand and dry sand. Slight undulating layers are observed at shallow depths between depth range of 0.2 m to 8.0 m.

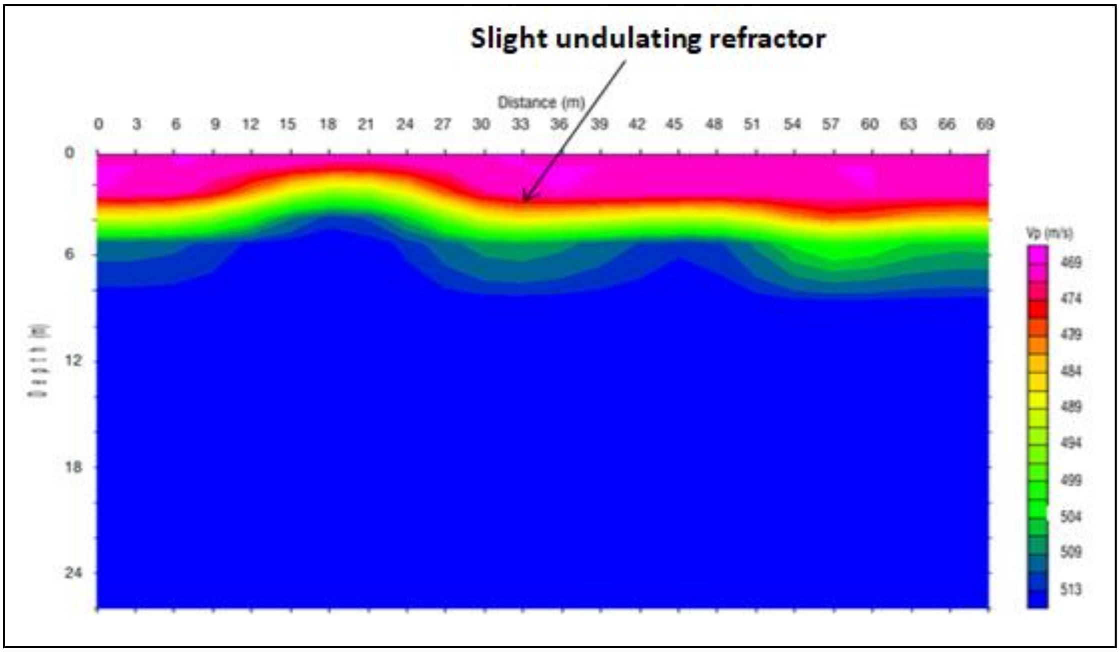

Figure 8: 2D refraction tomography model section of profile six

2D Tomography Model of Profile P7: The 2DSRT model (Figure 9) obtained from **s**urvey line P7 trending east-west and parallel channel of the gully is of dimensioned 69m long and 26m deep. The range of registered and processed p-wave velocity data is 365 ms^{-1} to 434 ms^{-1} and this is shown in six layers of increasing consolidation and grades of density down the depths. The predominant interpreted lithologies based on the range are sand, dry sand and sandy clay. The model's refracting layers at shallow depths are characterised by suspected landslide slip subsurface occurring with depth range of 0 m to 7.0 m and within 24.0 and 39.0 m on the horizontal scale.

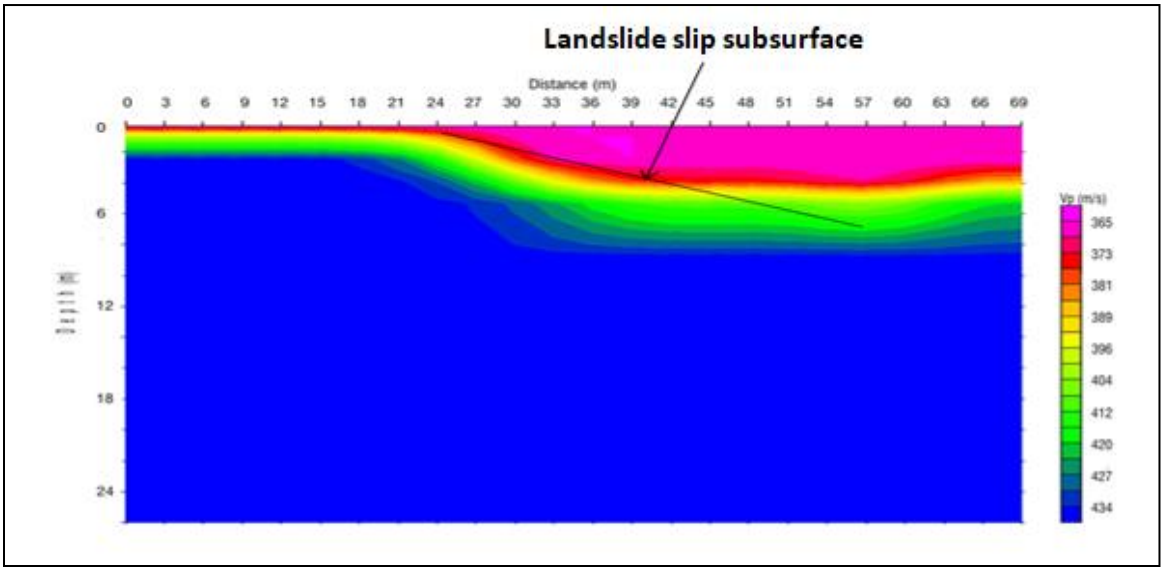

Figure 9: 2D refraction tomography model section of profile seven

In summary, four perpendicular and three parallel survey lines to the strike of Uruagu-Nnewi gully site were laid at its vicinity. Three, out of the four 2D ERT models showed indication of landslide slip refracting subsurface layers towards the gully (Figures 3, 6, and 7). This suggests instability of the intact soils, sedimentary layers and rocks around the gully location. The other one also perpendicularly delineated (Figure 8), indicated a slightly undulating refracting layers. Along the refracting layers parallel to the direction of the gully, undulations of low and high amplitudes and a suspected land slide slip subsurface were observed (Figures 4, 5 and 9). This is also an indication of instability of the gully site's vicinity at show depths. Interpreted lithology based on the consideration of the study area's geology and the standard p-wave velocity referred, showed predominance of sand and sandy clay. Table 1 shows the seven 2DSRT survey models from the surrounding of Uruagu Nnewi gully site and the interpretations of them.

CONCLUSIONS

The interpretation of the model tomograms showed that the p-wave velocity range in the range of about 300 to 670 ms^{-1} encompasses the ranges for sand and sandy clay predominantly. Therefore, it is inferred that the gully's vicinity is relatively weak being clayey. Also, results show that the gully site is unstable owing to the fact that topography of the refraction interfaces delineated at shallow depths of the site is predominantly characterized by undulating and slip subsurface. Hence, it is inferred that these most probably led to existing landslides observed at the gully site. Differential settlement of superstructures would invariably occur owing to expected unstable equilibrium for deep foundation depths within the horizon of the rugged refraction interfaces delineated. Erosions control and mitigation of them would promote development and civilization. Lives, infrastructural facilities and property are in danger of disaster require careful attention of the government for proactive interventions, expertise of geophysicists and expedition of civil engineering works for control and where possible, mitigation of the impact of the geohazard.

Table 1: The summary of the 2D SRT Refraction Tomography interpretations made on the model results obtained from the surrounding of Uruagu Nnewi gully site in Anambra State.

Profile Identity	Number of p-wave Velocity Model layer Model	P-wave Velocity range (ms^{-1})	Dimen sion (m)	Predominant Lithology	Suspected Refractors' Topography at Shallow depths
P1	5	444 – 473	46x18	sand and dry sand	landslide slip surface
P2	6	403 – 467	46x18	sand, dry sand and sandy clay	undulating refracting layers
P3	3	487 – 668	46x18	sand and dry sand	relatively flat refracting layers
P4	5	356 – 426	46x18	sand, dry sand and sandy clay	Landslide slip surface
P5	6	318 – 360	46x18	suspected air-filled column, sand, dry sand and sandy clay	anticlinal structure flanked by slip surface
P6	5	469 – 513	46x18	sand and dry sand	Slightly undulating refractor
P7	6	365 – 434	69x26	sand, dry sand and sandy clay	sharp slip surface

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