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Application of Geophysical Methods in Civil Engineering

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Abstract

Geophysical methods originally championed by geophysicists are becoming popular in the civil engineering field. In the past, most engineers applied their conventional method with rare to any other alternative method. This study describes some of the civil engineering applications discourse where the geophysical method is especially suitable in the preliminary stage of site assessment. Some of the geophysical method which can assist the civil engineering works is still rarely understood for several reasons. Hence, this study presents a resistivity and seismic refraction method applied in several civil engineering problems in Malaysia such as in geotechnical engineering, rock mechanics and engineering geology, water and environmental engineering and pavement engineering. The utilization of geophysical method can increase the effectiveness of civil engineering works since it can provide the information which the conventional civil engineering method was hard to determine due to the concern of money, time and quality. For example, the method helps to reduce the number of conventional drilling method and possibly decides a critical spot of interest which directly decreases the cost of the project. Some of the common earth materials and related parameter in civil engineering application that can be utilized by the geophysical method are minerals, soils, rocks, water, subsurface layers, thickness and depth. The results produced by the geophysical survey increase the awareness of civil engineers of their wide area of applications. The utilization of this method have been successfully used in the civil engineering field and has the potential to be integrated with a conventional method to produce reliable information thus enhance the project effectiveness especially during the design and construction stages.

Keywords: conventional method, resistivity, seismic refraction, site assessment.

1. INTRODUCTION

In this multidisciplinary era, most of the science and technology researchers diversify their research area with the application of alternative method beyond their own conventional method. The alternative method is to increase the cost, time efficiencies, and the quality of their researches.

Civil engineering is a broad field which covers several disciplines, such as structural engineering, environmental engineering, transportation engineering, geotechnical engineering, water resources engineering, material engineering, municipal or urban engineering, coastal engineering, survey and construction engineering. Most of these disciplines have the potential to include for the application of an alternative method such as the geophysical method. Geophysical techniques offer the chance to overcome some of the problems inherent in more conventional ground investigation techniques [1].

Geophysical method applies the principles of physics is studying the earth. Some of the geophysical methods which are commonly used are resistivity, seismic, gravity, magnet, electromagnet and radiometry. According to [1], geophysical techniques offer the chance to overcome some of the problem inherent in more conventional ground investigation techniques. In most equipment testing, the geophysical methods apply a non destructive testing which can reduce cost and time of the project. Geophysical techniques also can be of help in locating cavities, backfilled mineshafts and dissolution features in carbonate rocks and can be extremely useful in determining the stiffness properties of the ground [1]. Geophysical methods are generally less expensive, less invasive and less time consuming. They provide a large-scale characterisation of the physical properties under undisturbed conditions [2].

Since such potential of geophysics in engineering are yet to be realized, the application of these techniques are still not being fully utilized. Problems may arise during the applications when the geophysical methods are not being fully explored by the civil engineers due to their lack of exposure and expertise in this field. According to [1], some of the reasons are due to poor planning of geophysical survey by engineers whom are ignorant of the techniques, and over optimistic geophysicist leading to poor reputation of the available techniques. Hence, this paper presents several case studies regarding the studies of resistivity and seismic method, which can be adopted and applied in civil engineering works.

1.1 Resistivity Theory

Electrical tomography, also referred as electrical imaging is a survey technique which aims to build up a picture of the electrical properties of the subsurface by passing an electrical current along many different paths and measuring the associated voltage [3]. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation in the rock. According to [4], igneous and metamorphic rocks typically have high resistivity values while clay has a significantly lower resistivity than sand (refer Tables 1 to 3 in the Appendix). To obtain a good two-dimensional (2-D) picture of the subsurface, the coverage of the measurements must be in 2-D as well.

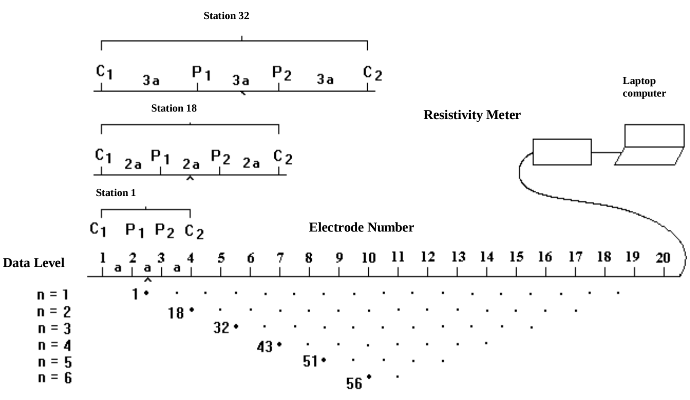

Fig. 1 The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo section

Figure 1 shows a possible sequence of measurements for the Wenner electrode array in a system with 20 electrodes.

1.2 Seismic Refraction Theory

The basis of seismic refraction investigation is the measurement of the time taken for a wave to travel from one location to another location. The time travel is a function of elastic modulus of the material through which the wave travels. This method applies the Snell's law towards the seismic waves and was used to study the layers below the earth surface.

Waves travelling in a medium, i.e. soils or rocks will follow the elastic characteristics in all directions and produce reflection and refraction. The motion of the wave particle is recorded as a function of time along the travel path. Then, the type of layers and structures in the subsurface are determined. Figure 2 shows the distribution of ray path.

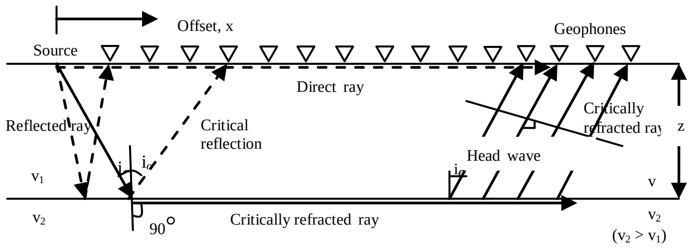

Fig. 2 Ray path diagram showing the respective paths for direct, reflected and refracted rays

2. MATERIALS AND METHODS

Several case studies regarding the application of resistivity and seismic method in civil engineering works were presented for some of the selected area in Selangor, Pahang and Negeri Sembilan.

Two geophysical methods used in this study are resistivity and seismic refraction method. According to [8], [9], electrical resistivity survey and seismic method are geophysical methods used in civil engineering concerns. In resistivity method, ABEM Terrameter SAS 4000 was used for data acquisition. The array used for 2-D resistivity was pole dipole and Wenner with a 5 m minimum electrode spacing and the RES2DINV software. In seismic refraction method, the sledgehammer was used as a source with 5 m geophone interval. The ABEM Terraloc MK6 of 24 channels was used to record the seismic wave with seven shot point location. For processing and interpretation, Optim software was used to pick the first arrival and generates the velocity of the subsurface profile layers. Field arrangement for the equipment was shown in Fig. 3 and Fig. 4 (also refer Figs. 5 and 6 in the Appendix).

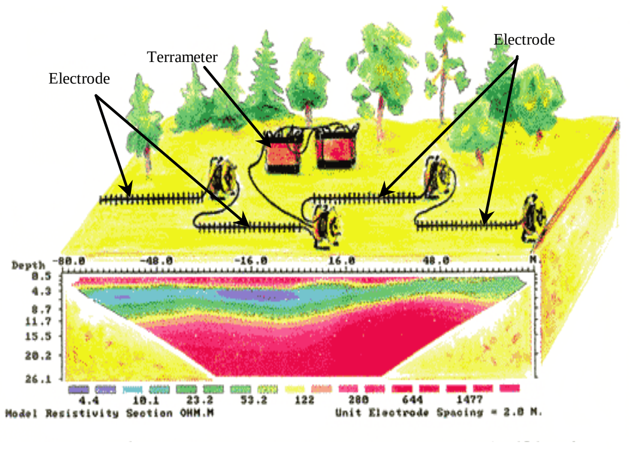

Fig. 3 Field arrangement of the ABEM Lund system in the resistivity method

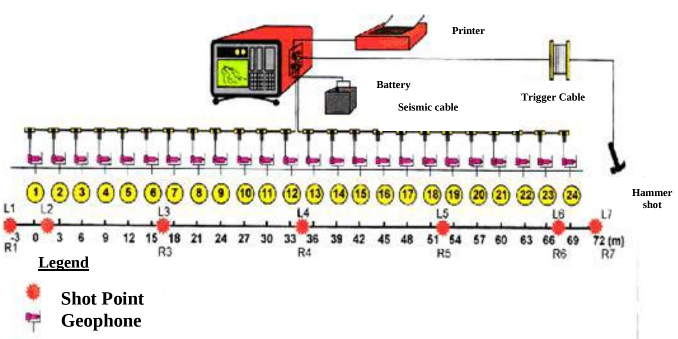

Fig. 4 Field arrangement of the ABEM Terraloc MK6 in the seismic refraction method

3. Case Studies

3.1 Geotechnical Engineering, Rock Mechanics and Engineering Geology

Information on surface condition is necessary in the planning, design and construction stages, e.g. determination of suitable method and equipment to be used based on the site surface topography. Information on the existing subsurface conditions on site is a critical requirement because it is required in the planning and design stage of the building foundation and other below ground works. According to [1], site investigation is the process in which geological, geotechnical and other relevant information which might affect the construction or performance of a civil engineering or building project are acquired.

A correlation between seismic refraction method and borehole exploration method was presented as one of the most significant approach since it can increase the effectiveness of site investigation information such as thickness layer, types of material and depth to the bedrock by reducing cost and time. Many geophysical methods exist with the potential of providing profiles and sections so that the ground between boreholes can be checked to see whether the ground condition at the borehole are representative of those elsewhere [1].

The results presented for the three case studies of application of seismic refraction method are shown in the Appendix. Figure 7 and Tables 4 and 5 show a case study involving the relationship between seismic refraction and borehole data in Selangor. The results from seismic refraction show three types of materials based on primary velocity V_p (refer to Table 1 for material interpretation). These are top soil (clay and sand V_p = 304 m/s) at 0 to 1.7 m, clay (V_p = 609 m/s to 1685 m/s) at 1.7 m to 14 m and sand (V_p = 1808 to 3660 m/s) at 14 m to 27 m. The results from borehole as given in Table 5 show that the profile consists of four layer, i.e. clay (0 to 0.75 m), sand (0.75 m to 13.5 m), clay (13.5 m to 28.5 m) and sand (28.5 m and above). The results from the seismic refraction have successfully been proven with the borehole findings, where both methods produce similar types of material and layer thickness.

The rippability of an earth material, e.g. rock is the measure of its ability to be excavated with conventional excavation equipment. Figure 8 shows a case study of a relationship between seismic refraction and rippability techniques studied in Selangor. Six distinct velocities layering was found, i.e. the residual soil (unsaturated zone), residual soil (saturated zone), very strongly weathered, strongly weathered, moderately weathered and the metamorphic bedrock layer. Table 6 shows the summary of the results obtained from the seismic line profile extracted from Fig. 8. The distinct velocities were compared in Table 2 for materials interpretation. These layers indicate the different type of material that present at the different depths below ground. The result shows that there is no obvious velocity variation in lateral direction. This indicates the layers are almost homogenous throughout the gradient of the terrain. The proposed borehole 1 of subsurface condition are similar with the cross section of profiles A-A' in Fig. 8. According to Fig. 8 and Table 3, the study area can be excavated up to a depth of 27 m without blasting.

The branch of geology devoted to crustal deformation is known as structural geology [13]. Common structural geology features that can pose danger to civil engineering structure are fault, fold, joint, and foliation. Figure 9 shows a case study of a relationship between seismic refraction and structure geology of fault detection in Pahang. Based on Fig. 9, the possible major fault zone was clearly visualized at depth of between 4 m and 20 m. According to [15], the ultimate aim of engineering geology is to provide information on the mechanical properties of rock or a zone of rock or soil to enable an adequate and economical design to be prepared. Thus this information is useful especially during site assessment process of a new construction site to determine the ground stability of the proposed structure.

3.2 Groundwater and Environmental Engineering

Groundwater is defined as water below the water table in the geologic strata where the pore space is 100 percent occupied by water [16]. This alternative source of water is important in our life. The problem always encountered by a groundwater and environmental engineer is to determine the accurate location of the fresh groundwater zone. Zones located near the coastal area normally are affected by groundwater contamination of saltwater intrusion. The best geophysical method, particularly in salinity mapping, is geoelectrical method [17].

Figure 10 shows a case study of a relationship between resistivity and groundwater exploration for a proposed mineral water source site in Negeri Sembilan. The application of 2-D resistivity is very practical in this study since it can provide information to fulfill the requirement of the authority which require that the groundwater sources to be at least 100 m deep for approval and commercialization purposes. The 2-D resistivity provide cross section in two dimensional as compared to the conventional drilling method which could only provide information at the location of drilling. Therefore, the resistivity method saves time and cost. The suitable location proposed by Fig. 10 was located at 40 m from the center of measurement to a minimum depth of 100 m. The presence of weathered granite to fresh granite in this zone was a strong indication that the proposed spot is of fresh groundwater. Water can be stored in the fractured granite which is located at between the weathered to fresh granite zones, as seen in the resistivity image.

Figure 11 shows a case study of a relationship between resistivity and saltwater intrusion in Selangor. It was found that there are three water zones in this area which are the saline water, brackish water and fresh water. The transition zone (brackish water zone) was approximately 5 m thick and this information is important in determination of a suitable location as an alternative source of water for human consumption.

3.3 Pavement Engineering

According to [20], the evaluation of existing road structures has a major potential for the application of electrical resistivity method since there is increasing interests on maintaining and improving the service standard of current road network. Figure 12 shows a case study of a relationship between resistivity and pavement thickness assessment in Selangor. The resistivity test was used and being calibrated by a dynamic cone penetration test (DCPT). The result from resistivity method shows four layers of bituminous pavement structure with a small significant error of 30.05% in surface course, 18.21% in base course, and 1.2% in subbase and subgrade courses. Based on Fig. 12 and Table 7, both pavement thickness obtained by each method were almost similar and this proved the geophysical method is applied successfully. Hence, this alternative geophysical method has the potential of being used to supplement the information related to pavement depth and thickness layer especially for a long continuous pavement assessment, thus reducing the number of coring tests that can cause damage to the pavement structure.

4. CONCLUSION

Geophysical method, the 2-D resistivity imaging method and seismic refraction method was a good alternative tool for civil engineering application such as in geotechnical and engineering geology, water and environmental and highway. The resistivity can be used in geotechnical engineering, groundwater exploration, contamination studies and highway pavement study. Seismic method was suitable in geotechnical and engineering geology studies since it can determine the depth of bedrocks, types of materials and thickness of materials. All the case study presented show that the integration of the geophysical methods plus the information from borehole data can successfully mapped some of the civil engineering interests and objectives, particularly during the preliminary stages.

The theory and application of geophysical method need to be explored in depth by an engineer since it contributes in most of the civil engineering project by saving cost, time and it is environmentally friendly. Other relevant civil engineering subfield that has a good prospect by applying this geophysical method is earthquake engineering, mining engineering, geodesy and forensic engineering.

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Appendix

Table 1: Resistivity and velocity of some common rocks and minerals [5]

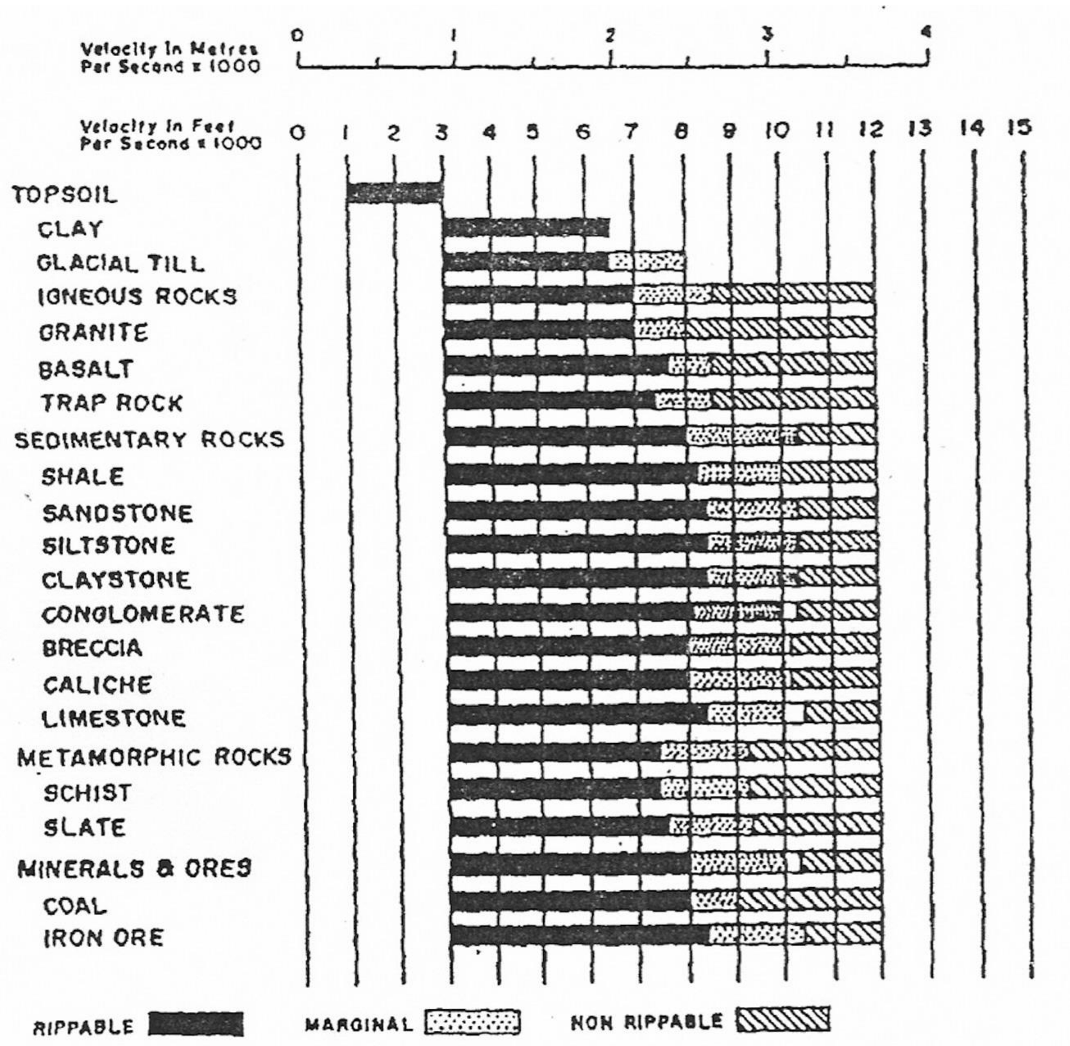
Material	Seismic (m/s)	Resistivity (ohm-m)
Igneous / Metamorphic		
Granite	4580 - 5800	$5 \times 10^3 - 10^8$
Weathered granite	305 - 610	$1 - 10^2$
Basalt	5400 - 6400	$10^3 - 10^6$
Quartz		$10^3 - 2 \times 10^6$
Marble		$10^2 - 2.5 \times 10^8$
Schist		$20 - 10^4$
Sediments		
Sandstone	1830 - 3970	$8 - 4 \times 10^3$
Conglomerate		$2 \text{x} 10^3 - 10^4$
Shale	2750 - 4270	$20 - 2 \times 10^3$
Limestone	2140 - 6100	$50 - 4 \times 10^2$
Unconsolidated sediment		
Clay	915 - 2750	1 – 100
Alluvium	500 - 2000	10 – 800
Marl		1 – 70
Clay (wet)		20
Groundwater		
Fresh water	1430 - 1680	10 – 100
Salt water	1460 - 1530	0.2

Table 2: Typical p-wave velocities of weathered and fractured igneous and metamorphic rocks [6]

Material	Grade	V_p (m/sec)
Fresh, sound rock	F	5000 +
Slightly weathered or widely spaced fractures	WS	5000 – 4000
Moderately weathered or moderately close fractures	WM	4000 – 3000
Strongly weathered or close fractures	WH	3000 – 2000
Very strongly weathered (saprolite) or crushed	WC	2000 – 1200[a]
Residual soil (unstructured saprolite), strong	RS	1200 – 600[a]
Residual soil, weak, dry	RS	600 – 300[a]

V_p (water) ≈ 1500 m/sec

Table 3: Velocity versus rippability [7]



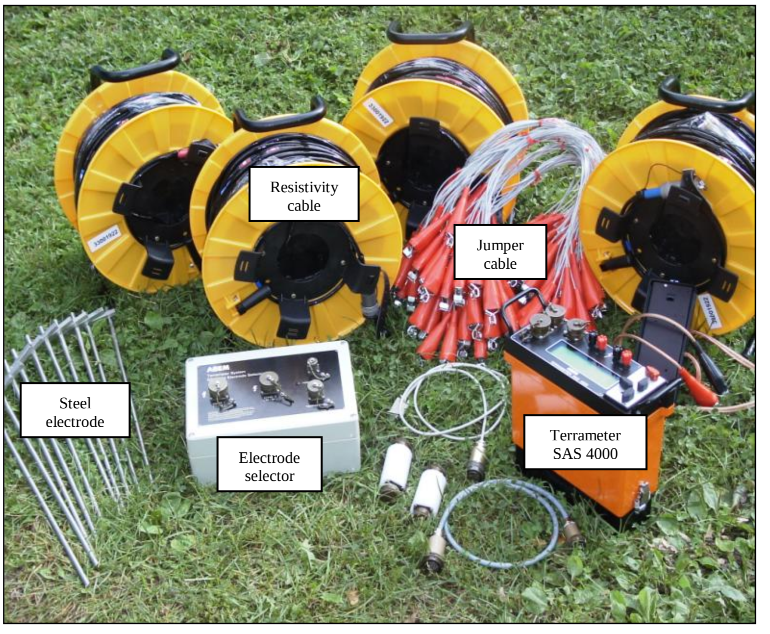


Fig. 5 Complete instrument for resistivity

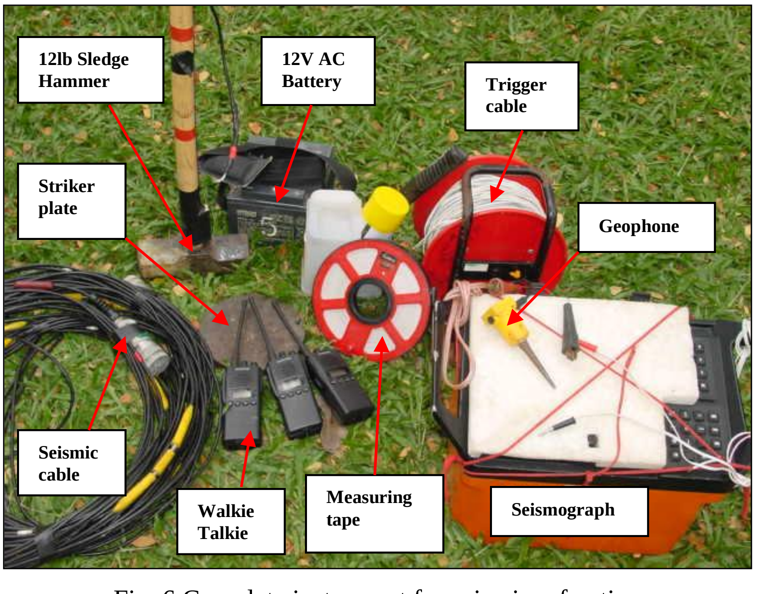


Fig. 6 Complete instrument for seismic refraction

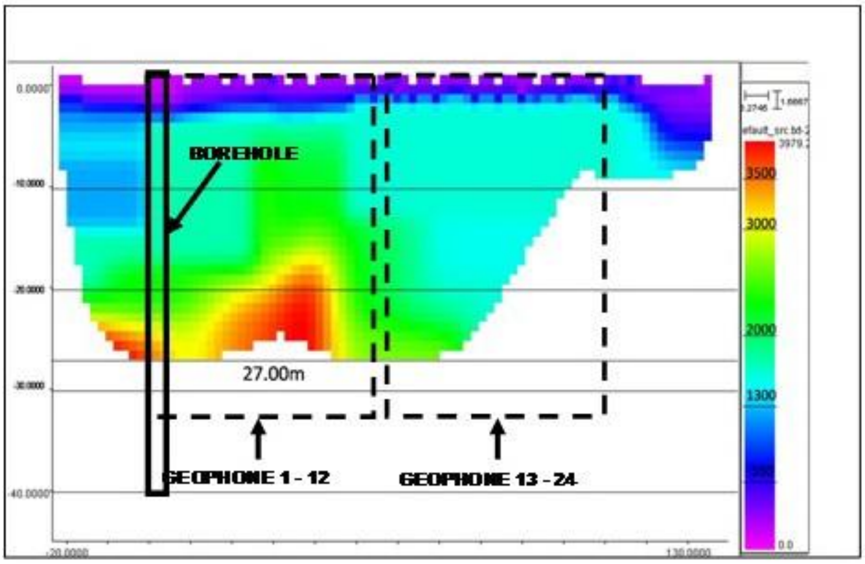


Fig. 7 Subsurface image results by seismic refraction method in Selangor [10]

Table 4: Seismic refraction method result in Selangor site [10]

Depth (m)	Primary wave V_p (m/s)	Materials
0.00 – 1.70	304	Top soil (Clay and sand)
1.70 – 14.00	609 – 1685	Sand
14.0 – 27.10	1808 – 3660	Clay

Table 5: Borehole lithology description in Selangor site [11]

Depth (m)	Lithology description
0.00 – 0.75	Silty CLAY
0.75 – 6.00	Silty SAND
6.00 – 13.50	Silty SAND
13.50 – 28.50	Silty CLAY
28.50 – 40.45	Silty SAND

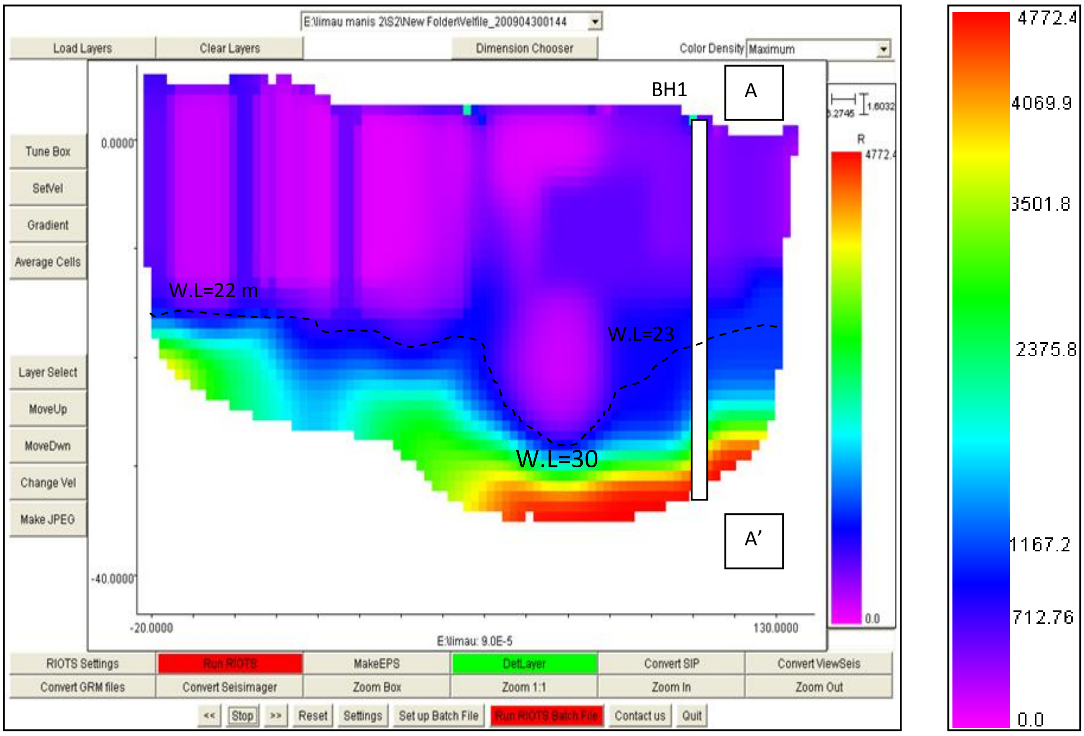
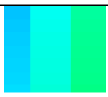
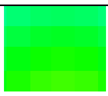


Fig. 8 Subsurface image results by seismic refraction method in Selangor [12]

Table 6: Summary of results from seismic refraction method at cross Section A-A' (Borehole 1) [12]

Depth from land surface (m)	Colour	Thickness of layer (m)	Velocity V_p (m/s)	Materials
0		14	500	Residual soil weak, (unsaturated) dry (300-600)
14		8	950	Residual soil, strong, (saturated) (600-1200)
22		3	1850	Very strongly weathered (1200-2000)
25		2	2950	Strongly weathered (2000-3000)
27		2	3800	Moderately weathered (3500-4000)
29		3	4450	Fresh metamorphic rock (3500-7000)

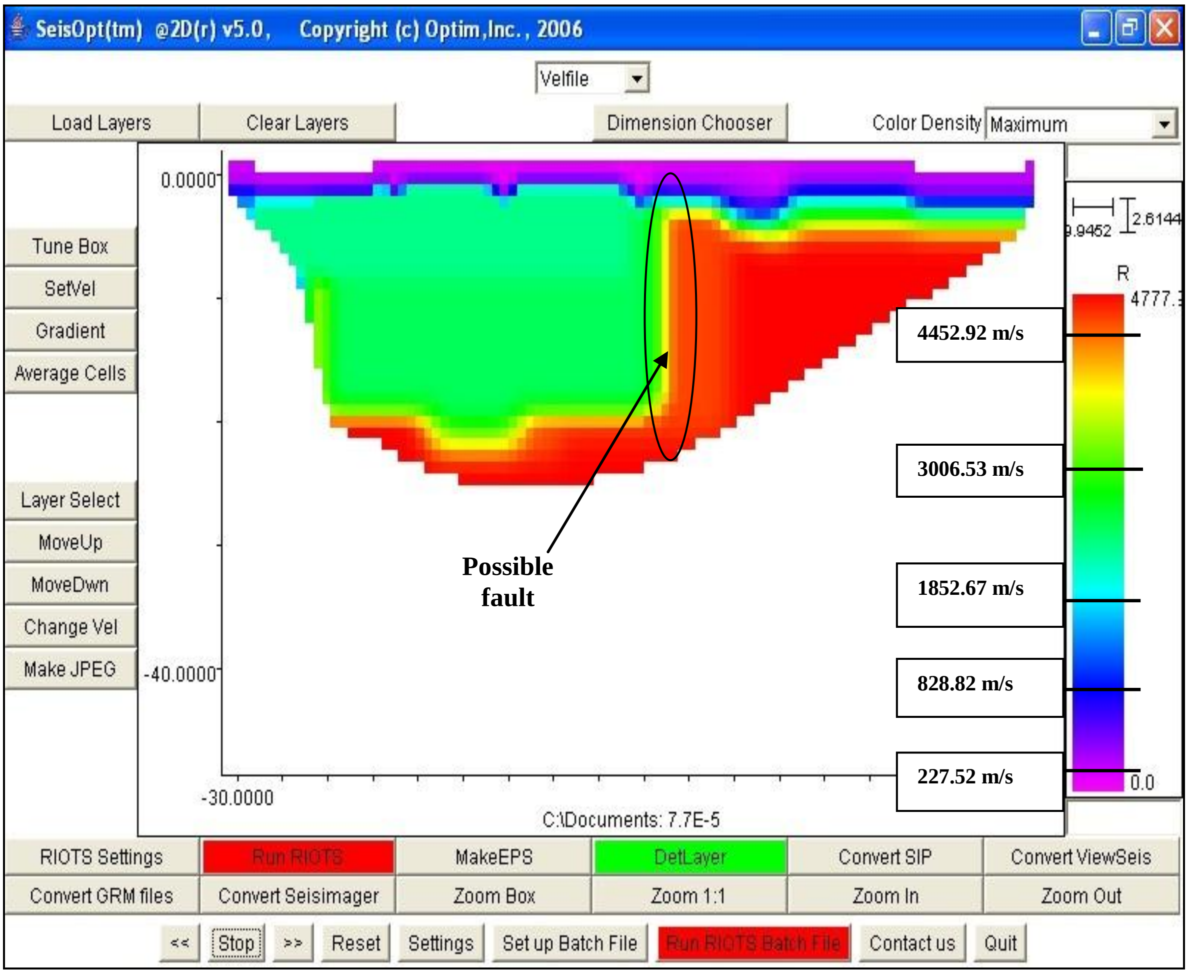


Fig. 9 Subsurface image results by seismic refraction method in Pahang [9]

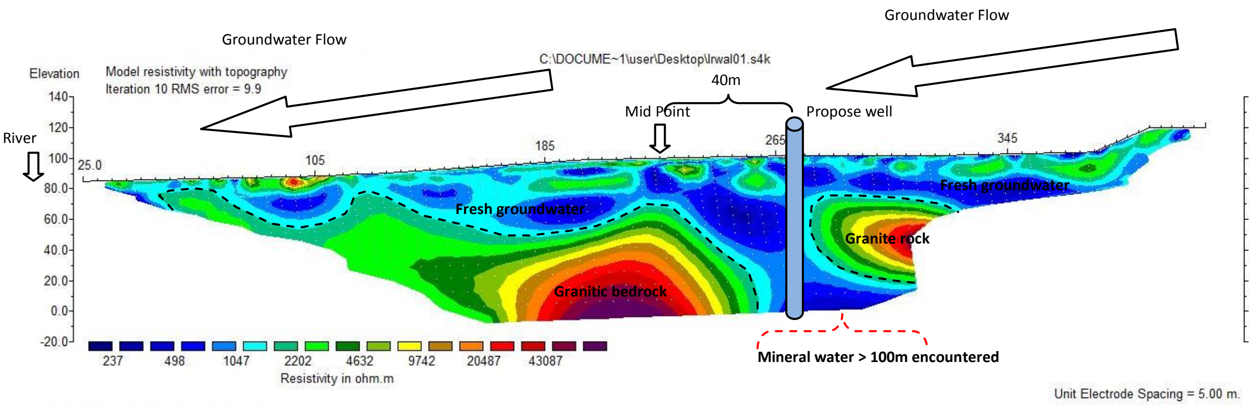


Fig. 10 Subsurface image results by resistivity method in Negeri Sembilan for groundwater exploration [18]

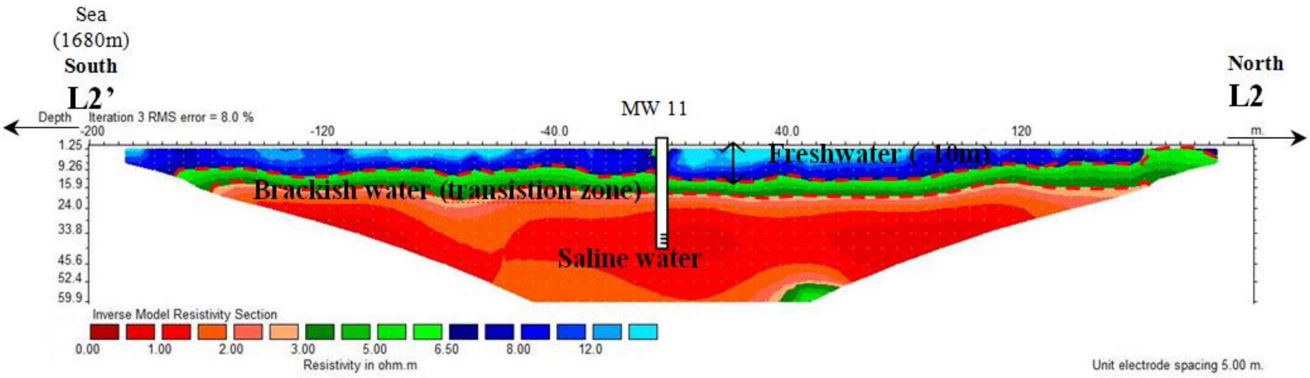


Fig 11 Subsurface image results by resistivity method in Selangor [19]

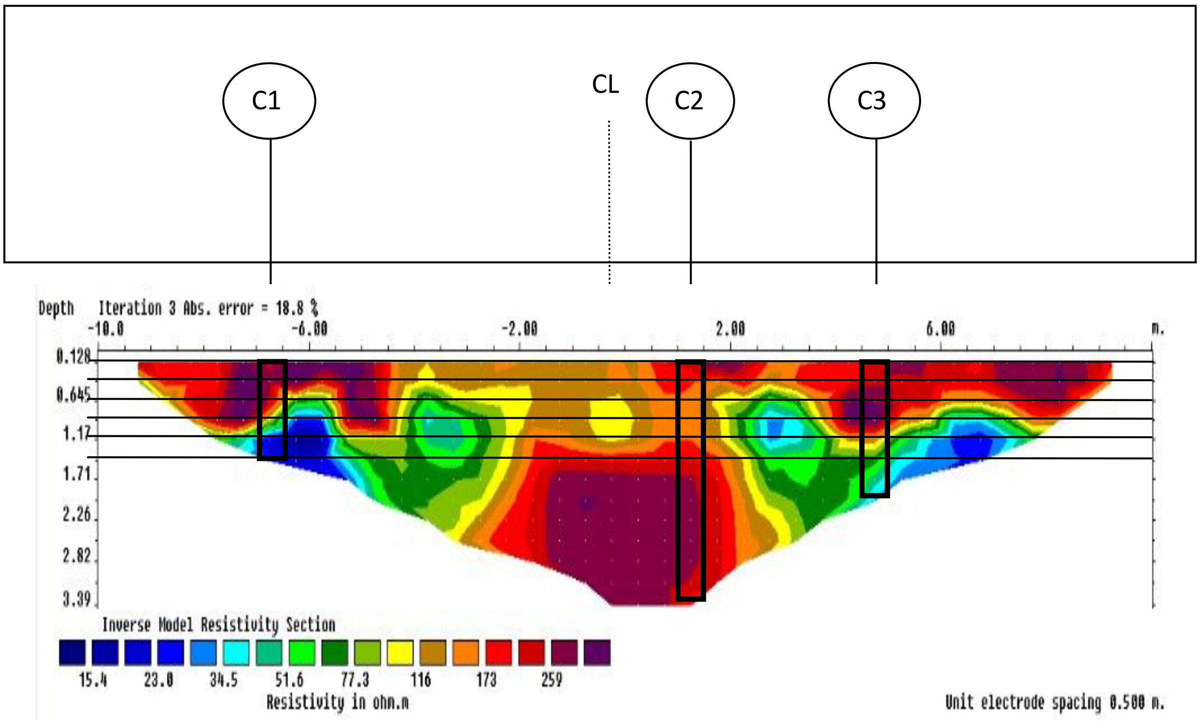


Fig 12 Resistivity results for pavement assessment in Selangor [20]

Table 7: Comparison of cumulative thickness layer between resistivity results with dynamic cone penetration test result [20]

Layer	Thickness of resistivity test (mm)			Thickness of dynamic cone penetration test (mm)		
	1	2	3	1	2	3
Surface	257.5	257.5	257.5	198.0	203.0	193.0
Base	515.0	515.0	515.0	456.0	438.0	413.0
Subbase	777.5	777.5	777.5	728.0	710.0	689.0
Subgrade	>777.5	>777.5	>777.5	>728.0	>710.0	>689.0