Seismic Surveying to Improve the Subsurface Characteristic Interpretations

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Abstract

Subsurface exploration determines the characteristics below the earth's surface, such as; stratigraphic sequences and their thicknesses, depth to the bedrock and watertable, etc. The non-destructive methods provide rapid exploration capabilities with minimal consumption of time and financial resources, provided the resultant interpretations are appropriately validated for accuracy. Accordingly, to evaluate the accuracy of seismic surveying, a twelve-channel seismic refraction survey was conducted at the play-ground premises of the University of Moratuwa, and obtained subsurface seismic profiles for the particular location. "PickWin" and "Plotrefa"software were used to pick the first breaks and plot the time-distance curves respectively to obtain subsurface profiles for each seismic surveying line. The resultant profiles indicated two distinctive layers which resembles a residual soil layer and the completely weathered bedrock. These seismic survey interpretations complement the available resistivity surveying results and borehole information. Additionally, the depth information obtained from seismic slices were used to generate a 3D model through "ESRI ArcMap" and "Surfer" software by rendering depth information to express the contact layer undulations of the residual soil and weathered bedrock. Hence, the study reveals, strength of using multiple geophysical methods to improve the accuracy of subsurface interpretations and modelling capabilities of subsurface layer contacts with a greater accuracy.

Keywords: Geophysical method, Seismic methods, Subsurface exploration

1. Introduction

Seismic methods are based on the principles and behaviors of elastic waves. Hence, materials having different elasticiticity properties can have dissimilar seismic wave travel velocities. And these velocities are determined by the Elastic Moduli and the densities of materials through which they travel. Seismic surveying make use of this characteristic of the subterranean material to determine unique seismic velocity values for each layer in the subsurface [1]. The travel time between a selected shot point and the arrival of reflected or refracted seismic waves are important in seismic surveying and a seismograph is produced using amplitude and travel time of waves recorded by the "geophones". Seismic interpretations depend on the depths which the waves travelled (influenced by the distance between shot point and geophone locations) in addition to the densities of the strata. Among several methods, seismic refraction is mostly used to explore the shallow subsurface [2,3].

In this study, a location which has bore-hole data and resistivity survey interpretations [4,5] were used to model the subsurface profile using seismic method. Comparisons between the available data and seismic interpretations reveal disparities between the results and modes of accuracy improvements for non-invasive exploration methods.

2. Methodology

2.1 Seismic Refraction Survey

The seismic refraction survey was conducted by creating a shock wave on the ground surface with a sledge hammer (5 kg) and a metal plate. The resultant waves were recorded by a seismograph (Geode – 12) with 12 geophones [6].

The 12 geophones of 14 Hz frequency was installed along the survey line with a 5 m interval using a measuring tape. Then, the geophones, sledge hammer display unit and the battery (12 V) were connected to the Geode. After switching on the battery, seismogram and the display unit respectively, the geophone connection was checked. Initial instructions were given to "Seismic controller" software which communicates with the seismograph and the computer and the seismic waves were created closer to the geophones 1 and 12 as well as middle of the survey line and offset points. Three shots per each location was performed to reduce the signal to noise ratio.

For each survey line, five seismic shootings were performed as given in Table 1. Purpose of the first shooting was to locate the energy source at the first geophone and to determine the cross-over distance of layers in the subsurface.

Table 1 - Location of the energy source for 5 shootings

Shot No	Place of the energy source
1	Near geophone 1
2	With an offset equal to the cross over distance
3	At the middle of the survey line (in between 6 and 7 geophones)
4	Near 12th geophone
5	A distance equal to the cross over distance away from the 12th geophone.

A total of forty seismic shooting were conducted for eight survey lines. Among those 8 and 4 lines were oriented NW-SE direction in the eastern part of the university ground, and the others in NE-SW direction. Figure 1 shows the plan view of survey lines of this study.

Figure 1 - Survey locations

The data was acquired using the "Siesmodule" software. Then the first arrivals of each shooting were obtained using " PickWin" software. Manual corrections were done for the first picks whenever necessary. "Plotrefa" software was used for the interpretation of each seismic line.

2.2 Data Interpretation

Data obtained from the survey was opened with "PickWin" software to identify the 1st pick. Then, the file which has only 1st pick of wave (output file of PickWin) was opened with "Plotrefa" software and time-distance graph is generated. The reciprocal error was checked and corrected to maintain it less than 5%. With "time-term inversion method", subsurface profile was interpreted with RMS error less than 1.5 [6,7].

The profiles generated using "PickWin" and "Plotrefa" software presented the number of subsurface layers. The interface of these layers were transferred into "ArcMap" 10.5 software to generate layer files. A 3D view of the interface was obtained by taking the above layer file to "ArcScene" 10.5 software. The same layer file information were taken to "Surfer" software to construct a wireframe model of the layer interface.

3. Results and Discussion

The profiles generated from "PickWin" and "Plotrefa" software demonstrated two distinct layers having different seismic velocities. According to the profiles, 1st layer velocity varies from 0.6-0.7 km/s while the 2nd layer velocity varies from 1.6-2.1 km/s [Table 2].

The seismic velocities of subsurface layers can be used to identify the soil or rock types [7,8,9]. Accordingly, the velocities obtained from this study corresponds to residual soil layer and a highly weathered rock layer [Table3].

Table 2 - Seismic velocities of layers in generated profiles

Survey Line	Velocity Layer 1 (km/s)	Velocity Layer 2 (km/s)
AB	0.6	1.6
EF	0.7	1.9
IJ	0.7	1.9
LK	0.7	2.1
MT	0.7	2.1
NO	0.7	1.7
PQ	0.7	1.9
RS	0.7	1.9

Table 3 - Geological classification of subsurface P-wave velocities [8]

Geological Classification	P-wave velocity (km/s)	N value (%)
Residual Soils	0.4 - 1.0	50 <
Completely weathered rock	1.0 – 1.7	50-65
Highly weathered rock	1.7 – 2.1	65-75
Moderately weathered rock	2.1 – 2.7	75 - 85
Fresh rock	2.7 <	85 <

Approximately E-W directed seismic profiles (RS, NO & AB) obtained from the southern part of the ground, demonstrates identical depth variation along the interface of the two layers. The thickness of the residual soil layer increases along A to B and it is determined as ~4.75 m at A and ~7 m towards B [Figure 2a]. Seismic profile obtained on the northern side of the ground (PQ) also revealed identical depth variations for the residual soil layer [Figure 2b] with its thickness slightly improving towards the NE corner of the ground.

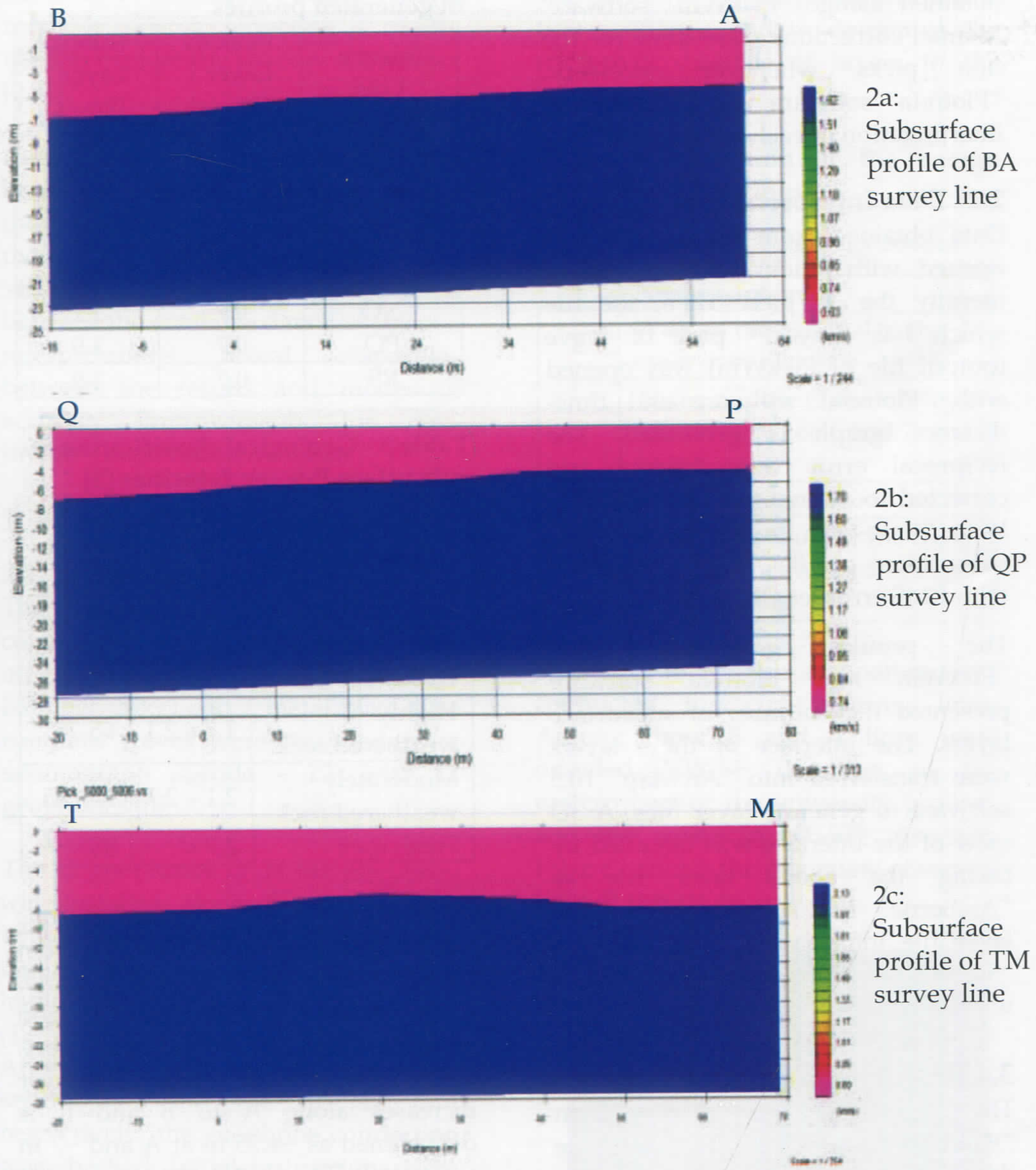

Figure 2 - Subsurface profiles generated for BA, QP and TM seismic survey lines

Seismic profiles approximately oriented N-S (EF, KL & MT) and surveyed on the eastern side of the ground display a relatively horizontal but undulating contact between the residual soil layer and the highly weathered bedrock [Figure 2c]. The thickness of the soil layer varies from ~7 m to a maximum of ~8.75 m within the surveyed distance. The survey line IJ, which diverges from the N-S orientation harmonizes with the general trend of the NE corner of the location.

The spot-depth information extracted from each of the seismic survey lines were imported to "ESRI ArcMap" software to model the contact layer at the location and the obtained output is presented in Figure 3. Further, the same information was modeled using "Surfer" software to obtain a wireframe model to better represent the layer contact [Figure 4].

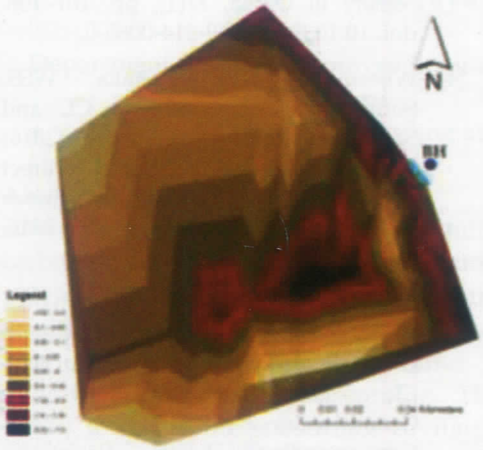

Figure 3 - Plan View of the interface of the layers (Generated by ArcMap)

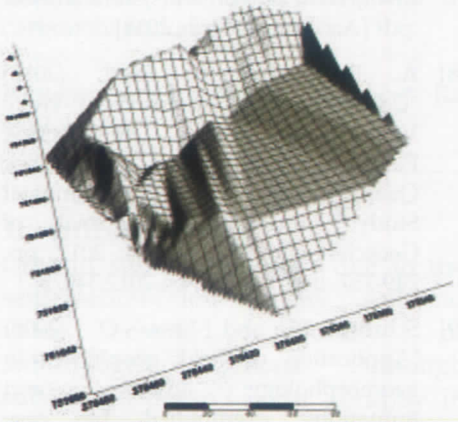

Figure 4 - Wireframe model of layer interface (Generated by Surfer)

The distance from the closest point of the generated model to the existing exploratory borehole [5] was ~5.9 m. At that point, depth to the layer interface was computed as ~6.7 m. However, the borehole log reveals the contact depth as ~7.5 m [Figure 5], creating an error of 10.7% for the seismic method.

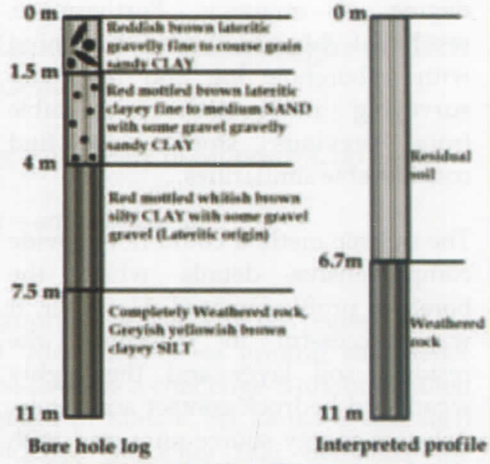

Figure 5 - Comparison of Bore-hole & Interpreted profile

An earlier study conducted using resistivity method [4] at the same location reveals a layer contact at the depth of ~6.58 m. Hence, it provides a very close resemblance between the results obtained from two non-destructive subsurface exploration methods, for the particular location.

Even though, continuous recording of depth of the water table in the exploratory borehole was performed, the seismic survey did not provide sufficient details to correlate the obtained data. Hence, this study was limited only to the identification of subsurface strata. The lateritic soil which is separately identified in the borehole log, was categorised as residual soil in the seismic method. However, an overall performance accuracy of 89.3% was achieved by the seismic method in comparison to the details depicted by the borehole log.

4. Conclusions

It was observed that multiple depth information interpretations obtained from a seismic survey could be used to model the layer contact with a higher degree of accuracy. Furthermore, results of this study was compared with a borehole log and resistivity surveying interpretations available from previous studies to find considerable similarities.

The seismic method could not provide comprehensive details which the borehole profile exposed. However, it was successful to determine the residual soil layer and the highly weathered bedrock contact accurately. A better energy source on a grid with closely spaced shot points, are recommended to detect the layering within the residual soils due to lack of variation in elastic properties between the strata.

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