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The Use of Seismic Refraction Technique for Geotechnical Investigation: A Case Study of KNUST Campus, Kumasi, Ghana

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Abstract: *Subsurface geotechnical investigations and subsequent reports are essential parts of the planning phase of many construction projects. These investigations in Ghana are commonly done using methods like trenching, boreholes and pitting, which gives direct and/or visual access to the subsurface material, and also allows sampling for laboratory analysis. However, the methods are expensive, time consuming and requires a lot of effort to execute, and the results are discreet, requiring extensive inter and extrapolation and a good expertise to make meaningful interpretations. Alternatively, the seismic refraction method was used to explore the subsurface material for their elastic properties, which could be related to some of the geotechnical properties or conditions at the site. The work was conducted on KNUST campus in Ghana, on the premises of the faculty of Art building. A 50m traverse line was used to probe up to about 16m depth, and with intermediate shot points. It was found that the subsurface material may be underlain by dry loose sand for the first and second layer and clay materials for third layer at an average velocities of 303 ms^{-1}, 447 ms^{-1} and 1301 ms^{-1} respectively. Higher velocities indicate high competence hence the third layer was found to be more competent than the first and second layer. Also layers with lower velocities are more rippable than the ones with higher velocities.*

Keywords: *Seismic, Refraction, Technique, Geotechnical, Investigation, KNUST Campus, Ghana*

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I. Introduction

Practical planning of scientific foundation designs and constructions requires information about the subsurface ground conditions. Geotechnical investigations are vital in generating relevant information representative of a site specific ground condition pertinent to a proposed development and for repair of distress to earthworks and structures caused by subsurface conditions. The information derived can be used to assess the general suitability of a site, problems associated with construction arising from ground or groundwater conditions and the quantity, quality and ease of extraction of construction material for a proposed work. Traditional geotechnical investigation involves digging of trenches, pits and boreholes at wide intervals to generate discrete subsurface information. This results in the generation of discontinuous subsurface information that may not be representative of the site ground conditions. For example, a single or a few discreet boreholes could be used to generalize a uniform overburden thickness of a site which may have a different depth to bedrock as a result of the difference in weathering pattern of the area. This may result in differential settlement when a structure is constructed over it. However, the seismic refraction method is more affordable and the survey cover large areas at any possible investigation time. Velocities of the subsurface materials obtained after the survey is used in determining the thickness of the subsurface velocity layers and most importantly, depth to bedrock. The relation between the layer velocity and rippability index acts as a guide in choosing the appropriate equipment for drilling and excavation. The bedrock influences the stability of structures built above it, and its depth can also strongly impact initial construction cost based on rippability and excavation volumes. Seismic refraction technique is used to determine geologic discontinuities such as fractures, cracks, faults etc., whose impact on the stability of structures can't be overlooked. Seismic refraction method readily detects groundwater level when there is a change in the velocity of the same layer. The significant effect of groundwater level on structural integrity is realized especially when the water level is at a shallow depth and has a drastic seasonal change. Knowledge of the groundwater and its seasonal fluctuations can help the engineer design a structure that accommodates the effect of these fluctuations. Also seismic refraction technique is predominantly used because it overcomes the high logistical challenges associated with traditional geotechnical investigation techniques and other limitations of geotechnical investigation procedures like drilling boreholes in urbanized areas.

II. Location and Physiography of Study Area

KNUST Campus is located in Kumasi in the Ashanti region, an area underlained predominantly by the middle Precambrian rocks, specifically the Birimian which comprises of metasediments and metavolcanics with granitoids that intruded the deformed Birimian rocks. Kwame Nkrumah University of Science and Technology (KNUST) is predominantly underlained by the basin type granitoids (Kesse, 1985). The campus has no significant change in the soil properties to that of the general geology of Kumasi except for some few feet into the ground surface. This soil covering the Birimian is generally called by engineers as "rock laterite" and they are zones of very stiff and structureless silt changing gradually at about 6-8m depth to typical phyllite, foliated and purple or brown in color. It is established largely that the rocks over the Birimian is weathered to deeper levels in the flanking ridges than in the valley, and boreholes on the university campus gives a strong indications similar situation (Ruddock, 1967).

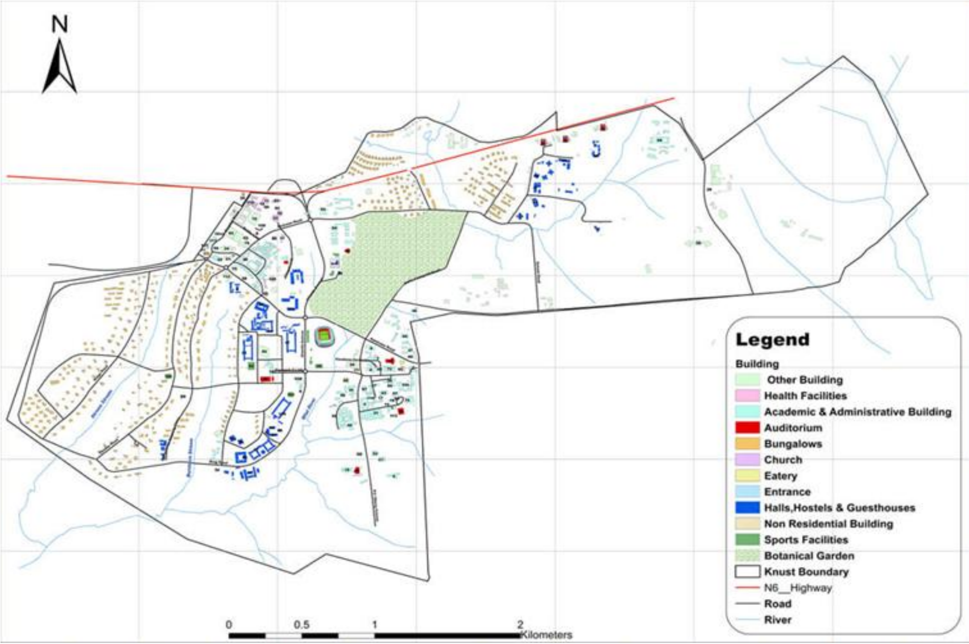


Fig. 1: Map of KNUST [Digital image]

III. Vegetation and Climate

The study area falls within the wet sub-equatorial type. The average minimum and maximum temperature are 21.5 and 30.7 degree centigrade with an average humidity of 84.16 percent at sunrise and 60 percent at sunset. The metropolis lies in a transitional forest zone specifically within the moist semi-deciduous south east ecological zone. The study area has a green environment which has conscientious conversation plan (KMA, 2017).

IV. Materials and Methods Used

The seismic refraction survey was done using a 12-channel smartseis seismograph system of recording. The field was inspected and a traverse line was chosen along a slope. A tape measure was spread along the traverse line; the shot points and geophone points were then marked. The total spread was 50m with 16 geophones placed vertically along the traverse line at an interval of 3m. The distance between the first geophone and the shot point was 2m. This was done to obtain the crossover distance. For this project the shot points were marked with intermediate shot point of 6m from the preceding shot point thus the shot points were 0. 6m, 12m, 18m, 24m, 30m, 36m, 40m and 46m. This was done to build high resolution and robust the velocity. Also the positioning of the shots relative to a given spread is to achieve adequate coverage of the refractor surface and to provide adequate lateral resolution (Reynolds, 1997). The seismic waves were generated by a sledge hammer as a source of energy from the two ends as well as the intermediates shot points of the profile. A metallic plate was pinned to the ground to improve the contact between the plate and the ground. The hammer was then struck on the plate at the shot point to generate the seismic waves. Under the field conditions, vertical stacking was done at least 2-3 times to increase the intensity of the waves. This was repeated for the shot points on all the traverse lines. The seismogram was recorded and stored using the seismograph from which the first breaks was then picked. Filters were used to help the seismograph record high frequency signals of small amplitude which would otherwise not be covered by the dynamic range of the instruments and to eliminate noise. The GPS coordinates and elevations were taken at the various geophone positions. Figure 2 shows the setup of the equipment on the field.

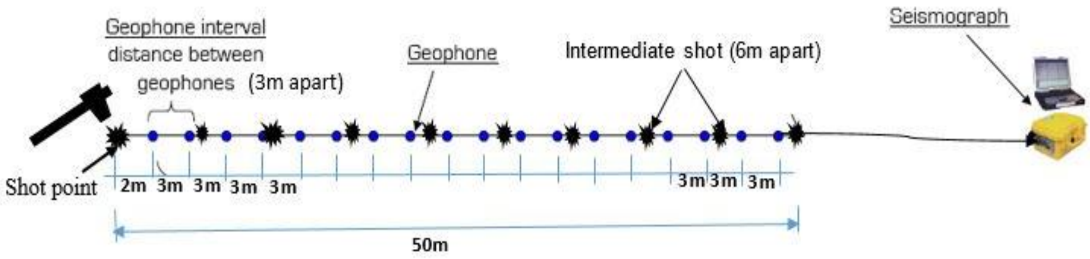


Fig. 2: Setup of equipment in the field

V. Data Processing

The data which were generated during the field data collection from the various shot points were stored on the seismograph. These data were processed with a Seisimager software to determine the arrival times of the waves. Figure 3 shows a seismogram data collected from shot point 40m on the traverse line by the seismograph. The red ticks on the seismogram indicates where the arrival times of the waves from the same shot point were picked by the Seisimager. The arrival times picked by Seisimager were transferred to Microsoft Spreadsheet. Distance time graphs were plotted to obtain the various layers and their corresponded seismic velocities were calculated using the inverse of the slopes.

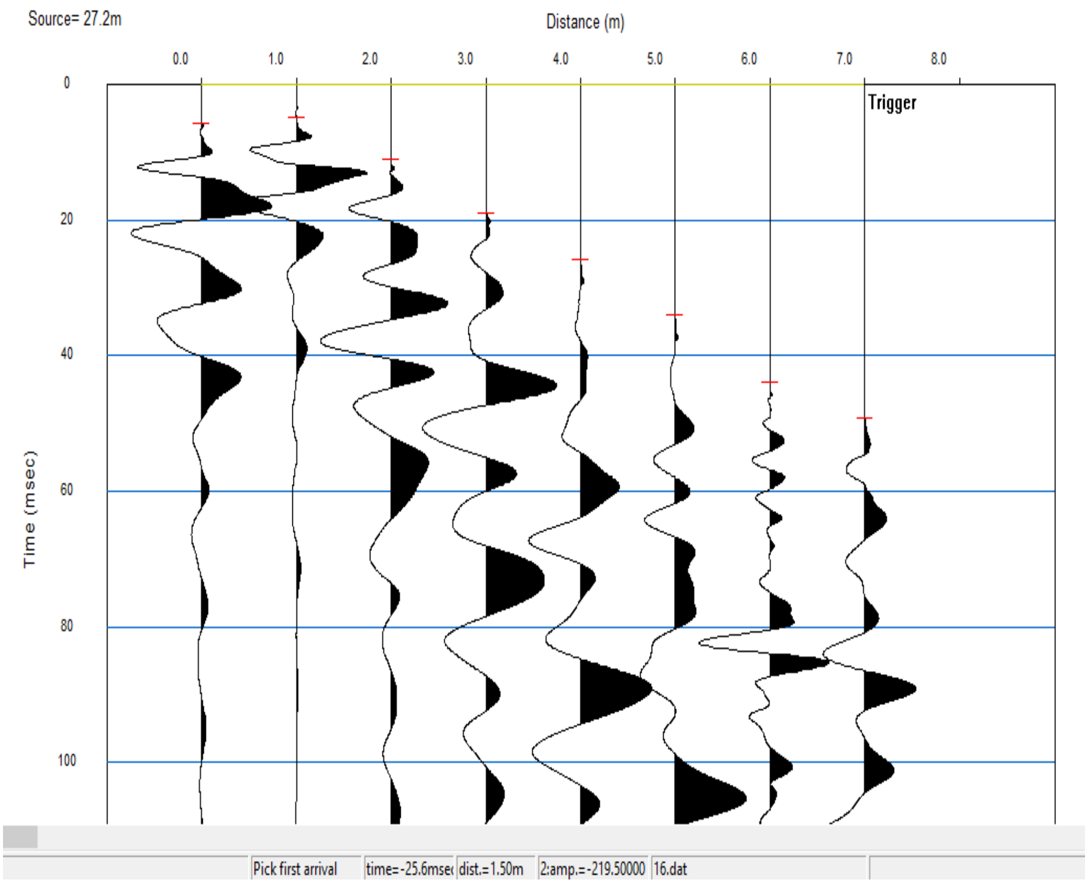


Fig. 3: A seismogram and picking of first arrival time for shot at 40m

VI. Results and Discussions

The field work using seismic investigations was done using a single traverse line during the investigation. The arrival times were generated using the seismograms that were displayed by the smartseis seismograph. The first arrivals were then picked using the seisImager which consist of the pickwin and ploterfera. The first arrivals were then plotted against the distances. A distance time graph produced a view of points that fall in a defined pattern, therefore the number of defined patterns that can be obtained indicates the layers seen in the subsurface formation. Gradient from these separate lines from the graphs aids in computing their seismic velocities and thicknesses. The Figure below shows the distance time graph showing 3 layers from a shot point 6m (SP-6) with their Equations.

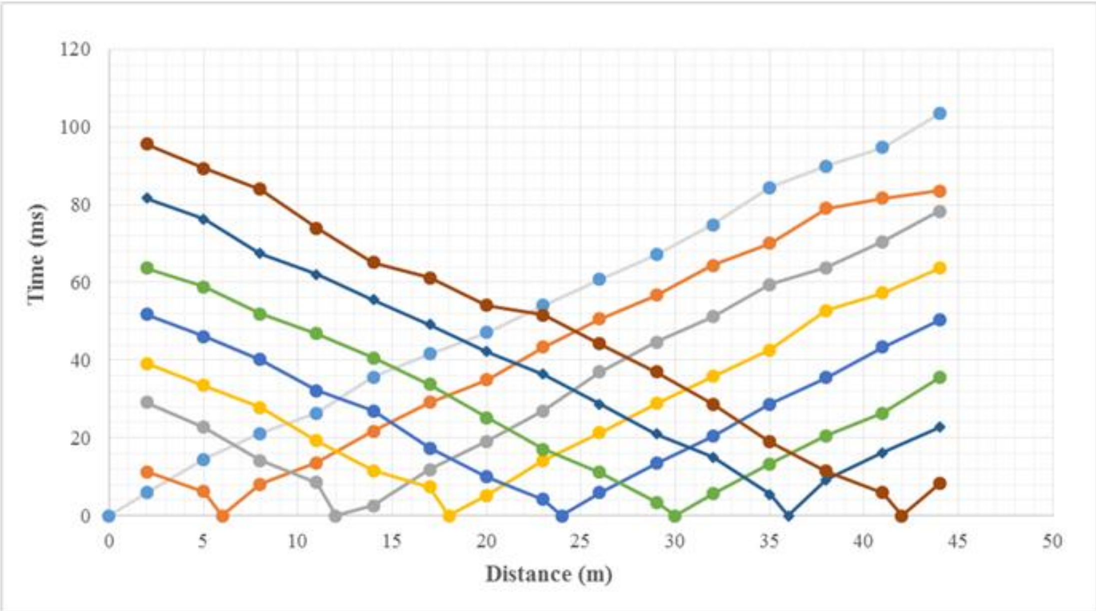


Fig. 4: A distance time graph of the various shot points

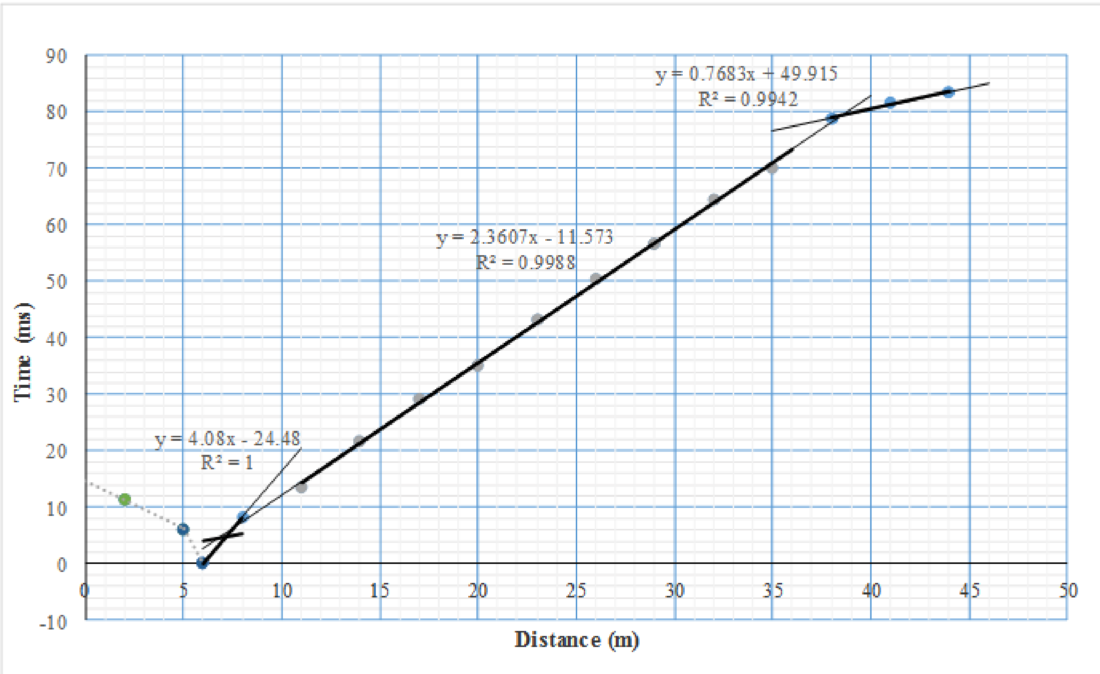


Fig. 5: Distance time graph of shot point 6m along the traverse line

From the graph in Figure 5, the velocities of each layer is determined from the inverse of the gradient of the line representing the layer. Shown below is the computation.

Where V1, V2 and V3 are Velocities in layer 1, 2 and 3 respectively; h1 and h2 are thicknesses of layer 1 and 2 respectively.

$$V_1 = \frac{1}{m_1} = \frac{1000}{4.08} = 245.10\text{ms}^{-1} \quad (1)$$

$$V_2 = \frac{1}{m_2} = \frac{1000}{2.36} = 423.60\text{ ms}^{-1} \quad (2)$$

$$V_3 = \frac{1}{m_3} = \frac{1000}{0.77} = 1301.57\text{ ms}^{-1} \quad (3)$$

The thickness of the various layers is determined as shown below;
For h_1, using a cross over $X_c = 1.80$m

$$h_1 = \frac{X_c}{2} \times \sqrt{\frac{V_2 - V_1}{V_2 + V_1}} = \frac{1.8}{2} \times \sqrt{\frac{423.6 - 245.1}{423.6 + 245.1}} = 0.39\text{m} \quad (4)$$

Also, for h_2, using $t_2 = 49.915\times10^{-3}$s,

$$h_2 = \frac{V_2 V_3}{\sqrt{V_3^2 - V_2^2}} \times \left(\frac{t_2}{2} - \frac{h_1\sqrt{V_3^2 - V_1^2}}{V_3 V_1} \right) \quad (5)$$

$$h_2 = \frac{423.6 \times 1301.57}{\sqrt{1301.57^2 - 423.6^2}} \times \left(\frac{14.915\times10^{-3}}{2} - \frac{0.39 \times \sqrt{1301.57^2 - 245.1^2}}{1301.57 \times 245.1} \right)$$

$$h_2 = 10.29\text{m}$$

TABLE 1 shows Layers detected at shot point 6m along the traverse line.

E	Layer	Gradient	Velocity (m/s)	Thickness (m)
SP 6m	1	4.08	245.10	0.39
	2	2.36	423.60	10.29
	3	0.77	1301.57	

The traverse line reveals three layers with average velocities of about 245 ms-1, 424 ms-1 and 1302 ms-1. The velocities indicate that the area may be underlained by dry loose sand and clayey material using chart from Kearey, 2002. The difference in velocities between the first and second layer may show their competency because from literature, the higher the velocity, and the more competent the material thus the second layer may be more competent than the first layer. The difference in the velocities also indicate their state of weathering. Figure 6 shows a simplified profile of the subsurface with the thicknesses of the various layers along the traverse line.

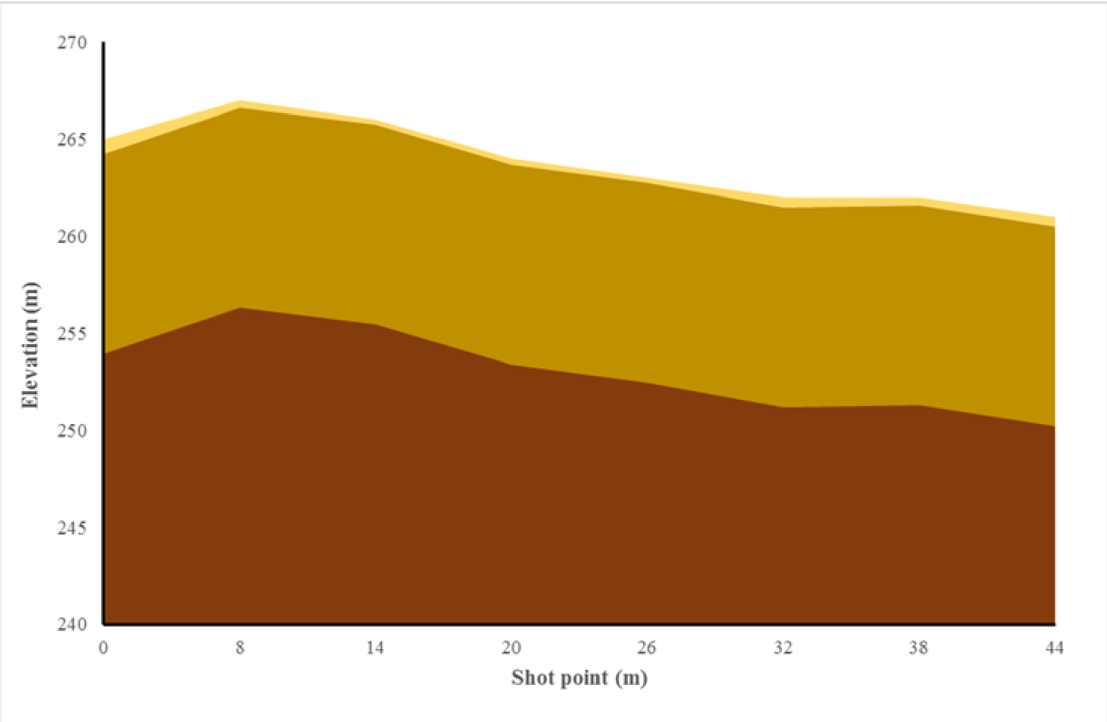


Fig. 6: Simplified subsurface profile of the site

VII. Conclusion

There is an increasing requirement for geophysical surveys carried out during geotechnical investigations to provide information about rock quality. To estimate the geotechnical characteristics of the subsurface materials, seismic refraction method was conducted. Based on the insitu seismic measurements, a distance time graph of the site was introduced. The ground structure from the analysis consist of three layer (Figure 5). The first layer has an average velocity of 303 ms^{-1} and a thickness of 0.4 m. The second layer has an average velocity of 447 ms^{-1} and an average thickness of 10 m. The third layer also has an average velocity of 1301 ms-1. From these velocities, the area may be underlained by dry loose sand and a clayey material using chart from Kearey, 2002. With the knowledge of the geology of the area, the interpreted layers depicted appears reasonable. The difference in velocities between the first and second layer may show their state of weathering. The traverse line revealed three layers with interfaces between the layers mimicking the topography as shown in Figure 6. The distance-time graph at the various shot points as seen in Figure 4 shows similar trends in material properties with slight variations at some points. For instance, the thicknesses of the first layer vary at each shot point. The variation in velocities for the same layer as seen in Appendix A, shows variation in material competence of the same layer. For instance, considering the first layer, the velocity at shot point 1 (303 ms^{-1}), and shot point 6 (160 ms^{-1}) suggest difference in material competence. Also the difference in velocities values indicates the difference in materials susceptibility to weathering at the difference shot points, thus the likelihood of differential weathering occurring within the same layer. Also areas with the lower velocities have greater erodability of their materials. With the velocities, the rippability of the materials were determined, that is the ease with which the materials can be excavated using machines. Although rippability is also a function of vehicle size, power and machine type, a standard rippability chart (as shown in Appendix B) relates the geological material and rippability to machine type. From the standard rippability chart, areas with lower velocities are more rippable and easy to excavate than areas with higher velocities. It can therefore be deduced that layer one and two are more rippable than layer 3.

VIII. Recommendation

The first layer may be dry sand, and such soil, in the foundation structure, may pose danger due to their instability under the effect of quite small vibrations (Atkinson, 2007) and operations of heavy machinery nearby can also result in settlements, compaction of soil using compaction methods such as vibrofloatation is recommended before the foundation structure.

The bedrock was not encountered at the depth of investigation nonetheless from the rippability chart, any excavation within a 10m depth can be done with some simple tools like shovels and excavators (D-9 tractor) for large excavations (Atkinson, 2007).

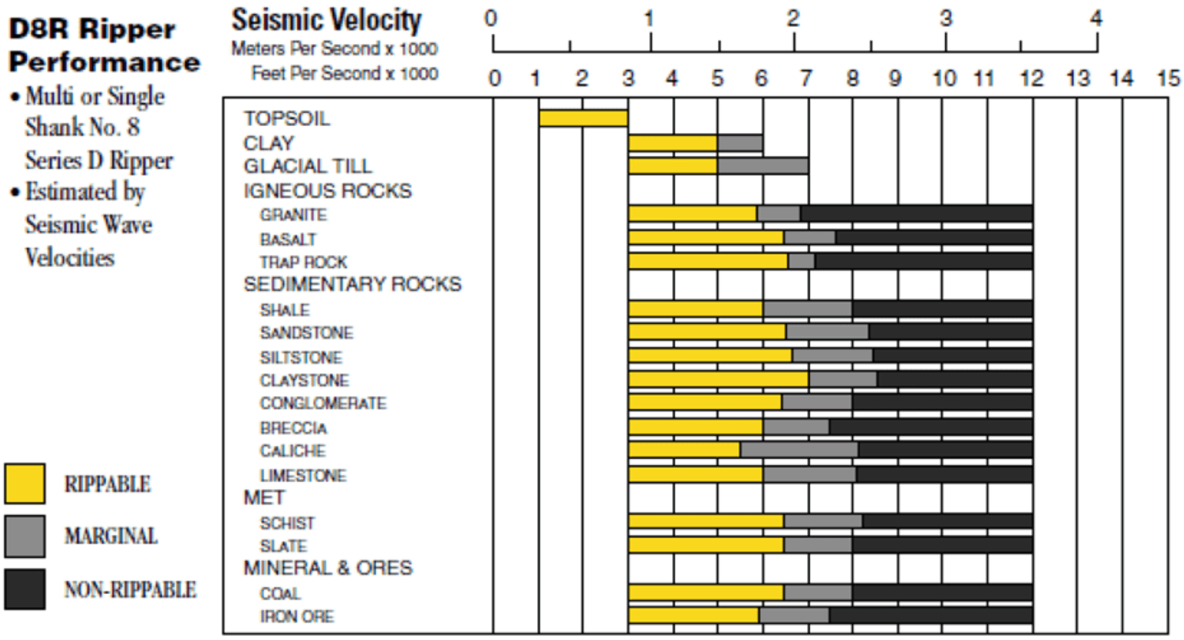
Appendix

APPENDIX A. Raw field seismic refraction data collected in front of K.K Adarkwa Building KNUST

x (m)	SP 0	SP 6	SP 12	SP 18	SP 24	SP 30	SP 36	SP 42	SP 46
0	0								
2	5.90	11.35	29.10	39.22	51.81	63.67	81.64	95.60	106.10
5	14.50	6.19	22.78	33.56	46.06	58.93	76.37	89.30	98.50
6		0.00							
8	21.20	8.16	14.22	27.91	40.18	51.91	67.42	84.01	90.99
11	26.40	13.56	8.56	19.25	32.25	46.81	62.06	74.00	86.51
12			0.00						
14	35.70	21.72	2.63	11.58	26.93	40.56	55.62	65.18	79.40
17	41.60	29.10	11.85	7.32	17.43	33.82	49.18	61.25	72.42
18				0.00					
20	47.10	35.02	19.09	5.25	9.93	25.28	42.27	54.12	64.75
23	54.16	43.32	26.97	14.18	4.22	17.12	36.39	51.62	57.48
24					0.00				
26	60.83	50.56	37.00	21.30	5.89	11.15	28.70	44.24	47.27
29	67.24	56.75	44.64	28.79	13.50	3.39	21.07	37.00	41.34
30						0.00			

32	74.87	64.43	51.22	35.87	20.37	5.63	15.14	28.70	33.07
35	84.45	70.05	59.52	42.60	28.75	13.30	5.53	18.93	26.70
36							0.00		
38	89.98	79.01	63.86	52.81	35.50	20.56	9.22	11.45	18.46
41	94.81	81.62	70.45	57.37	43.35	26.37	16.19	5.93	11.10
42								0.00	
44	103.40	83.62	78.35	63.68	50.31	35.46	22.78	8.18	3.55
46									0.00

APPENDIX B: Rippability chart



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