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Geotechnical Investigation at Sanzule Beach, Ghana, Using Seismic Refraction Tomography

Kwame .N. Asamoah, Jamel Seidu, Anthony Ewusi and Ebenezer Ansah

Department of Geological Engineering, University of Mines and Technology,
Tarkwa, Western Region, Ghana

kasamoah38@yahoo.com

Abstract

Seismic Refraction survey was carried out using a 12-channel seismograph (Geometrics ES 3000) at Sanzule beach, in the Western Region of Ghana. The focus of the study was to determine the geologic formations of the subsurface and estimate some geotechnical parameters (Rock Quality Designation (RQD), N-value and Internal friction) of the subsurface. Seismic Refraction Tomography (SRT) was employed to estimate the P-wave velocities of the various subsurface strata. Results from the analysis showed that the subsurface consists of four layers. The first layer is a medium dense sand with an average thickness, P-wave velocity, RQD, N-value and internal friction of 9 m, 323 m/s, 15 %, 20 blows/foot, and 35-40° respectively. The second layer is a dense silty sand of an average thickness of 2 m, P-wave velocity of 582 m/s, RQD value of 27 %, N-value of 31 blows/foot and internal friction of 40-45°. The third stratum is a very dense silty clay with an average thickness of 7 m, P-wave velocity of 1620 m/s, RQD value of 74 %, N-value of 75 blows/foot, and internal friction of more than 45°. The fourth stratum is a hard basement of sandstone/shale with a P-wave velocity of 2000 m/s, RQD value of 91 %, N-value of 92 blows/foot and internal friction of more than 45°. The study has proven that civil engineers and geological engineers can use seismic refraction tomography to estimate the soil type and geotechnical parameters of the subsurface of a construction site.

Keywords: *Seismic Refraction Tomography, Internal Friction, Rock Quality Designation, Ghana.*

1. Introduction

With the dawn of modern electronics and computer-aided geophysical interpretation methods, geophysical surveys now offer cost effective and robust options in the estimation of subsurface conditions. There are a number of geophysical techniques, including inductive electromagnetic conductivity; electromagnetic ground probing radar; electrical resistivity; seismic refraction and reflection; magnetics; and gravity. These geophysical techniques operate based on the difference in physical properties between various geological strata and soils. Haeni (1988) reported on the major use of seismic refraction to map the depth and geometry of the subsurface.

Of recent, seismic refraction has been considered one of the most accurate and cost effective methods for determining geotechnical parameters of an engineering site and environmental studies (Abdel et al, 2017). Seismic refraction has been employed by many engineers and geoscientists to investigate the subsurface conditions of construction sites. (ASTM, 2000; Rucker 2000; Rucker and Ferguson, 2006). K'Orowe and Mulumbu (2010) used seismic refraction to investigate the subsurface condition of the Magadi Basin. Young et al (1998) also used high-resolution seismic refraction to study the structural controls and the base of alluvium aquifers on the Batimah plain in the Gulf of Oman.

The P-wave velocity of the subsurface layers can be used to estimate the strength, rippability and the fluid contents of rocks. It can also be used to investigate engineering parameters such as N-values, Rock Quality Designation (RQD), friction angle (φ), relative density, velocity index, penetration strength and Unconfined Compressive Strength (UCS). The study employed Seismic Refraction Method as the geophysical method, to investigate the subsurface conditions of the study area.

The main objective of the study is to estimate the geotechnical engineering parameters of the subsurface materials at the study area, from the P-wave velocity values obtained from the seismic refraction survey.

2. Location and Physiography of Study Area

Sanzule is a coastal town, located in the Nzema East Municipality of Western Region of Ghana. It is located at the southwestern end of the region with geographical coordinates of N 4° 57’ 28’’ and W 2° 26’ 59’’. The study area is bounded by the Gulf of Guinea to the south and the Sanzule community settlement to the east and west. No high voltage, electrical or network cables, sewer or water pipelines were observed within the study area. Fig 1 shows the location of the study area. Though the topography of the study area and the surrounding environs is generally undulating, there are no significant peaks. The highest point reaches a height of about 100 m above sea level.

The study area lies between the wet semi-equatorial climates zones of the West African Sub region. Rainfall is experienced throughout the year with the highest monthly mean occurring around May and June each year. The average temperature is about 29.40 °C with variation in monthly mean ranging between 4.0 and 5.0 degree Celsius throughout the year. The district records high relative humidity figures ranging from 26.6 % to 27.6 % between May and June, and 27.3 % to 27.9 % during the rest of the year (Anon., 2014).

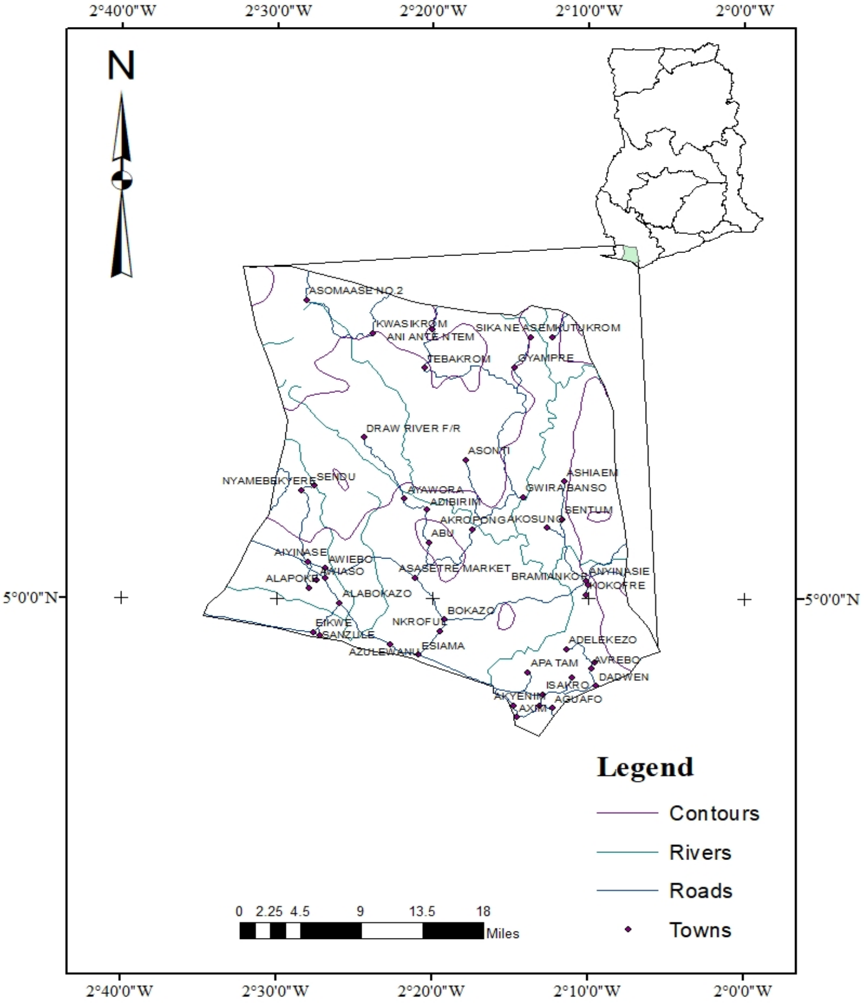

Fig 1 Map of Nzema East Municipality showing location of Sanzule

Geologic Setting

The study area, Sanzule, lies at the southwestern end of the Ashanti belt and is dominated by the southwestern trending bands of Birimian meta-sediments/volcanics and the Tarkwaian clastic formation (Fig 2). Structurally, the study area covers a segment of the Konongo-Axim Shear System and the rocks of the area are variably grained, sheared, metamorphosedquartzites containing a constant level of mafic and carbonaceous minerals, presumably derived from genetic activity (Boadi et al., 2013). According to Loh and Hirdes (1990), the southern portion of the Ashanti volcanic belt forms three branches referred to as the Axim branch, Cape Three Points branch and Butre branch, with three plutons (locally termed as Prince's Town, Dixcove and Ketan pluton) occupying positions between these branches.

The study area is underlain by meta-volcanic rocks, mainly andesitic and basaltic lava flows and some dacites. They are greenish in colour to dark grey, fine-grained and massive. The primary minerals comprise of mainly plagioclase and pyroxene, which are partially or completely replaced by secondary minerals such as actinolite, epidote, chlorite and sericite.

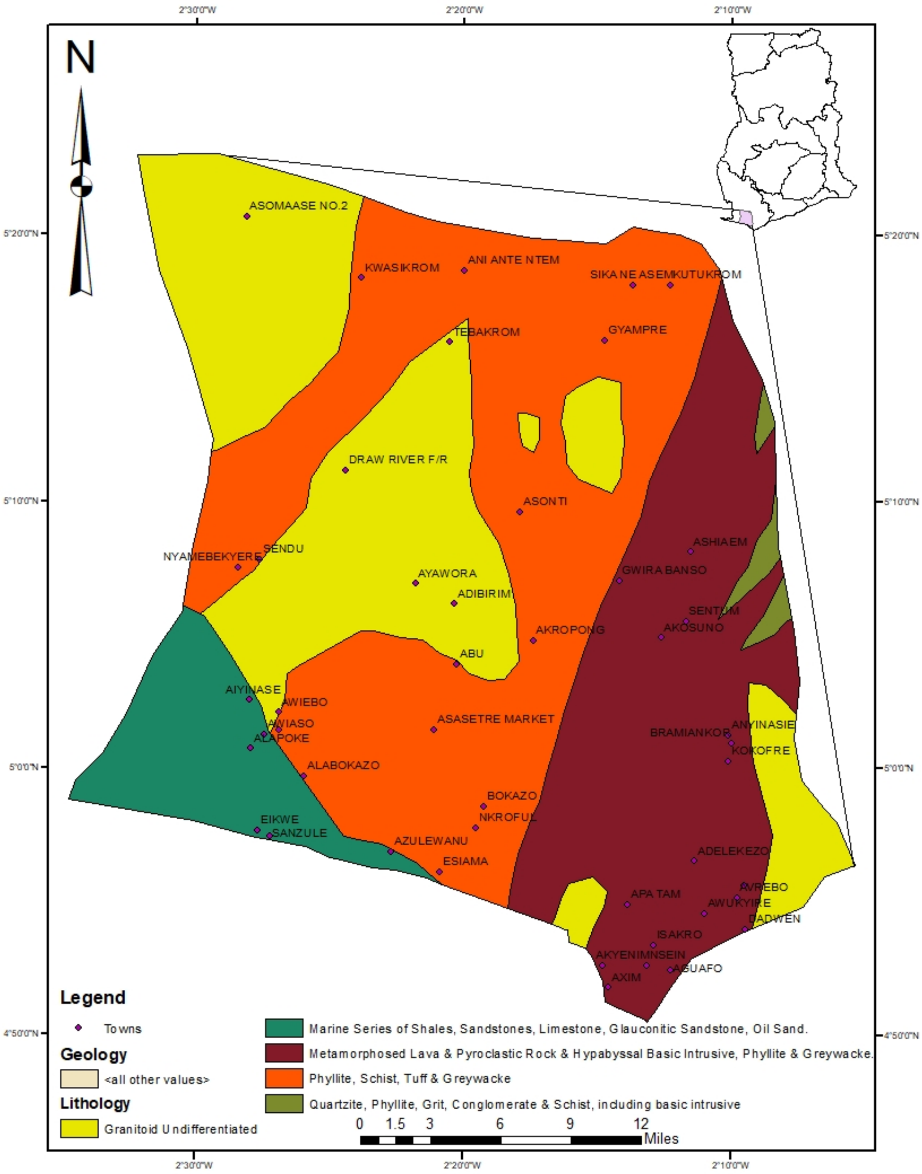

Fig 2 Geological map of study area

4. Methods Used

4.1 Principles and Theory of Seismic Methods

A seismic wave is acoustic energy transmitted by vibration of rock particles under the earth. They are short-lived parcels of elastic strain energy known as pulses that propagate from a source point through the earth and containing a wide range of frequency (Osumeje and Kudamnya, 2014). The propagation of seismic (energy) disturbance through a heterogeneous medium is very complex although it can be expressed in some equation, where the velocity, travel time, distance can be used to estimate the elastic properties of the medium through which they propagate (Leucci et al 2007).

4.2 Seismic Refraction Tomography

In the seismic refraction method, the seismic waves, created by artificial sources such as a hammer, propagate through the medium and are refracted at interfaces, where the seismic velocity or density changes. Seismic refraction tomography is an imaging technique that generates a cross-sectional image of a medium by utilising the medium's response to the nondestructive, probing energy of an external source. The study employed seismic refraction tomography involving ray tracing through wavefront inversion, which utilises the finite difference approximation of the eikonal equation. For the smoothing of the tomography models, the iterative model updating, using simultaneous iterative reconstruction techniques (SIRT) was employed.

4.3 Data Acquisition and Processing

A Geometric ES-3000 seismograph was used for the seismic data collection. The equipment is made up of a seismograph, 60 m spread cable, geophones, a sledgehammer and a metal striker plate.

Ten (10) seismic refraction profiles were acquired across the study area. Stack of three (3) shots was used at various shot locations on a profile to minimize background noise effect and to increase signal to noise ratio, enabling first breaks to be seen clearly. For each profile, the distance between two receivers (geophone interval) was 5 meters and had nine (9) shot points. A sampling rate of 62.50 µs with recording length of 0.25 s was used. Moreover, a low cut filter of 15 Hz was used to filter noise frequency from sea waves.

Field precautions were taken to make sure that the readings taken conformed to standard practices. The geophones were firmly inserted into the ground and kept as vertical as possible to achieve best coupling of the seismic signal with the geophones. Lower frequency geophones in particular have loose sensitivity if they are not vertical. To achieve maximum signal coupling, loose materials were cleared before placing the striker plate on the ground. The sledgehammer was prevented from bouncing on the striker plate when striking, to prevent false trigger from occurring.

The first step in the data processing is to pick the first arrivals (first breaks). This was done with Pickwin, a software designed by Geometrics to be used to pick first arrivals from seismograms. The first breaks were picked automatically and adjusted manually, to achieve high accuracy in the travel times.

The next step was to assign layers to the travel times, which were picked with the Pickwin software. This was done with the aid of Plotrefa, which is a seismic refraction analysis software produced by Geometrics. This arrival time picks are used to plot the travel time curves from where the velocity layers can be estimated from the reciprocal of the slopes obtain from the plot. After the layer assignment, an initial velocity model is estimated using Time-term inversion. In this case, a two or three velocity layer model is represented by the results obtained from the simple interpretation of the travel time plot from the seismic refraction data. Refraction rays are traced through this model to calculate the depth (d) to reflectors by using the following formula:

$$Z_1 = \frac{t_i V_i V_{i+1}}{2\sqrt{\left({V_{i+1}}^2 - {V_i}^2\right)}} \qquad (1)$$

where;
V_i is the velocity of the *i*th interface
Z_i is the depth at the base of a layer of velocity V_i
t_i is the intercept time at the *i*th interface

Tomographic inversion is then generated from the initial velocity model after some number of iterations are completed. After each iteration, ray tracing is initiated to produce a calculated travel time curve. The difference between the calculated and the observed travel times is shown as the RMS error. The rule of thumb is that, the smaller the RMS error, the higher the accuracy of the data. The highest RMS error recorded from all the tomography models was 4.8. This is satisfactory, and implies that all the models are representative of the study area.

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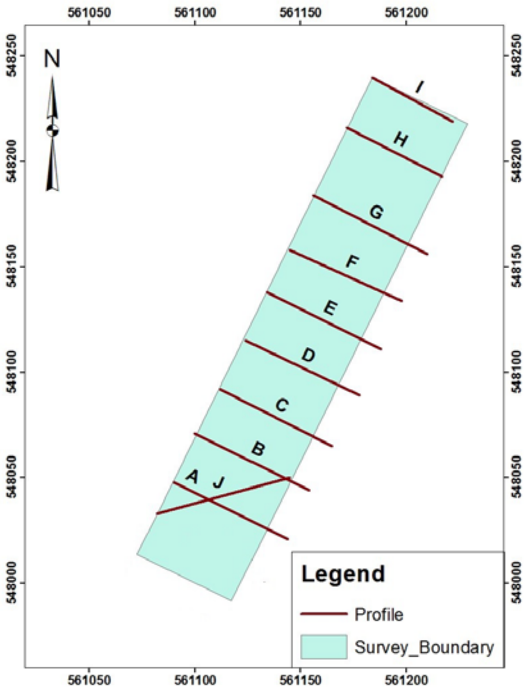

Fig 3 Map of Profiles distribution on the study area

5. Results and Discussion

5.1 Interpretation of Tomography Models

The seismic refraction survey was conducted on profiles; A, B, C, D, E, F, G, H and I in the NW – SE direction. However, profile J was conducted in the NE –SW direction (Fig 3). Also, Profile C was carried out along a geotechnical borehole which was drilled in the study area All the survey profiles were aligned with respect to a given baseline which runs NW – SE direction. The profiles were separated at an interval of 25 m. Summary of the seismic refraction survey results for each profile, as interpreted from the seismic tomography models is shown in Table 1. The seismic tomography models are shown in Fig. 4.

5.2 Geotechnical Assessment

Andy and Rosli (2012), developed empirical formulas for estimating engineering parameters from P-wave velocity values of geologic materials (igneous and sedimentary) in the tropical environment. The engineering parameters included N-values and RQD. Meyerhof (1956) also estimated the internal friction values for various geologic materials from a correlation between N- values and respective values of internal friction (coefficient of friction).

Rock Quality Designation (RQD)

RQD is an index used for the description of the state of rock mass in terms of fracture (Lucian and Wangwe, 2013). It is a measure of the degree of jointing or fracture in a rock mass, measured as a percentage of the drill core in lengths of 10 cm. The empirical correlation between RQD and P-wave as estimated by Andy and Rosli (2012) is given by:

$$V_p = 21.951\ (RQD) + 0.1368 \qquad (2)$$

Equation two (2) was estimated at a a regression coefficient of 83.77 %. The RQD values for the various formations and the respective interpretations are shown in Table 2.

Table 2 RQD values for the subsurface formations

Material	Average Thickness (m)	Vp (m/s)	RQD (%)	Description
Sand	9	323	15	Completely weathered
Silty sand	2	582	27	weathered
Silty clay	7	1620	74	Moderately weathered
Sandstone/Shale	-	2000	91	Fresh rock

(After: Deere, 1989)

Standard Penetration Test (SPT)

SPT is a dynamic test as described in BS 1377 and is a measure of the density of the soil. The standard penetration test is the most commonly used in-situ test, especially for cohesionless soils, which cannot be easily sampled. For SPT, the number of blows required for 300 mm of penetration beyond a seating drive of 150 mm gives the standard penetration number (N). The N value is extremely useful for determining the relative density and the angle of shearing resistance (Arora, 2004). It can also be used to determine the unconfined compressive strength of cohesive soils.

Andy and Rosli (2012) estimated the correlation between V_p and N-values to be:

$$V_p = 23.605\ (N) - 160.33 \qquad (3)$$

Equation three (3) was estimated at a regression coefficient of 97.56 %. The N-values for the various materials encountered at the subsurface of the study area is estimated below (Table 3).

Table 1 Summary of the results obtained from the seismic refraction survey

Profile	Velocity (m/s)	Average Thickness (m)	Description of layer
A	300	10	Sand (medium density)
	1530	10	Saturated sand
	1620	3	Silty clay
	2000	-	Sandstone/Shale
B	300	7	Loose sand
	1530	9	Saturated sand
	1620	4	Silty clay
	2000	-	Sandstone/Shale
C	390	8	Topsoil
	490	2	Silty sand
	1620	10	Silty clay
	2000	-	Sandstone/Shale
D	390	5	Topsoil
	490	3	Silty sand
	1620	7	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
E	390	5	Topsoil
	680	2	Silty sand
	1620	4	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
F	390	13	Sand
	580	2	Silty sand
	1620	9	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
G	390	7	Top soil consisting of humus
	680	2	Silty sand
	1620	5	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
H	490	2	Topsoil
	1060	5	Slightly compacted silty sand
	1620	6	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
I	390	5	Topsoil
	680	1	Silty sand
	1620	10	Silty clay
	2000	-	Hard basement made of Sandstone/Shale
K	300	8	Sand
	1530	7	Saturated sand
	1620	5	Silty clay
	2000	-	Hard basement made of Sandstone/Shale

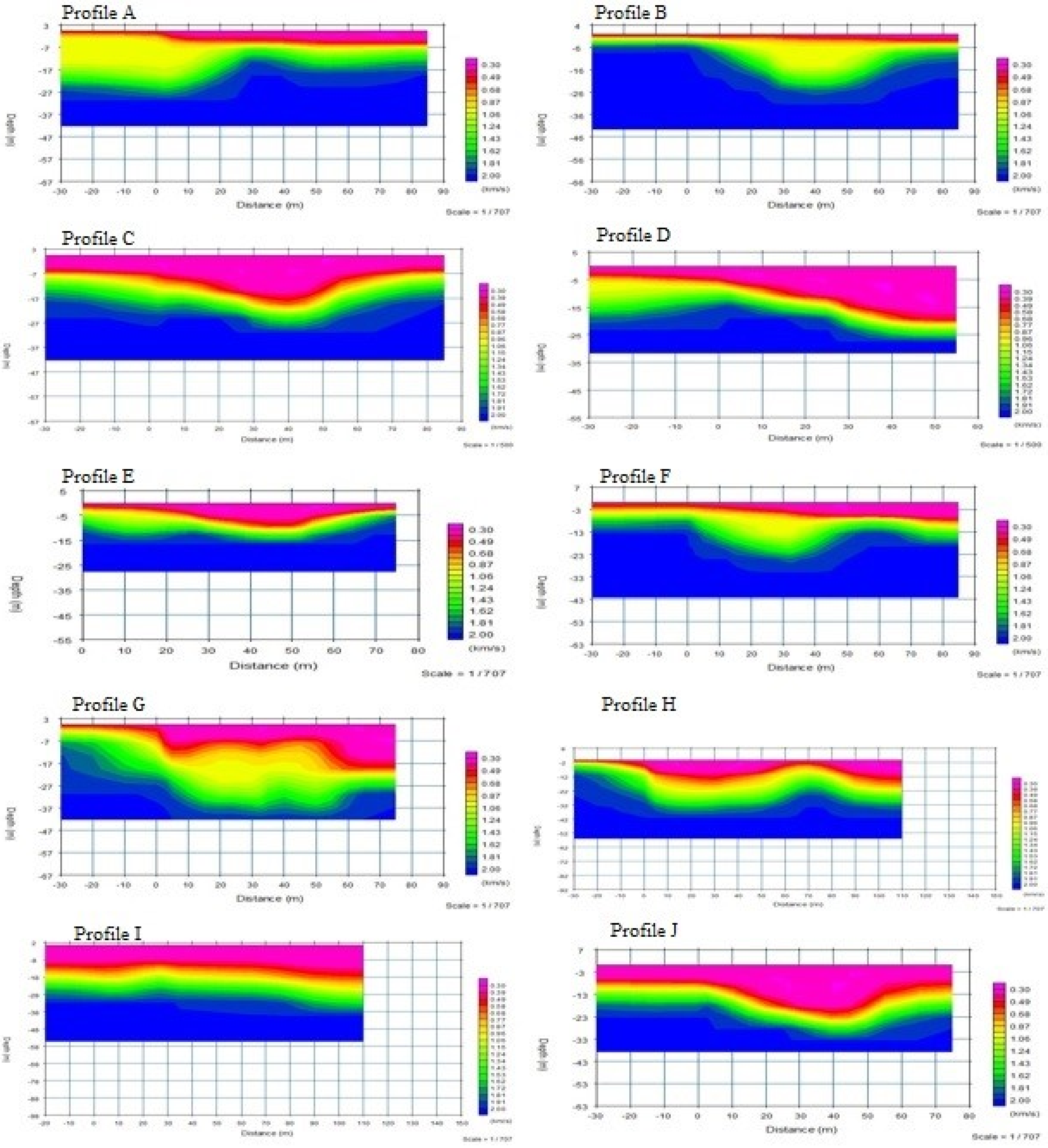

Fig 4 2D subsurface seismic refraction tomography models for profiles A to J respectively

Table 3 N-values of subsurface materials

SN	**Material**	**Average Thickness (m)**	**Vp (m/s)**	**N-value (blows/foot)**
1	Sand	9	323	20
2	Silty sand	2	582	31
3	Silty clay	7	1620	75
4	Sandstone/Shale	-	2000	92

Angle of internal friction (φ)

Angle of internal friction for a given soil is the angle on the Mohr's Circle of the shear stress and normal effective stresses at which shear failure occurs. Angles of internal friction, (φ), can be determined in the laboratory by the Direct Shear Test or the Triaxial Stress Test. However, there are empirical values for (φ) based on the standard penetration number (N-value). According to Meyerhorf (1956), the (φ) values for the subsurface materials can be estimated as follows (Table 4).

Table 4 Internal friction values for subsurface materials

SN	**Material**	**Denseness**	**N-value (blows/foot)**	**Internal friction (°)**
1	Sand	Medium	20	35 - 40
2	Silty sand	Dense	31	40 - 45
3	Silty clay	Very Dense	> 50	> 45
4	Sandstone/Shale	Very Dense	> 50	> 45

6. Conclusions

Results from the 2D P-wave tomography show that the area is made up of four layers. The first layer is a medium dense sand with an average thickness, P-wave velocity, RQD, N-value and internal friction of 9 m, 323 m/s, 15 %, 20 blows/foot, and 35-40° respectively. The second layer is a dense silty sand of an average thickness of 2 m, P-wave velocity of 582 m/s, RQD value of 27 %, N-value of 31 blows/foot and internal friction of 40-45°. The third stratum is a very dense silty clay with an average thickness of 7 m, P-wave velocity of 1620 m/s, RQD value of 74 %, N-value of 75 blows/foot, and internal friction of more than 45°. The fourth stratum is a hard basement of sandstone/shale with a P-wave velocity of 2000 m/s, RQD value of 91 %, N-value of 92 blows/foot and internal friction of more than 45°.

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Authors

Kwame .N. Asamoah holds a BSc in Geological Engineering from the Kwame Nkrumah University of Science and Technology (KNUST), Ghana. He is a demonstrator at University of Mines and Technology (UMaT), Ghana and is currently pursuing MPhil in Geological Engineering at UMaT. His research areas include geophysics, geostatistics, GIS and remote sensing.

Jamel Seidu is an Assistant Lecturer at the University of Mines and Technology (UMaT), Tarkwa. He has an MPhil and BSc in Geological Engineering from UMaT. His research interest include Geophysics, Groundwater Studies and Water Resources Management.

Anthony Ewusi holds a PhD Hydrogeophysics and an MSc in Environmental Hydrogeology from the Brandenburg University of Technology, Germany. He obtained a BSc (Hons) Geological Engineering from the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. He Lectures in Geophysics and Hydrogeology. His research interests are in groundwater management and geophysics.

Ebenezer Ansah holds BSc in Geological Engineering from the University of Mines and Technology (UMaT), Tarkwa, Ghana. His areas of research include groundwater resources management and protection, hydrogeology, geophysics and GIS.