High resolution seismic reflection and geoelectrical resistivity imaging at Pengkalan School Teacher's Quarters Pegoh, Ipoh, Malaysia

MOHAMMED ISMAEL ABU SHARIAH, ABDUL RAHIM SAMSUDIN, UMAR HAMZAH AND ABDUL GHANI REFAK

Geology Department, FSFG
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor D.E.

Abstract: Seismic reflection and geoelectrical resistivity imaging techniques were employed to investigate the shallow features of buried karstic limestone of Kinta Valley limestone formation because the sinkholes and cavities are quite common in this formation. The techniques were conducted along three traverse lines to evaluate the subsurface ground conditions for construction work of the school teacher's quarters blocks. The site is located at Pengkalan, Pegoh in Ipoh district of Perak. The limestone bedrock topography has complex phenomena and highly relief subsurface topography due to the presence of karstic features. These features rise considerable difficulties in both the design and construction of the foundations, such as: foundation stability, settlement, and subsidence during the construction in this site. These geotechnical problems arise whenever foundations are established on the surface of the limestone bedrock or within the overburden soils.

The common depth point (CDP) shallow seismic reflection sections of the traverse lines show clearly the displacement system within the bedrock and the poor reflection data. This displacement system is usually associated with sinkholes or slow subsidence in the site caused by chemical dissolution. The poor reflection data qualities in the CDP sections were interpreted as voids of cavity zone.

The Two dimensional resistivity inverse models of the traverse lines are showing the low resistivity anomalies. These anomalies are interpreted to represent swallow holes and determine the location of cavities zone.

Interpretation based on the combination of seismic reflection and electrical resistivity imaging survey has been a successful and satisfactory way to identify the location of the surface depression and subsurface conditions.

INTRODUCTION

Geophysical methods occupy a most important place in minerals exploration since early 1680, and oil exploration since early 1920 (Dobrin and Savit, 1988). The geophysical methods are extremely useful in the engineering site investigations and environmental studies (Abu Shariah, 1995; Coffen, 1978; Miller *et al.*, 1993; Sheriff, 1984; Steeples & Miller, 1993). The geotechnical engineering and environmental applications are normally interested in small-scale features of shallow depth, which may range between a few metres to hundreds of metre (Abu-Shariah, 1995). Geophysical methods allow subsurface conditions to be examined indirectly, quickly, cheaply, and reliably with sufficient results. The methods utilize different physical properties of the earth materials to study subsurface structure. Two-dimensional (2-D) geoelectrical resistivity imaging and seismic surveys are two geophysical techniques, which are now widely used in geotechnical and environmental studies.

Seismic reflection and geoelectrical resistivity imaging techniques were employed to investigate the shallow features of buried karstic limestone of Kinta Valley limestone formation because the sinkholes and cavities are quite common in this formation (Abu Shariah, 1999). Kinta Valley is considered to be a developed area where "about 80 percent of the Kinta Valley is underlain by limestone bedrock, (Sum *et al.*, 1996). The site is located at Pengkalan, Pegoh in Ipoh district of Perak State. The limestone bedrock topography has complex phenomena and highly relief subsurface topography due to the presence of karstic features. These features rise considerable difficulties in both the design and construction of the foundations, such as: foundation stability, settlement, and subsidence during the construction in this site. These geotechnical problems rise whenever foundations are established on the surface of the limestone bedrock or within the overburden soils.

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LOCATION

The school teacher's quarters site is located in Kampung Pengkalan Pegoh, south of Ipoh in Perak state (Fig. 1). The distance from Ipoh to the school site is around 10 km.

GEOMORPHOLOGY, TOPOGRAPHY AND GEOLOGICAL SETTING

The limestone as described by the Geological Survey Memoirs is formed from carbonate rocks, weakly metamorphic to crystalline limestone or marble. The limestone formations in Malaysia were deposited from Silurian to Triassic periods whereas the Kinta Limestone Formation is of the younger Paleozoic era (Silurian to Permian). The limestone has been uplifted, compressed, folded during the Permian period forming the limestone hills during this period. The schist is interbedded with the limestone (Ingham and Bradford, 1959). The limestone bedrock floor of the Kinta Valley has a gradual slope to the south, and is covered with alluvium to depth varying from a few feet to more than a hundred feet; the general thickness of the alluvium increase southwards (Ingham and Bradford, 1959).

The geomorphology of the limestone in the Kinta Valley in Perak state can be shown as two geomorphological expressions, which are karstic limestone hills and called tower karst, and buried karstic limestone. The geological map of the Kinta Valley showing the location of both buried karstic limestone and karstic limestone hills are in Figure 1, where the Kinta limestone formation is bounded on the eastern and western sides by granite. The subsurface limestone bedrock topography is usually complex and highly irregular due to the presence of the karstic features (Fatt and Pee, 1986; Yeap, 1986). The depression surfaces and sinkholes were recently developed in the buried karstic limestone bedrock at Kinta Valley.

The school teacher's quarters site is characterized as a flat area with the buried karstic limestone bedrock covered by alluvium of silt stone. The elevation of the school teacher's quarters site is around 125 feet (40 metres) above mean sea level. In the southern portion of the Kinta Valley very gentle gradient can be shown in the Kinta limestone formation because their elevation levels drop from about 240 feet to about 20 feet (73 to 6 metres) above mean sea level (Ingham and Bradford, 1959).

A geotechnical engineering company drilled several boreholes and micro-piles in the school site at blocks A and B. The drilling records indicated that the subsurface geology of the school site is mainly made up of two layers. The first layer is alluvium of silty sand. The second layer corresponds to the limestone bedrock showing several cavities at depth below 16 metre from the earth's surface. The cavities were filled up with water or loose silty clay sand. The depth of the limestone bedrock ranges from 15 to 20 metres under earth's ground according to the micro-piles drilling, boreholes, and the previous studies that have been done by Walker (1955) and Ingham and Bradford (1959).

During the micro-piles drilling in the school site, a sinkhole was formed. The main objective of this survey is to determine the geohazard zone and subsurface conditions in the site by using the geophysical techniques. With knowledge of the karstic topography of the subsurface limestone bedrock, it is possible to design a suitable and viable foundation system (Sum *et al.*, 1996).

GEOPHYSICAL METHODS AND INSTRUMENTATION

The significance of this research appears considerable in detecting the serious geohazard in selected limestone developed area of the school site (Abu-Shariah, 1999). The work was divided into three parts, which are the following:

1. Preliminary studies that included preliminary field reconnaissance of the school site, during October 1998.
2. Field work, which started on October 1998 and ended in the end of the same month. In this survey, electrical resistivity imaging by using Wenner array with electrode spacing of two metres and seismic reflection techniques were conducted along three traverse lines (Fig. 2) where their characteristics are shown in Table 1.

The seismic reflection was employed for shallow subsurface investigations by using common depth point (CDP) technique with limited distance of offset shot. After each recording, the spread line of the source energy and all geophones were shifted along the profile with space equal to the geophone spacing to produce if possible a maximum of 12-fold common depth point (CPD) profiles. "The main objective of the common depth point investigation is to sample each subsurface point several times. True reflection arrivals will be enhanced and various unwanted signals will tend to be reduced or eliminated, thereby producing superior records" (Burger, 1992).

An ABEM Terraloc (mark-3) 24-Channel Seismograph was used in the seismic data acquisition. Geophones with natural frequency of 100 Hz were used for the seismic reflection survey. 10-kg sledgehammer source energy was used to perform the seismic survey.

The electrode configuration that was used in

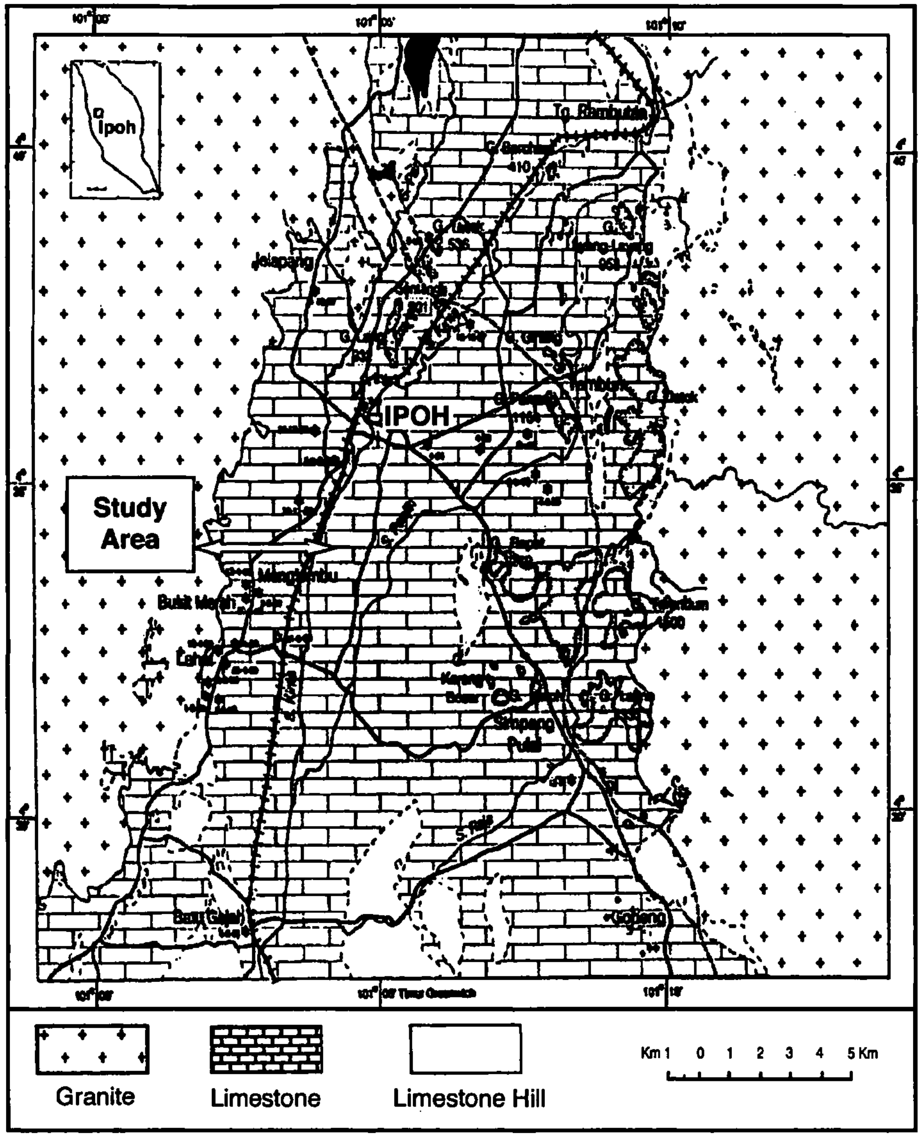

Figure 1. The geological map of Kinta Valley and the location of the study area.

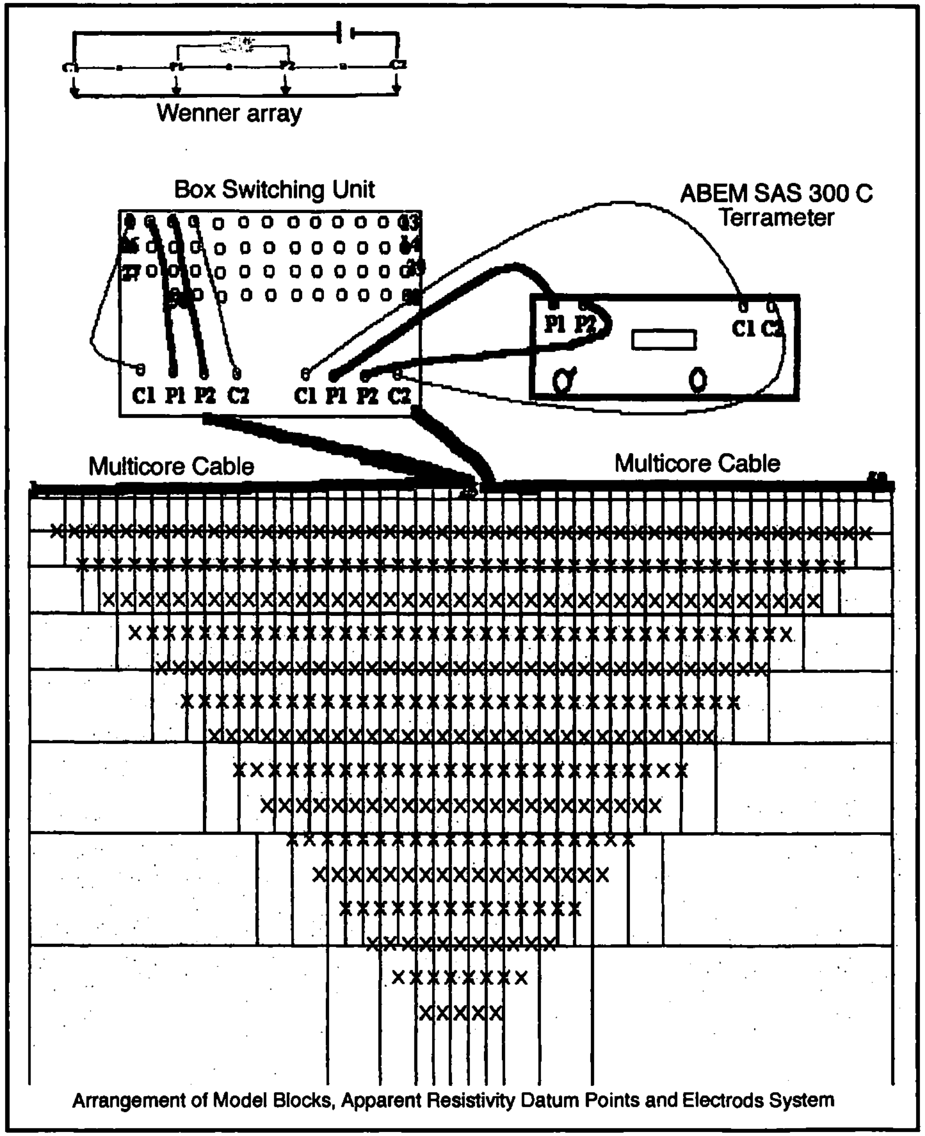

Figure 2. The location of the geophysical profiles in the school site.

Table 1. The characteristics of the geophysical profiles.

Profile No.	Electrical Resistivity By Using Wenner Array				Seismic Reflection		
	Electrode Spacing (m)	Number of Electrodes	Layers Number	Profile Length (m)	Geophone Spacing (m)	Offset (m)	No. of Shots
1	2.0	50	15	98.0	2.0	25.0	21
2	2.0	43	13	84.0	2.0	20.0	14
3	2.0	47	15	92.0	2.0	20.0	14

the resistivity survey at the school site was Wenner array profiling by using four collinear electrodes. The geometry of the Wenner array is shown in Figure 3, where the separation between electrodes is uniform and equal (a). The apparent resistivity (ρ_a) is calculated by using the following equation:

$$\rho_a = 2\pi a \Delta V / I$$

where, ρ_a = Direct current apparent resistivity
V = voltage
I = applied current
a = the electrode spacing

An ABEM SAS 300C Tetrameter was used to measure the datum points of the geoelectrical resistivity imaging with 50-electrodes system connected to a multicore cable and box switching (Fig. 3). The box-switching unit was used to select electrode numbers and electrode spacing during measurements manually.

3. The Office and Laboratory Works included the analysis and interpretation of the geophysical data and sketching the depth section by using the following softwares:
   a. Two-dimensional electrical resistivity inversion software (RES2DINV) (Loke, 1997). The measured apparent resistivity datum points of the geo-electrical resistivity imaging profiles were interpreted by using this software.
   b. EAVESDROPPER software: It was used to interpret the seismic reflection data and determine the seismic section.
   c. CORALDRAW5, CORALDRAW7, MICROSOFT97, IPHOTO, AND PRINTBRUSH.

RESULTS AND DISCUSSION

The geoelectrical resistivity technique was employed to describe the subsurface ground conditions. Although, the geoelectrical resistivity profiles were short, this technique was expected to give primary focus about the subsurface structure from the earth's surface until 15 metres below the earth's surface by using Wenner array. The depth of the limestone bedrock range from 16 to 20 metres. However, when the total length of the geoelectrical resistivity profile is short compared to the depth of the limestone bedrock, this technique cannot locate the presence of the cavities in the survey region. The general procedure to determine the location of the cavities zone and subsurface conditions, is by

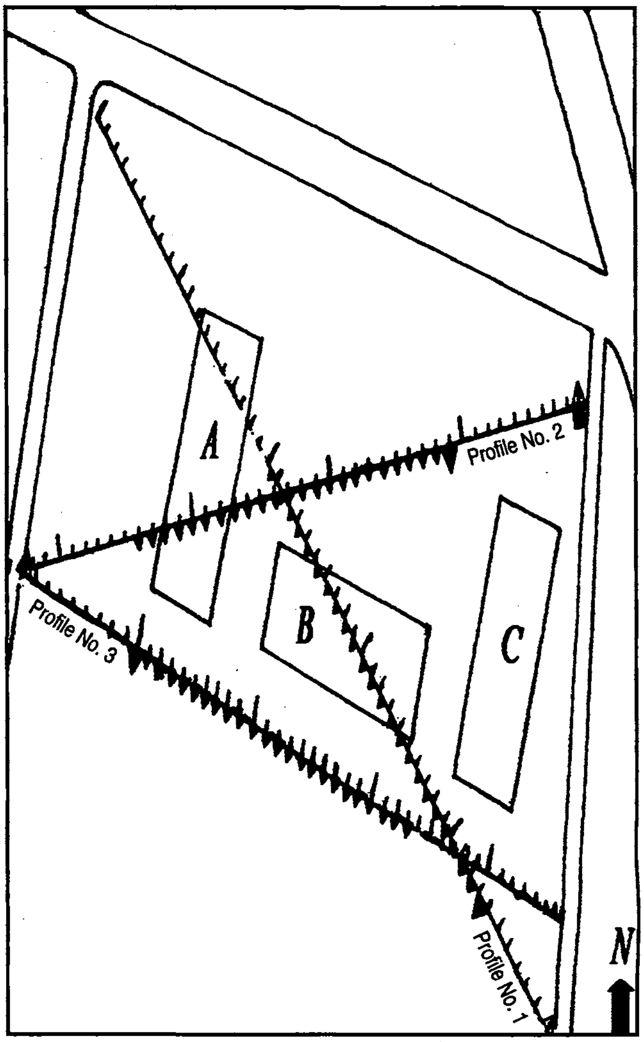

Figure 3. Schematic diagram that illustrates the system connection used to collect the datum points of a 2D electrical resistivity imaging by using Wenner array.

determining the phenomena that are associated with the geohazard of the karstic limestone bedrock such as: displacement system and slow subsidence, dolines, sinkholes, open fissure within the soil or rock, fracture zone, and water accumulation. These phenomenas are associated with internal drainage of the solutions into a cave or through limestone bedrock fissure.

The measured apparent resistivity pseudosections and 2-D algorithmic inverse model sections of the geoelectrical resistivity profiles are shown in Figures 4, 5 and 6 with low RMS (root mean square) values. Relatively high resistivity spots are shown on earth's surface of the inverse numerical models along the first and second geoelectrical resistivity profiles that are related to an old building foundation. The apparent resistivity measurements vary laterally of depth beneath six metres along the resistivity imaging profiles. The inverse model of the first profile shows the low resistivity anomaly in the center. The previous anomaly is found on the left and right side of the inverse models of the second and third geoelectrical profiles respectively. However it is expected, that this anomaly is caused by water accumulation in this region. Thereby, it is interpreted as sinkholes, where the solutions are moving into the active cavities group through the alluvium and limestone due to the natural fact that the limestone bedrock is very transmissive.

The high resistivity values shown on the inverse models at shallow depth, were considered to be related to cone boulders or open fissures. The other high resistivity anomaly was present at the bottom of the inverse models at depths below 12 metres. This anomaly which correspond to the surface limestone bedrock have a large effect on measured resistivity values and the calculated inverse numerical models.

Finally, the inverse model that was conducted along the first profile shows low resistivity anomaly on the left side of the model. It is interpreted as sinkholes or fracture and located outside the school site.

Seismic reflection by using CDP techniques was employed in the school site to verify the following objectives:

1. To determine the depth of the bedrock and thickness of the soil
2. To give the best image about the subsurface conditions and karstic features, and
3. To explain the reasons of the water accumulation at shallow depth in the pervious results of the 2D geoelectrical resistivity inverse models.

12-fold CDP seismic reflection section is shown in Figure 7a. It shows the displacement systems in the limestone bedrock. These displacements are associated with the development of sinkholes and slow subsidence in this region which are caused by chemical dissolution. The first strong reflector from the limestone, is located at 40 ms in two way time. The low S/N are placed between stations 14130 to 14145 and under 50 ms in two way time. This anomaly correspond to the fracture zone or sinkhole, which is located outside the school area. The CDP seismic reflection section in Figure 7b, shows the poor reflector data quality. These anomalies are related to possible cavities and cavity system within the limestone bedrock. The 2D subsurface geological section of the first profile in Figure 7c, shows the location of the cavities, cavity system, displacement system, and the fracture or sinkholes outside the school area. The depth of the limestone ranges between 18 to 21 metres.

The CDP seismic reflection section and the 2D subsurface geological section of the second profiles are shown in Figure 8a and 8b respectively. The depth of the limestone bedrock ranges between 20-22 metres. The cavity associated with the displacement system is very clear in the CDP section. The CDP section shows the poor amplitude of the reflector between 70 to 110 ms.

The CDP seismic reflection section of the third profile in Figure 9a shows the slow subsidence associated with the possible sinkholes at 30 to 45 ms in two time way. The seismic section shows the poor reflector that is located between 60 to 100 ms in two time way, thereby corresponds to the cavity. The 2D subsurface geological section in Figure 9b shows the depth of the limestone, which ranges between 18 to 25 metres beside the cavity location. The cavity is located at depths below 30 metres.

The collapse was developed in the site during the micro piles drilling (Fig. 10). The geophysical survey was done before the collapse. The combination between the seismic reflection and geoelectrical resistivity imaging techniques discovered the geohazard zone and the location of the subsidence (Fig. 10). These techniques were able to give a superior image about the reason of the collapse and the karstic features of the site such as the presence of cavities and sinkholes.

CONCLUSION

"The integrated geophysical methods by using several techniques give the ideal imaging of the shallow subsurface structure and geomorphology on the karst area of the limestone bedrock. Interpretation based on the combination of the seismic refraction, seismic reflection, and geoelectrical resistivity survey have been a successful and satisfactory way to identify the location of the surface depression such as sinkholes and cavities, and subsurface conditions. During

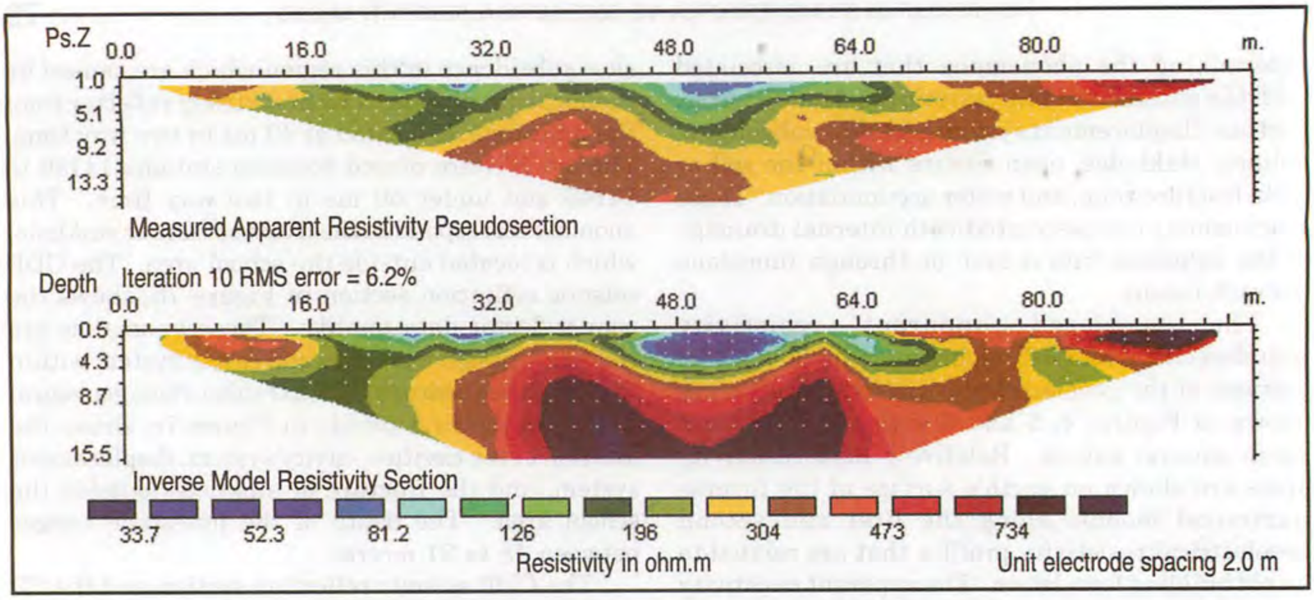

Figure 4. 2-D electrical resistivity imaging of the first profile.

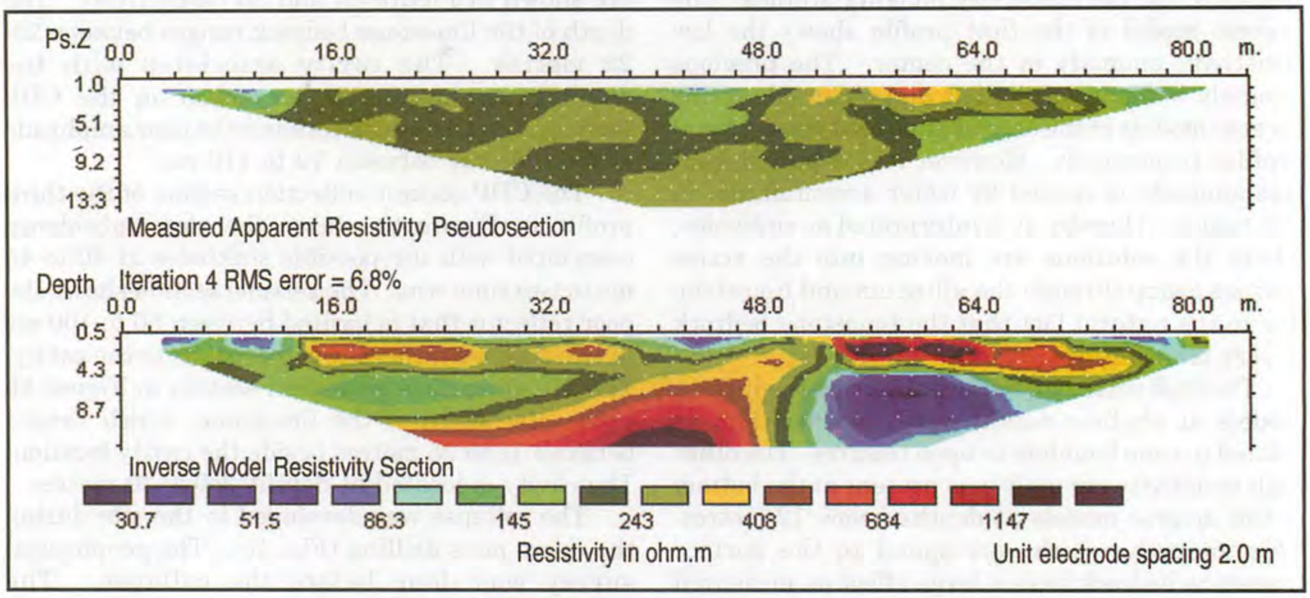

Figure 5. 2-D electrical resistivity imaging of the second profile.

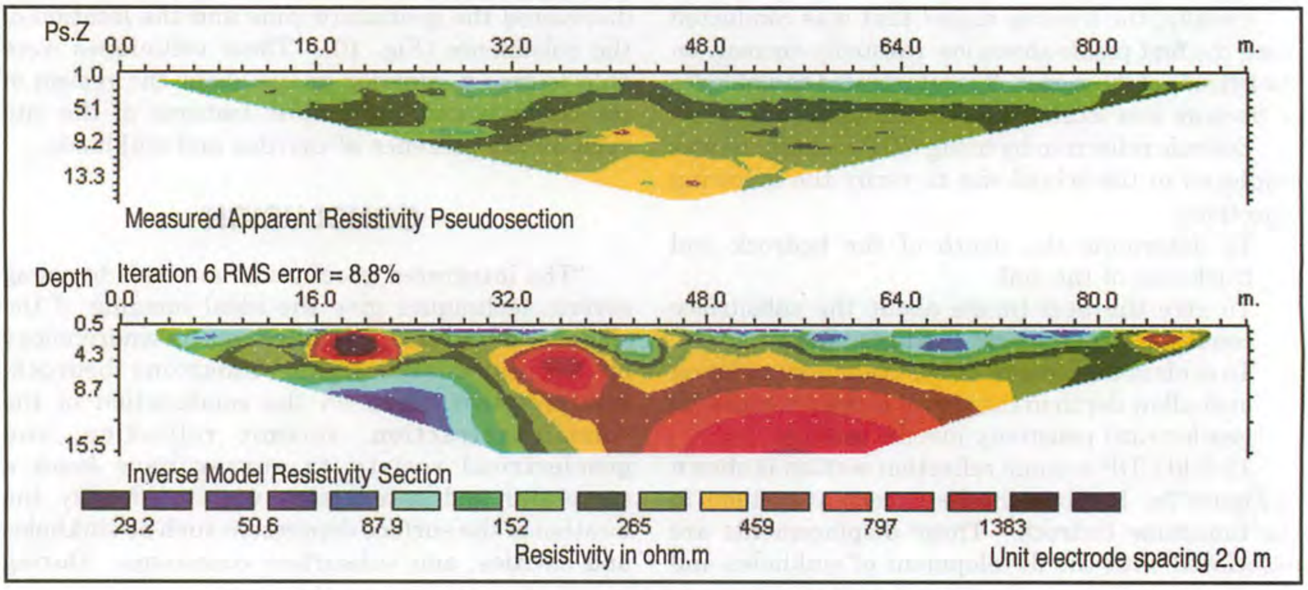

Figure 6. 2-D electrical resistivity imaging of the third profile.

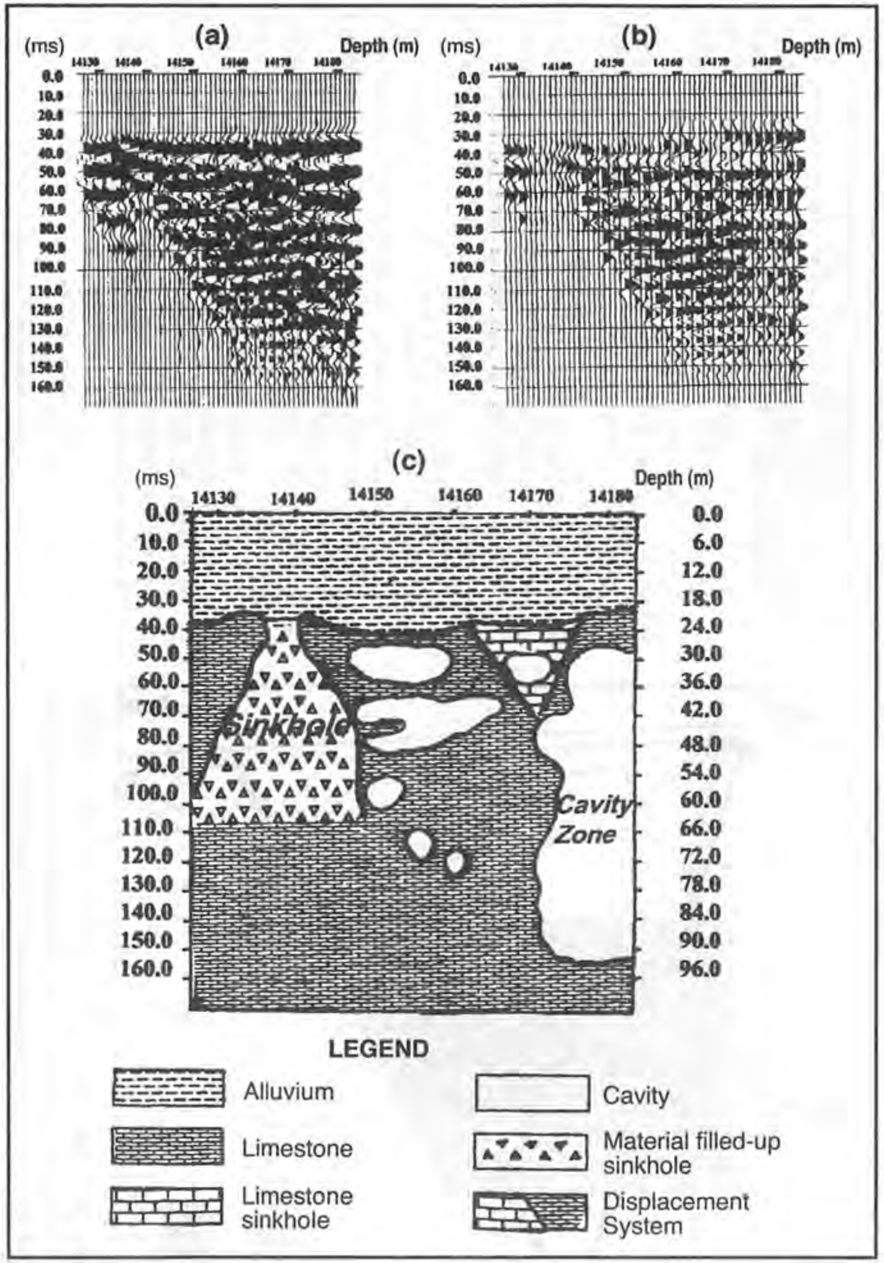

Figure 7. (a and b) 12-fold high resolution seismic reflection section of the first profile. (c) 2D subsurface geological section of the first profile.

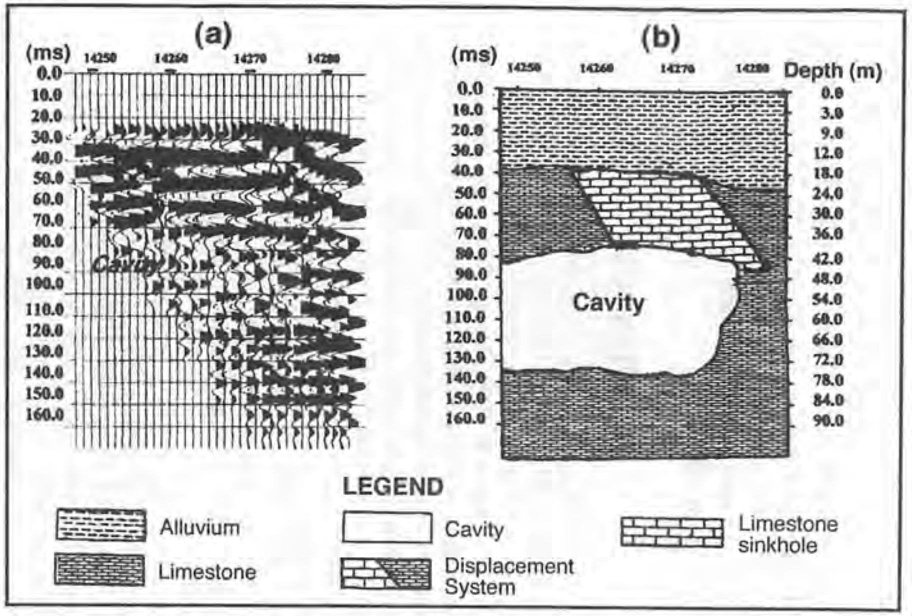

Figure 8. (a) The seismic reflection section of the second profile. (b) 2D subsurface geological section of the second profile.

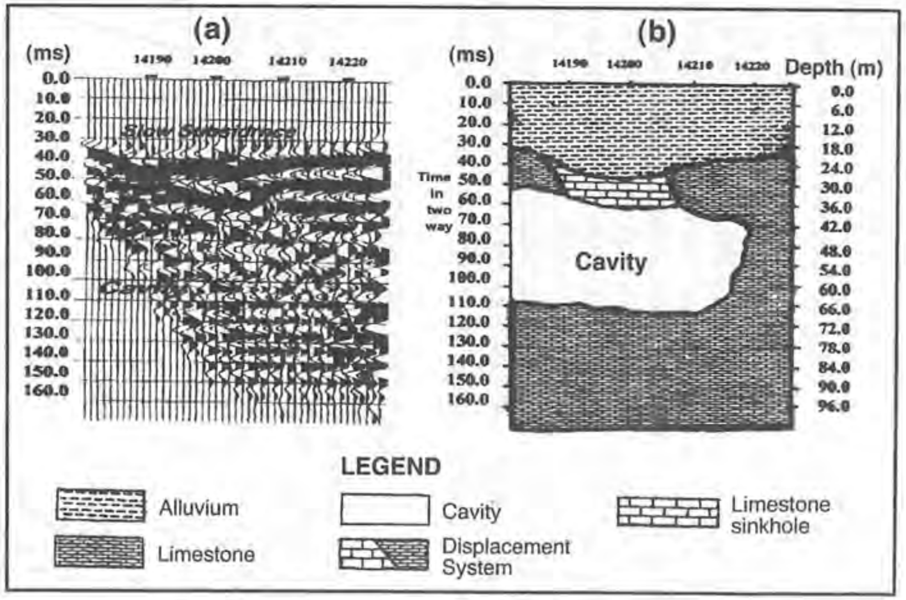

Figure 9. (a) The seismic reflection section that was conducted along the third profile. (b) 2D subsurface geological section of the third profile.

the micro-piles drilling, the collapse was developed. The geophysical survey was able to discover the reason behind this collapse and determine where the hazard zone at the school teacher's quarters blocks lies. These geophysical methods were able to determine the location of the sinkhole and the place of the multi cavities in the site" (Abu Shariah, 1999). It is important to remember that no single method or approach will solve all site investigation problems. By selecting the most suitable method and utilizing the synergistic benefits of an integrated programs approach, high level of accuracy and cost effectiveness can be achieved and the project can be done right on the first time.

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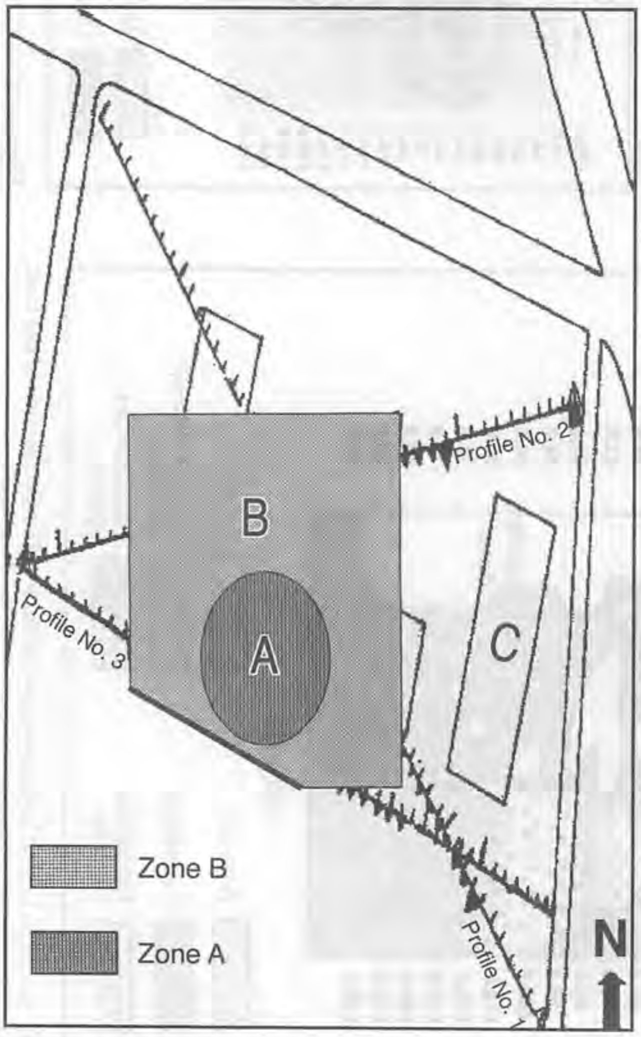

Figure 10. Location of the collapsed area zone (A) and the geohazard zone such as the presence of cavities and sinkholes by using geophysical survey in zone (B).

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