

Detection of surface water leakage through limestone cracks, using near surface geophysical techniques.

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Abstract

Near Surface Geophysical Techniques such as electrical resistivity tomography (ERT) ground penetrating radar (GPR) and Time Domain Electromagnetic (TEM) are useful techniques for delineating subsurface configurations such as stratigraphy, structural elements, caves and water saturated zones. The ERT technique is used to delineate the contamination, and buried objects, as well as to quantify some aquifer properties. Six 2-D electrical resistivity sections were measured using Wenner configurations. The spread length is about 45 m and the electrodes spacing are 1m, respectively, to reach a depth ranging from 8 to 10 m. The results indicate that, the subsurface section is divided into main three geo-electrical units, the first is fractured limestone, which exhibits high resistivity values ranging from 450 to 1000 ohm m. The second unit is corresponding to marl of moderate resistivity values from 100 to 250 ohm m. The third unit, which is the lower bed, exhibits very low resistivity values from 5 to 45 ohm m and corresponding to clayey marl with water. The presence of clay causes the most geotechnical problems, Also, the interpretation results of the obtained data for Wenner array were represented in the 3-D view to delineate the zones of very low resistivity values these values are corresponding to clayey marl saturated with water and have direct effect on the constructions and may cause cracks and fractures. In the present study, procedure on the processed GPR data, were displayed on 2D profiles that contain the expected anomalies. Because the study area is saturated with water, part of radar waves are attenuated and the reflections from the subsurface materials are weak. GPR and geoelectrical methods are used in the prospection of good electrical conductors at shallow depths. The obtained 1-D models were used as initial models for 1-D inversion of the TEM data, a trial and error modeling was applied to the comparable data sets to give a single model. Many geophysical techniques were used to solve the geotechnical problems such as geologic penetrating radar (GPR) and (TEM).GPR was used to detect these problems through the shallower part of subsurface layers whereas TEM method was used to measure the deeper part of subsurface layers. The prevailed subsurface structures such as fractures, joints, faults, voids, cavities and other There are many factors causing the slope failure in the National Research Institute of Astronomy and Geophysics (NRIAG), Helwan area such as the increased pore-water pressure due to domestic water leakage (both sewage and drinking water), earth vibrations resulting from large explosions in the limestone quarries of the cement factories of Tura and Helwan areas and instability of protruding (side) ridges between old crescent-shaped quarries and unstable roofs of the natural caves. Several precautionary measures and slope treatments are recommended in order to decrease the potentiality of slope failure in this area and its adverse impact on escalating encroachment of human settlements.

Keywords: 3D Electrical Imaging, Fractures Limestone, Voids, Cavities, landslides of shales GPR and EM technique

Introduction

The new urban regions around the Greater Cairo usually sited on limestone bedrocks that have run into the problem of caving and fracturing and reported construction damage. It became inevitable that high resolution near surface geophysical techniques be applied to

discover and help delineate and assessing these hazardous problems. At highly developed countries, the application of geophysical techniques is constrained for solving the engineering and Geo-technical problems, thus, this study introduces a confirmatory geophysical study of different instruments for solving and giving a clean characterization of these troubles to be constrained by the engineering viewpoint in Egypt.

The study area is a part of Greater Cairo, east of the River Nile and about 20 km south of Cairo city (Fig.1). The deposits of the Maadi Group consist mostly of shales, sandstones intercalated with limestones. The shales are grayish-green highly calcareous and partly sandy. This group is divided in Helwan area into Qurn, Wadi Garawi and Hof formations in ascending order (Farak and Ismael 1959). However, recent studies have shown that the lower two units are well developed in Helwan area and can be assigned as Middle Eocene (Strougo and Boukhary 1987). At El-Qurn height, Qurn Formation is made up of 70 m thick of white chalky limestone with compact dolomitic limestone bands and yellow marl to marly limestone alternating with shales and sandy marls. The Qurn Formation is overlain conformably by Wadi Garawi Formation with thickness of about 25 m. It is characterized by the presence of argillaceous limestones alternating with beds of marls and siltstones.

There are many factors causing the slope failure in Helwan area such as the increased pore-water pressure due to domestic water leakage (both sewage and drinking water), earth vibrations resulting from large explosions in the limestone quarries at the construction of area Helwan and instability of protruding (side) ridges between old crescent-shaped quarries and unstable roofs of the natural caves. Various precautionary measures and slope treatments are advocated in order to lessen the potentiality of slope failure in this area and its adverse impact on escalating encroachment of human resolutions. Fractured limestone is overlain by a Marl and clay layer which causes most engineering problems due to volume changes in swelling clays result from the human activities on the local environments. The main objective for the present study is to apply multi-sensor geophysical techniques to provide detailed subsurface geologic information, that is valuable for Investigation of shallow subsurface of the earth fractures, landslides of shales, marl beds, and surface water leakage through limestone cracks, geophysical methods ground penetrating radar (GPR) and electromagnetic (EM), are decided up on to apply in the present study.

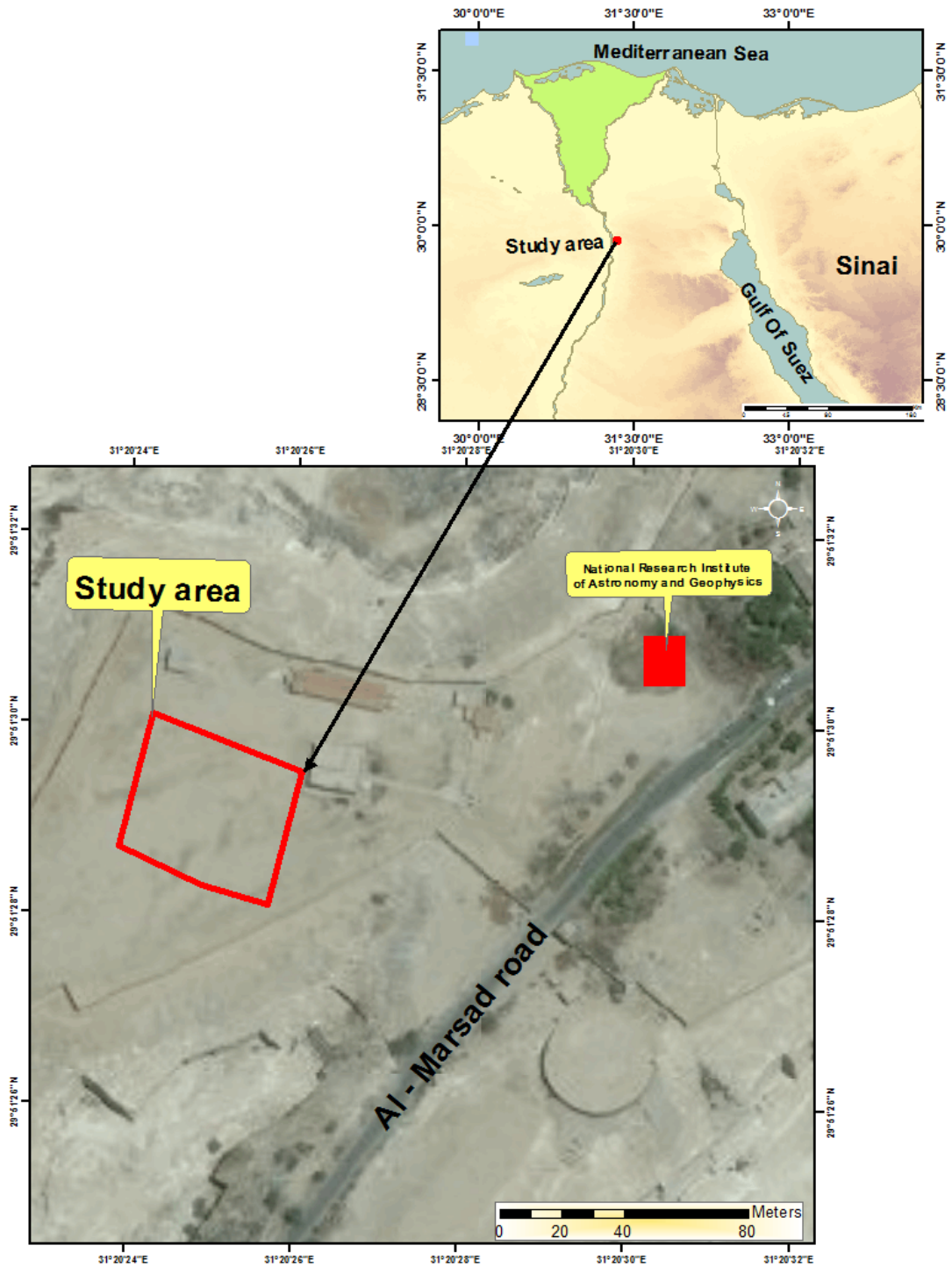


Figure 1: Location map of the study area Helwan region.

Geological setting:

Helwan area is characterized by a low relief and gentle slope from east to west. The surface of the floodplain that occupies the banks of the River Nile consists of the fertile top clay–silt layer underlain by sand and gravel forming the alluvial aquifer. The floodplain is formed by a tectonic depression, and probably bounded by faults. Cretaceous and Tertiary rocks are exposed at the border of the floodplain. From the geomorphologic point of view, the area is discriminated into three geomorphologic units: the structural plateau which

consists mainly of limestone and is dissected by a number of faults, the piedmont plain and the Nile flood plain which is formed by a tectonic depression. Rocks exposed in the Greater Cairo area include rocks of Quaternary, Tertiary and Late Cretaceous with a maximum thickness about 900 m. Eocene rocks constitute the most common outcrops and mainly are limestone, marls and dolomites (Awad and Abdel-Baki 1993). According to Aboushook and Sherif (2000) and Said (1962), Maadi Formation (Middle Eocene age) is made up of a series of brownish beds of fissured limestone, marl and shale (Fig. 3). It includes the following units from top to bottom: the yellowish white dolomitic limestone becoming sandy towards the base with traces of gypsum pockets; the alternating and joints which have east–west and northwest–southeast directions. The joints have nearly a vertical dip angle and are filled with silty clayey materials (Abdeltawab 2008). The underlying Mokattam Formation which belongs to the Middle and Upper Eocene is a succession of sedimentary carbonates and less abundant argillaceous rocks. It consists of four units from top to bottom: the upper carbonate unit, which is mostly formed of jointed sandy dolomitic limestone; the upper clastic unit, which is partly dolomitized marl with ferruginous and calcareous patches; the lower carbonate unit, which is an interbedded unit of sandy dolomitic limestone and gypsiferous marly sands and the lower clastic unit, which consists mainly of shale over sandy marly limestones interbedded with shale.

Structurally, the study area was affected by three sets of faulting systems striking mainly in NW–SE, E–W and NE–SW directions. All of them are normal faults, with dip ranges from 17° to 40° , where the beds are locally dragged. In addition to faults, at least two sets of joints dissect the area. These joints trend in E–W and NW–SE directions (Moustafa et al 1985). Faulting is the dominating structural element and is mainly vertical and facilitates both the downward passage of water and upflow from deep aquifers (Frag and Ismail 1955; Elawadi et al 2006; Sultan et al 2008) the following. The tectonic evolution of Egypt is complicated where all the tectonic trends are inherited from Precambrian tectonic discontinuities and had been reactivated several times during the Phanerozoic (Akawy 2009). The low angle of the normal faults (17° to 40°) resulted from reactivation of the older tectonic discontinuities on the one hand, and the tilting of the fault blocks by later movements on the other hand. This was evidenced by the analysis of the paleo- stresses that indicated a slow change in the stress direction of the faults. In general, the stress regime analysis in some parts of Egypt showed a tendency to change from compressive (horizontal stress) to extensional (vertical stress) regime which resulted in low angle faults and tilting of older fault planes (Akawy and Zaky 2008; Akawy 2009).



a) Cavity



b) Marl



c) Surface water leakage



d) Fractures

Fig. (2): Example of the problems that causing construction damages due to rock failure in the study area.

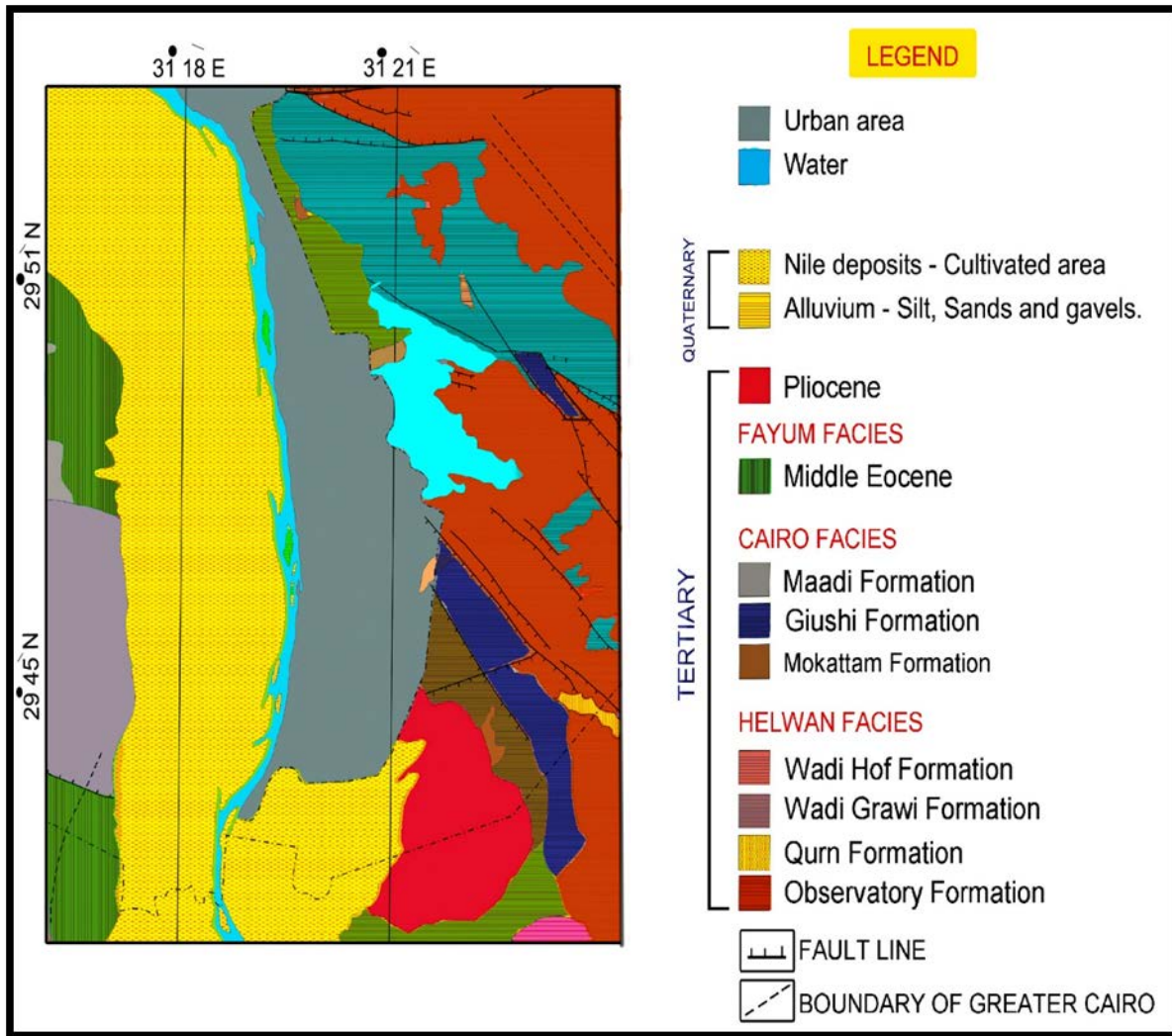


Figure 3. Geological map of the study area (Modified after CONOCO 1987).

Methodology

Geophysical surveys can play an important role in defining the subsurface geology. The 3D resistivity survey was carried out in the present work to outline the thicknesses and electrical resistivities of the encountered geoelectric units. Ground penetrating radar and Time Domain Electromagnetic (TEM) technique is a very useful geophysical method to be used in near surface mapping studies. It can be used to study subsurface structures (faulting, voids, cavities), all of which pose potentially dangerous engineering and geotechnical problems. These parameters are important for planning new urbanizing projects at helwan city. The integrated interpretation of both techniques was classified the subsurface into layers. It also gave interesting information about the geotechnical competent of the ground and some factors controlling the structure feature.

1. Geoelectric method:

The utmost constraint of the resistivity sounding method is that it does not take into description horizontal changes in the subsurface resistivity. The 2-D & 3-D imaging survey conquers this problem, where the resistivity changes in the horizontal direction as well as in the vertical direction along the survey line. Therefore, the 2-D & 3-D geo-electrical imaging techniques were selected for the survey. The Wenner array gives the smallest number of possible measurements compared to the other common arrays (Griffiths and Barker, 1993), also it competent to work in noisy fields and when good vertical resolution is required. The Wenner array was used in the present work. The geo-electrical data obtained along six profiles, of 45 m length, distributed over the study area (Fig. 4). The survey has been accomplished using a 45 multi-electrodes system connected to the SYSCAL R2 resistivity meter through a multicore cable (Fig 5). A built-in microcomputer with an electronic switching unit was used to automatically select the relevant four electrodes for each measurement. In geoelectrical survey, the digital computer–operated high–resolution resistivity meter (Syscal–R2), was used to acquire the field resistivity data The geoelectric survey was carried out 2-D & 3-D geoelectrical resistivity imaging. In the 2-D geoelectrical resistivity imaging, six profiles, of Wenner resistivity imaging were conducted in the Helwan area with a spacing of 1 m increased to 45 m (Fig. 5).

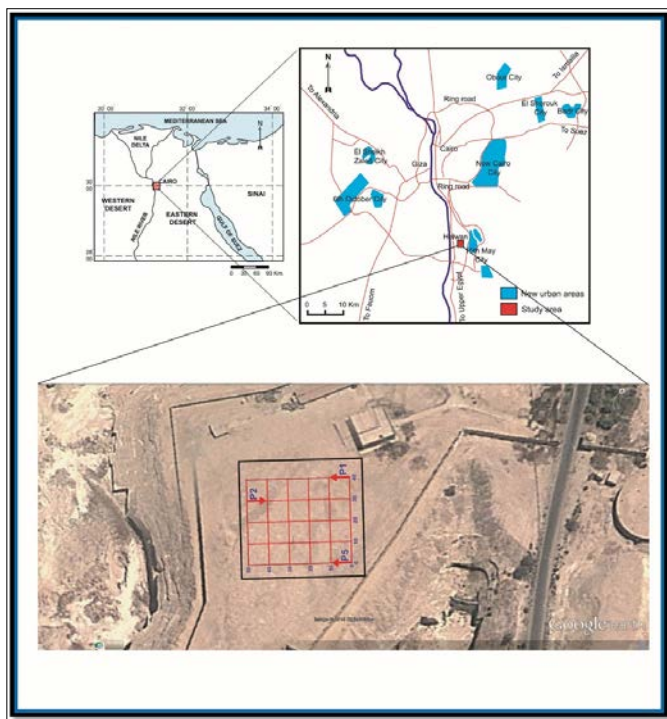


Figure 4: Location map of the near surface geophysical techniques surveys.



Syscal- R2



Wenner resistivity imaging

Figure 5: Instruments used in the geoelectrical surveying and 2-D geoelectrical resistivity imaging

2. Ground Penetrating Radar survey:

GPR survey was carried out using SIR) System-2000, with 100 MHz and 400 MHz antenna (Fig 6). The system was simultaneously used in a grid pattern consists of 22 GPR lines covering the study area (Fig.4). 11 profiles were obtained using 100 MHz center frequency antenna. Five profiles are conducted with 50 m length and spacing between each two successive profiles is 10 m. Six profiles are conducted perpendicular to the five profiles with profile length of 40 m with 10 m spacing between the successive profiles. 11 profiles are made by using 400 MHz center frequency antenna.



(A)



(B)

Figure 6: GPR–system component of (A) 400 MHZ antenna and (B) 100 MHZ antenna.

3. Time Domain Electromagnetic (TEM)

Electromagnetic, geoelectrical and Time Domain Electromagnetic (TEM) methods are used in the prospection of surface water leakage. The transient electromagnetic method was originally developed in the seventies of the last century for mining exploration through identifying conducting ore deposits. In recent years, it has shown that, TEM is very useful for identifying major aquifers, where large areas have been mapped by this method (Nabighian and Macanae, 1991).

The TEM method is generally based on the simple physical fact that, when a current in a coil is changed, a magnetic field is induced, and vice versa. Applying a current to a large coil creates a magnetic field, which is stable after some time. After the magnetic field has been stabilized the current is turned-off very rapidly (thus the term transient EM) and this induces a primary magnetic field, which is proportional to the effective area of the coil loop and the current. Just after the current is turned-off, eddy currents are instantly generated near the transmitting wire, maintaining the magnetic field. By passage of time, these horizontal currents diffuse down and outward. As a result of the finite conductivity of the ground, these currents decay with time. The decay of the currents induces a secondary magnetic field, which is only dependent on the electric conductivity of the ground, and that can be measured by an induction receiver coil (McNeill, 1990). The rate of diffusion depends on the earth's conductivity. In the resistive media, the currents will diffuse very rapidly. In conductive media the currents will diffuse more slowly. A conductive layer at a depth may “trap” currents in that layer, while currents elsewhere decay more rapidly. In this study, 4 TEM sounding in 1 station were measured using a SIROTEM MK-3 time-domain system of simple coincident loop configuration, in which the same loop transmits and receives signals (Fig.7). The loop side length was 25 m in all sites, the measurements were repeated four or five times. The best signal-to-noise data sets were chosen for further processing and interpretation (table 1). TDEM data were acquired using the SIROTEM MK-3 Conductivity meter. Delay times were used in the range of (20 – 40 Ms).



Figure 7: EM Survey using (SIROTEM MK-3)

Table 1: Measurements 4 TEM sounding in 1 Station.

Group no	Run no	Loop size	Gain	Run type	Window
1000	1	50	1.0	N	40
1000	2	50	1.0	C	40
1000	3	50	10.0	C	35
1000	4	50	100.0	C	35

Data interpretation:

1. Geoelectric method:

Wenner Resistivity Imaging System:

Two-dimensional (2-D) electrical imaging surveys are now widely used in areas with complex geology (Griffiths and Barker 1993). In the Wenner array, the spacing between the current electrodes (and potential electrodes) are equal (a). The depth of penetration is a function of (a) spacing and the dipole separation factor (n). Measurements were carried out with (a) values; 1, where Wenner section along profiles. The inversion problem is to find the resistivity of the cells that will minimize the difference between the calculated and measured apparent resistivity values (Loke and Dahlin 2002). The regularized least-squares optimization method with cell-based model is sufficiently flexible to represent almost any subsurface structures with an arbitrarily resistivity distribution (Loke et al. 2003). The processing and interpretation of the obtained data were carried out using the RES2DINV (2003) program, which produced an image of the electrical resistivity distribution in the subsurface based on a regularization algorithm (Loke and Barker 1996). The 2-D inversion model consists of a number of rectangular cells. The arrangement of the cells approximately follows the distribution of the data points in the apparent resistivity pseudosection. In the present study, the obtained data have undergone several processing steps through the RES2DINV software to produce a smooth model. An initial damping factor of 0.14 and minimum damping factor 0.010 were used where the quality of data is good and not too noisy. The width of the interior model cells is the same as the unit electrode spacing. The Wenner array 2-D surveys were carried out along profile 1 as shown in (Fig.5). The Wenner sections exhibit large variation of resistivity values corresponding to lateral variation in the subsurface lithological units (Fig.8). The inverted sections demonstrate that, the deduced subsurface section is classified into three main geoelectrical units. The first unit is fractured limestone, which exhibits high resistivity values ranging from 200 to 1000 ohm m. The second unit is corresponding to clayey marl of moderate resistivity values and the third unit is the deeper unit and exhibits very low resistivity values corresponding to marl saturated with water. Also, the results of interpretation of the obtained data for Wenner array are represented in the 3-D view to delineate the zones of very low resistivity values which are corresponding to clayey marl saturated with water and have direct effect on the constructions and may cause cracks and fractures (Fig. 9). This figure represents the slices at depths ranging from 0.5 to

10.2 m, which reveals the high resistivity values corresponding to marls at the southeastern and central parts of the study area (Fig. 9). The northern part of the area shows very low resistivity values corresponding to marly clay saturated with water at depths ranging from 3.5 to 10.2 m (Fig. 9). The constructions on this part of the area suffer from a lot of cracks and fractures due to this situation of subsurface geology

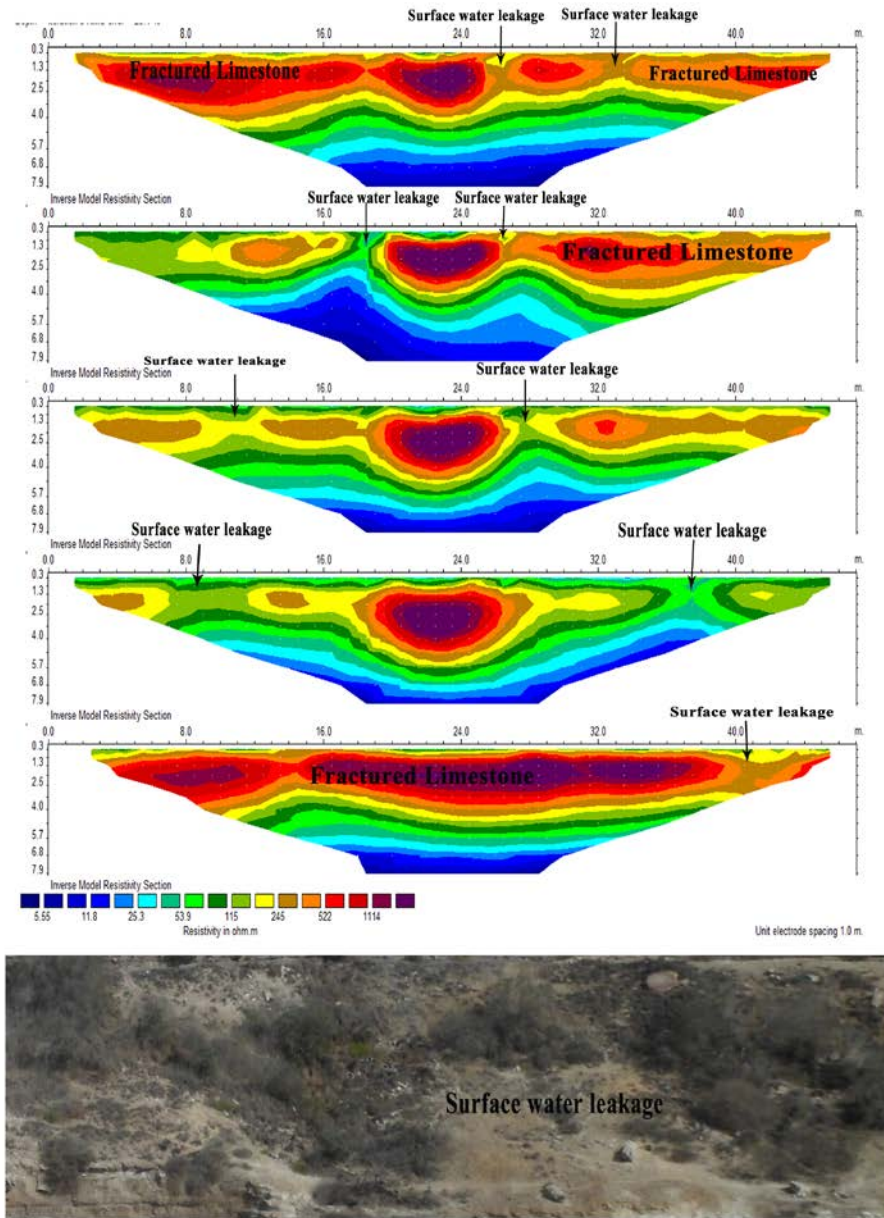
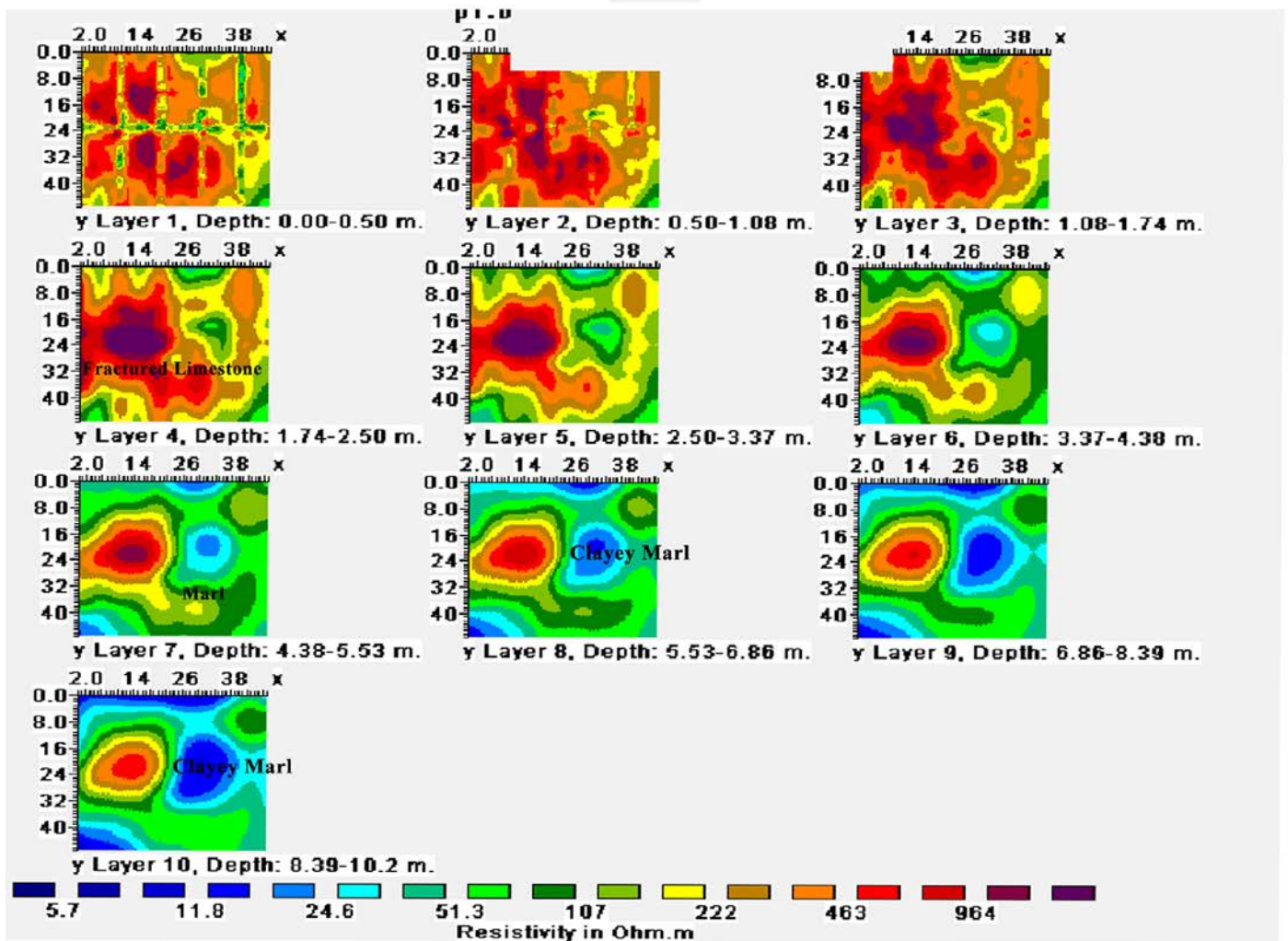


Figure 8: 2D electrical resistivity imaging of the study area.



A



B

Figure (9): (A) Natural fractures at limestone layer appeared on the earth crossing the Wenner profile as
 (B) 3D electrical resistivity mapping of the study area.

2. Ground Penetrating Radar Survey

Processing the digitally acquired radar data was achieved via system software (REFLEXW program). The processing sequence consists of three main steps: data display, data filtering, and data representation (plotting). Although data filtering is an important step in the processing of the georadar data, some of the acquired GPR–data were clear enough to need any processing. The filter of the main menu was applied to the data collected in the present study including; Ringing Filter to eliminate multiples and ringing, DC–Filter to remove the DC–component from the recons, Time–Gain Filter to compensate signal suppression, Finite–Impulse Response (FIR) Filter is a band pass filter in time domain, Averaging Filter to suppress noise and smooth the image, and Moving Average Filter, which is applied to retain non–horizontal structures and remove others.

After the data was filtered and an acceptable image was obtained for interpretation, the filtered image was plotted with the locations of subsurface inhomogeneities. The analysis and interpretation of the acquired GPR records are straight forward. Some of interpreted georadar records for surveyed GPR lines, using the 400 MHZ and 100 MHZ antenna, are show Figures 10-12. The drawn square, oblong, circles and ellipses indicate the location of the vertical fractures and voids or vugs, respectively. The observed primary arching of higher amplitude reflection pattern was interpreted as the interface between bedrock and voids. Any surface expressions of this slumping is most likely filled many years ago when the edge of the study area was formed. Some nearby cracking and warping in the edge of the study area may be clues that some subsurface movement is still active.

GPR data interpretation is an essential step to determine the location of the anomalies that appears on the processed sections and discriminate them from the other undesired reflections. The results are displayed in three categories: one-dimension trace (1D), two-dimension cross section (2D) and three-dimension block view (3D). The present study has been achieved to the next procedure of the processed GPR data, displaying 2D profiles that contain the expected anomalies. Because the study area is saturated with water, part of radar waves is attenuated and the reflections from the subsurface materials are weak.

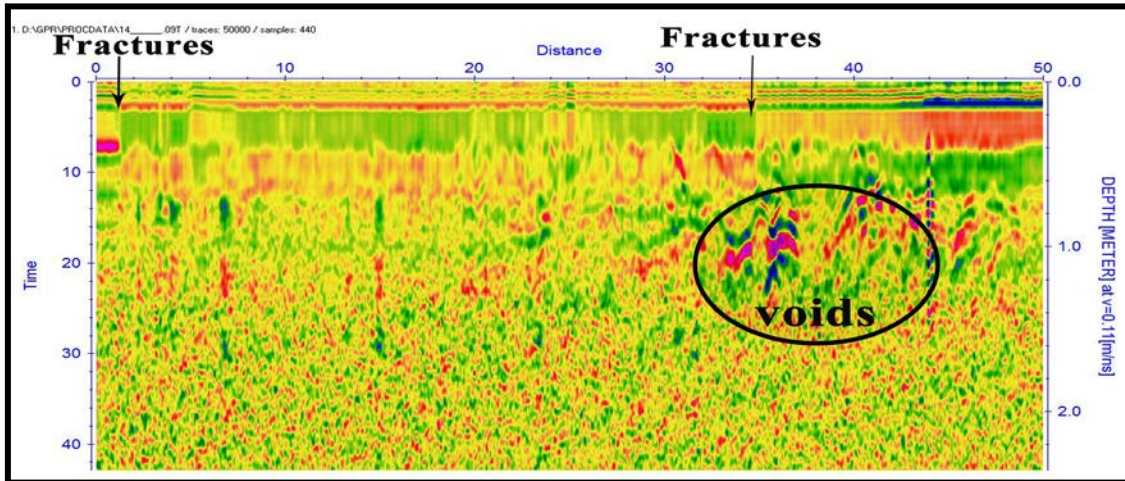


Figure (10): Profile 1 obtain using 400 MHz antenna from East to West.

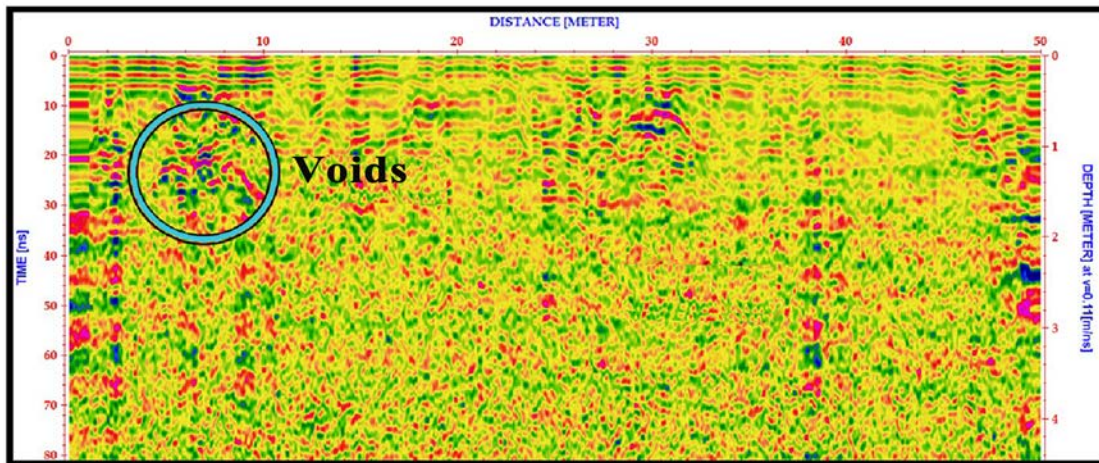


Figure (11): Profile 3 obtain using 400 MHz antenna from East to West.

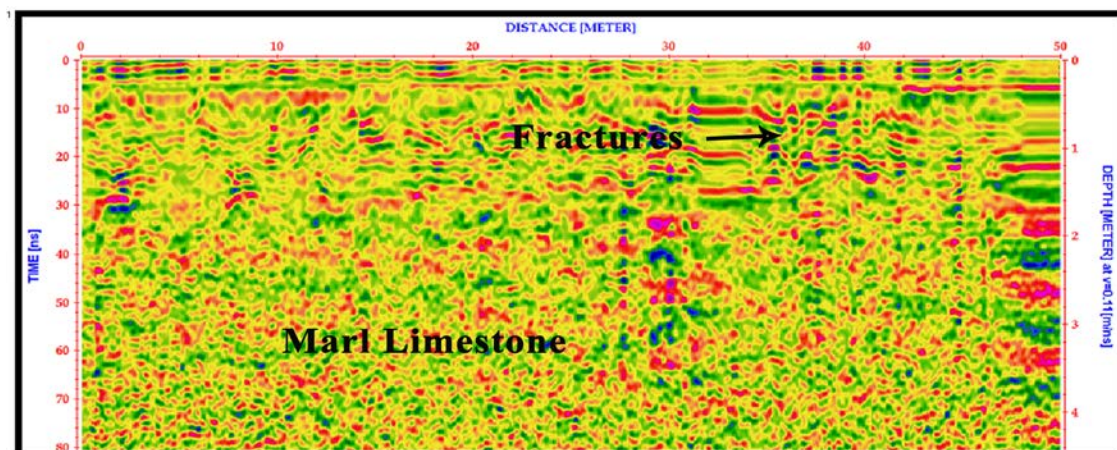


Figure (12): Profile 5 obtain using 400 MHz antenna from East to West.

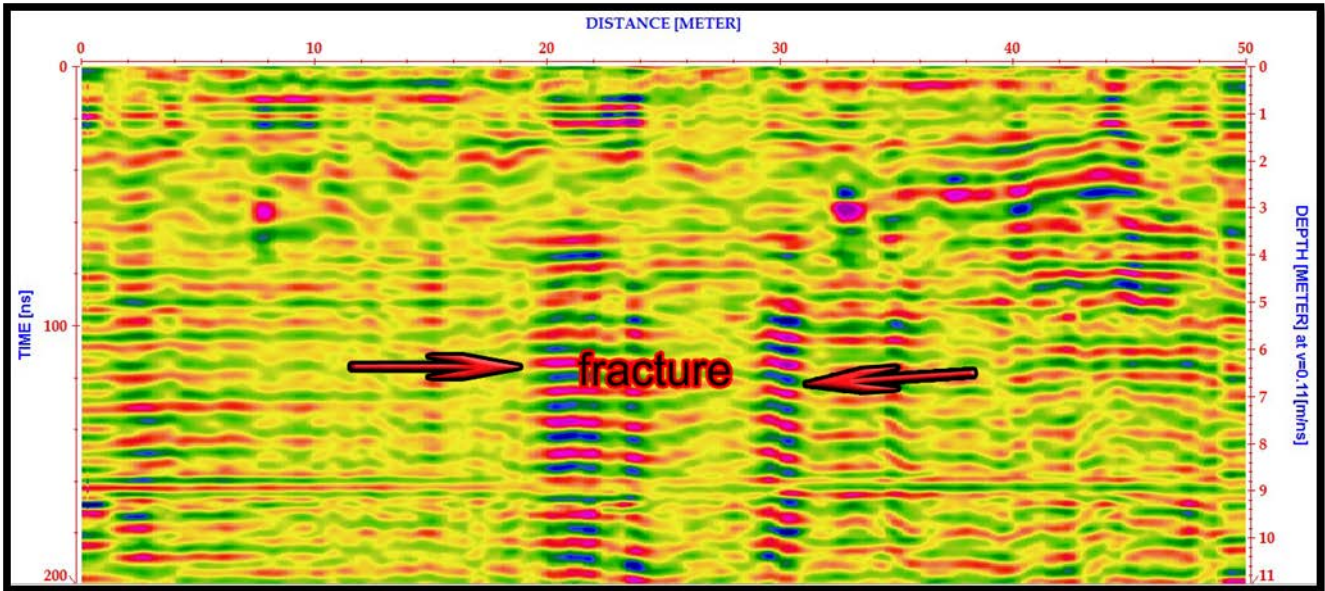


Figure (13): Profile 1 obtain using 100 MHz antenna from East to West.

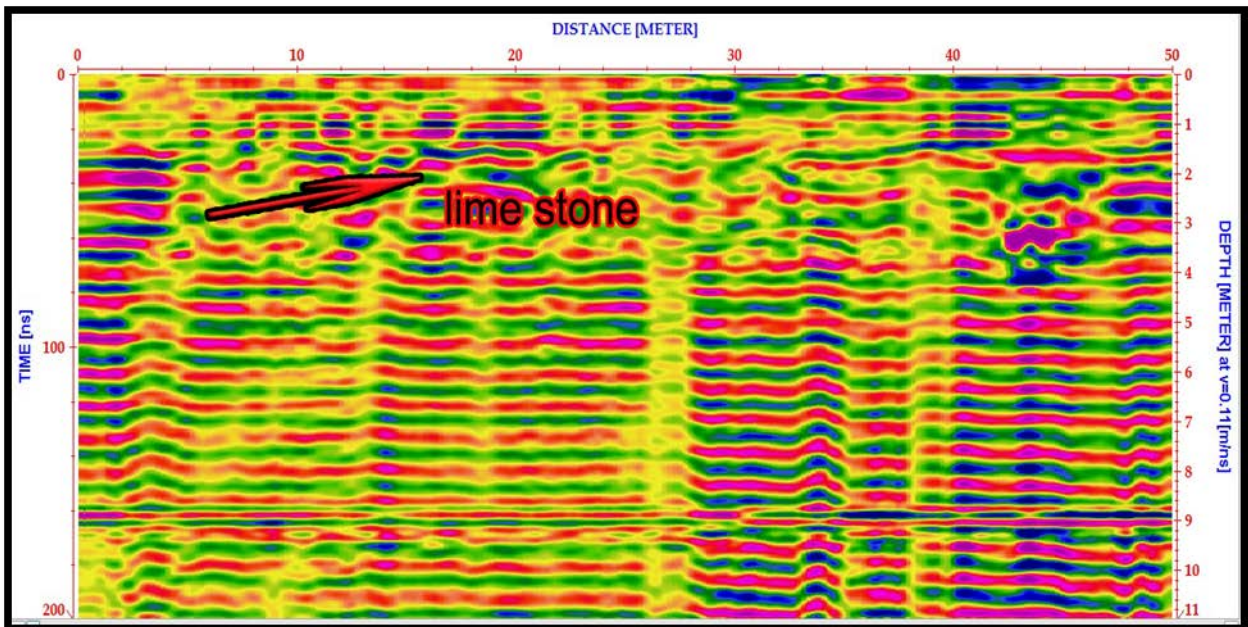


Figure (14): Profile 2 obtain using 100 MHz antenna from East to West.

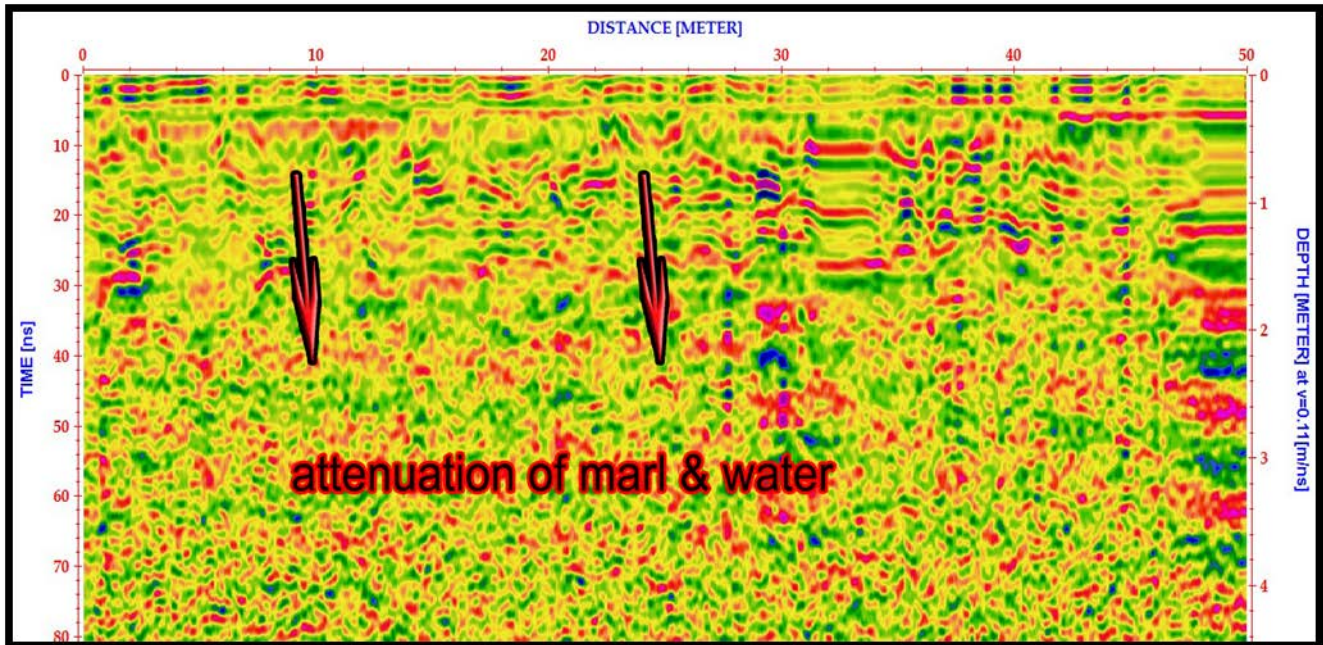


Figure (15): Profile 4 obtain using 400 MHz antenna from E-W direction.

3. Electromagnetic method.

TDEM data were acquired using SIROTEM MK-3 Conductivity meter. Delay times were used in the range of 20 – 40 Ms. TEMIX XL V4 (1996) and 1X1D V3 programs were used in the processing and interpretation. There are many ways, in which TEM data can be processed and these are largely dependent upon which instrument is used to acquire the original data. Consequently, these data can be processed to improve the signal-to-noise ratio. At the same time, the field data were checked for repeatability. Commonly, the data are normalized with respect to the transmitter current or other system parameters. The effects of the time decay may be amplified to normalize the observed field data at each point with the respective primary field value at the same point. The obtained 1-D models were used as initial models for 1-D inversion of the TEM data. A trial and error modeling was applied to the compared data sets in order to give a single model. A typical example of the inverted TEM soundings, is shown in table 2.

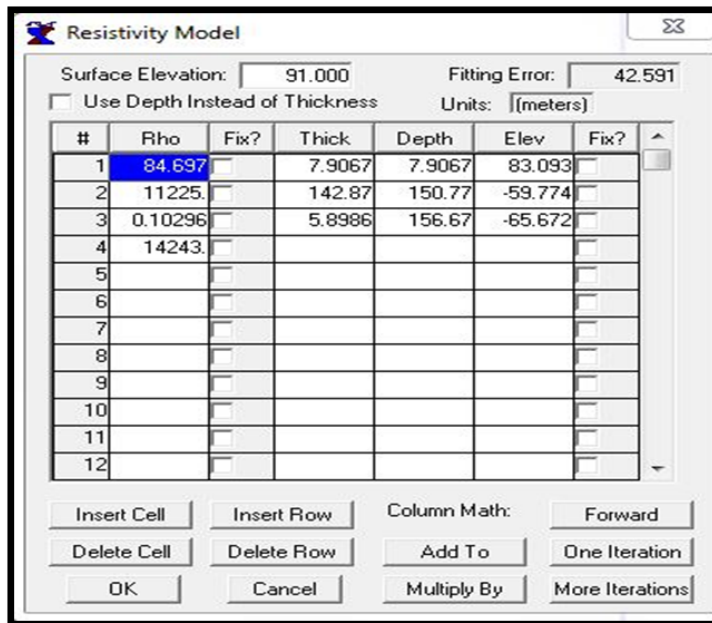


Figure (16): Interpretation of the TEM station

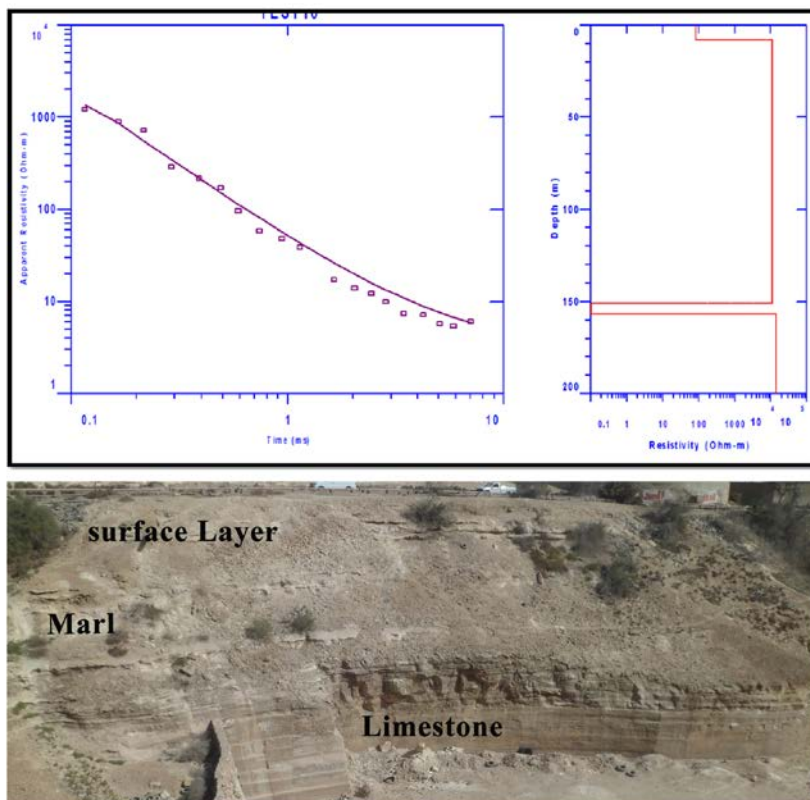


Figure (17): Calibration of the TEM station.

Table 2: Results TEM data.

Summary and conclusion

Lithology	Resistivity ($\Omega \cdot m$)	Thickness (m)	Depth (m)
Surface Layer	85	8	8
Limestone	11225	142	150
Marl	0.1	6	158
Limestone	14243	-	-

A geophysical investigation was carried out at Helwan city, passing through the study area to evaluate the effectiveness of two non-invasive geophysical methods for assisting the site characterization. The prevailed subsurface structures such as fractures, joints, faults, voids, cavities and other There are many factors causing the slope failure in the Research Institute Of Astronomy And Geophysics, Helwan area such as the increased pore-water pressure due to domestic water leakage (both sewage and drinking water), earth vibrations resulting from large explosions in the limestone quarries of the cement factories of Helwan area and instability of protruding (side) ridges between old crescent-shaped quarries and unstable roofs of the natural caves. Several precautionary measures and slope treatments are recommended in order to decrease the potentiality of slope failure in this area and its adverse impact on escalating encroachment of human settlements. The systems include: electrical resistivity imaging (2D & 3D), ground penetrating radar (GPR) and EM technique.

Investigation of shallow subsurface fractures, landslides of shales, marl beds, and surface water leakage through limestone cracks on observatory area. Shale beds represent dangerous problem in the construction of buildings, they cause sliding in the buildings and collapse in the near surface layers. Also the existence of because water in the near surface strata cause subsidence of the buildings. The study area suffers from water leakage due to the surrounding waste water that reached to the study area through the fracture and voids that formed in the rocks. These problems can be solved by modern geophysical techniques. There are many geophysical techniques can be used to solve the geotechnical problems such as

geologic penetrating radar (GPR) and (TEM). GPR detect these problems through the shallower part of subsurface layers whereas TEM method can be used to measure in the deeper part of subsurface layers.

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