

A Case Study of High-Resolution Gravity and Wenner-Schlumberger Resistivity for Geotechnical Engineering: An Example from North Jordan

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Abstract: During 2011, high-resolution gravity and Direct Current (DC) Wenner-Schlumberger resistivity geophysical techniques were made over an area of 80×70 m at the location of a proposed educational building at Jarash City, north Jordan. The objectives of the study were (i) to evaluate the resolution of these geophysical techniques in field work in detecting and locating anomalies caused by subsurface structures and (ii) to provide additional rock stratigraphy information at the site. High-resolution gravity data were collected on 5 m grid station along survey lines spaced 5 m apart. Resistivity measurements were carried out utilizing the Wenner-Schlumberger array configuration with 2-m electrode spacing along thirteen profile lines. Results of the survey demonstrated a strong correlation between the two geophysical techniques and subsurface geology. The interpretations obtained from gravity of the field data provided useful information in detecting near-surface channels. The DC-resistivity surveys allowed the determination of the specific resistivity down to a depth of about 6.5 m. The results indicate zones of chalk, marl and chalky marl with limestone intercalation with low resistivity values. Moderate high resistivity values were detected and were attributed to the presence of marly limestone sedimentary rocks.

Keywords: Geotechnical engineering, high-resolution gravity, north Jordan, Wenner- Schlumberger array

INTRODUCTION

Jordan's surface morphology varies from an arid to semi-arid desert on the east, to mountainous terrain on the west associated with the Jordan Dead Sea Transform Fault Zone. Faults and near-surface fractures in rocks present rock-fall and slope instability hazards for road and building construction and maintenance.

A new educational building was proposed to be constructed in the Jarash City, north Jordan (Fig. 1). The geology at the site consists of surficial deposits of gravels, alluvium and wadi sediments of Holocene to Recent in age at the surface. These sediments washed down from the surrounding area and are about 0.5 m thick. They overlie marl, chalk and chalky marl sediments with some limestone intercalation (Abdelhamid, 1993). These sediments are members of the Shu'ayb Formation of the Ajlun Group (Cinemania to Lower Turonian in age) of the Upper Cretaceous rocks. At the site these units are about 60 m in thickness and dip gently to the south/southeast direction and overlain by sediments mainly composed of massive and dolomitic limestone of the Wadi Es Sir Formation (Turonian in age).

In the present study, an application showing the use of high-resolution gravity and Wenner-Schlumberger 2D electrical imaging geophysical surveys were presented to investigate geology, environmental

management and engineering. The study was performed at the Jarash City, north Jordan. This site has a large existing stratigraphic data base that involves information on faults, shear zones, erosional surfaces, paleochannels, caverns and fractures and so is ideal for evaluation of the high-resolution gravity and Wenner-Schlumberger geophysical techniques for detection and location of these geologic hazards. The results of the analysis of the microgravity and Wenner-Schlumberger resistivity profiling over the field site are presented in this study.

METHODOLOGY

High-resolution gravity and Electrical Resistivity Tomography (ERT) geophysical methods were used to investigate the underground and to try to locate and trace the subterranean cavities in marly limestone unit and the determination of their dimensions. The study was performed at the Jarash City, north Jordan in the summer of 2011. Although these two methods vary in resolution limits, their joint application may substantially improve the information content obtainable from the methods separately, since each method senses different physical parameters and, consequently, can provide useful independent data.

The gravity method can provide records of subsurface structures such as cavities and tunnels

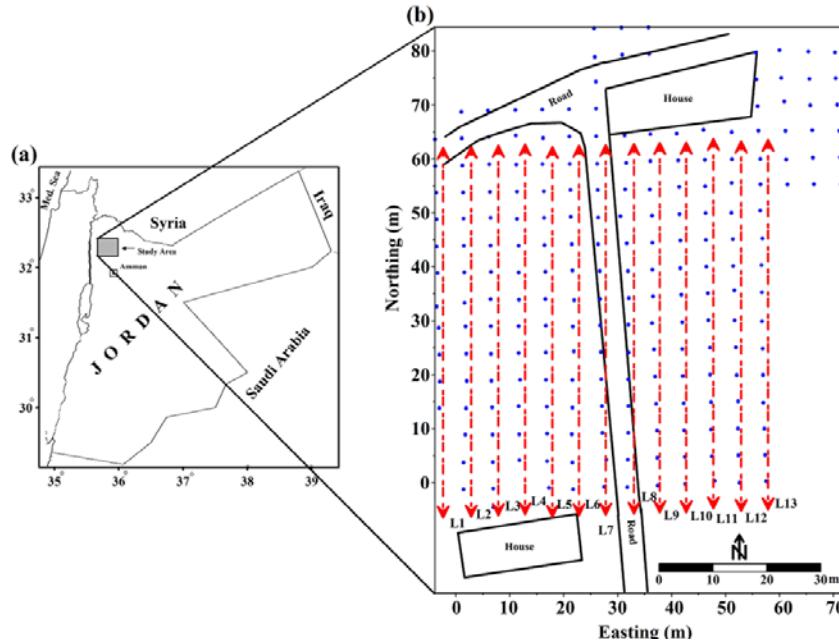


Fig. 1: (a) Site map, (b) Jarash research site map, the locations of gravity stations are shown as blue circles. The locations of resistivity profiles are shown as red dashed lines

associated with low densities and allow precise location and dimension. Air-and water-filled caverns are ideal targets for exploration by the gravity method (Butler, 1984; Lange, 1999).

Geoelectric surveys are used for the determination of underground variations of resistivity and the knowledge of this parameter can help for use in near-surface mapping studies. It can be used to study lithology, subsurface faulting and underground cavities and voids (natural or man-made), all of which pose potentially dangerous geological hazards. Determining their location and geometry has diverse applications including safe construction of buildings, road ways, airports, dams and archaeological excavations. Research relevant to the subject is that of Griffiths and Baker (1993), Batayneh *et al.* (1999), Batayneh and Al-Zoubi (2000) and Batayneh and Barjous (2003).

High-resolution gravity survey: A gravity meter measures variations in the gravitational field at the ground surface, which correspond to density changes in the subsurface. Density variations come about, for example, when crossing from soil to rock. Underlying caves and voids give rise to corresponding gravity anomaly lows (expressed in milliGals) at the surface.

Gravity data were collected over the study site with the LaCoste and Romberg D20 Gravity Meter (L and R Instruments Inc., USA) on 5 m grid station along survey lines spaced 5 m apart, oriented in a direction

90° (N-S) (Fig. 1). Gravity values were computed relative to main base-station benchmark and an auxiliary base-station established using Ashtech Z-Surveyor (Magellan Corporation, USA) near the investigation site. Two hundred and eighteen gravity stations were made along the survey traverses (Fig. 1).

ERT measurements: ERT is a method by which 2D images of subsurface resistivity distribution are generated. Using this method, features with contrasting electrical properties to that of surrounding material may be located and characterized in terms of electrical resistivity, geometry and depth of burial. ERT resistivity data are collected using computer-controlled measurement system connected to multi-electrode arrays.

The use of a resistivity method for near-surface mapping investigations has included the discovery of cavities and voids (Batayneh *et al.*, 1999; Batayneh and Al-Zoubi, 2000). Resistivity method also has the capability of mapping underground discontinuities, such as faults and boulders in the shallow subsurface (Batayneh and Barjous, 2003, 2005). The ERT data were collected along 13 profiles (L1-L13, Fig. 1) with a 5 m offset between adjacent profiles. Each survey line comprised 32 stainless steel electrodes 2 m apart. The location of the survey traverses was chosen depending on the gravity results. Stations along survey lines was marked using a theodolite. Iris Syscal R2 resistivity

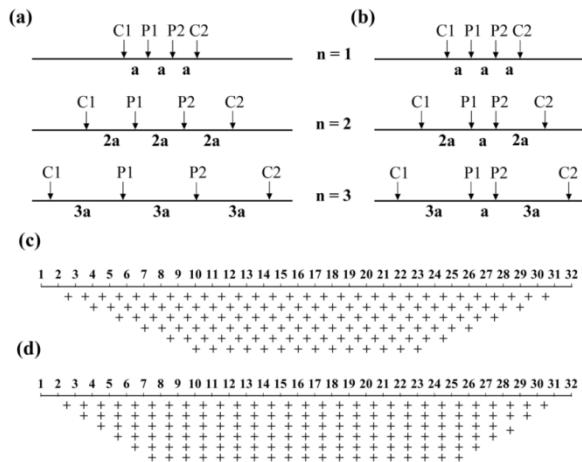


Fig. 2: A comparison of the electrode arrangement for the, (a) Wenner array, (b) Schlumberger array and pseudo section data pattern for the (c) Wenner, (d) Wenner-Schlumberger arrays

equipment (IRIS Instruments, France) was used to cover a sum of 1872 electrode positions altogether applying Wenner-Schlumberger array configuration.

The Wenner-Schlumberger array profiling method is a new hybrid between the Wenner and Schlumberger arrays. In the Wenner array, two current electrodes C₁ and C₂ and two potential electrodes P₁ and P₂ arranged on a straight line with a constant distance (a) between the electrodes (Fig. 2a). The Schlumberger array is one of the most commonly used array for resistivity sounding surveys.

Schlumberger array configuration (Fig. 2b) incorporates two current electrodes C₁ and C₂ and two potential electrodes P₁ and P₂ arranged on a straight line. The spacing between both electrode pairs is (a). The first sequence of measurements is made with a value of 1 for the (n) factor for this array, which is the ratio of the distance between the C₁-P₁ or P₂-C₂ electrodes to the spacing between the P₁-P₂ potential pair (Fig. 2b). The (a) spacing between the P₁-P₂ potential pair is kept fixed and the (n) factor is increased in order to increase the depth of penetration. In our case, a = 2 m and (n) separation were taken from 1 to 6. Note that the Wenner array is a special case of this array where (n) factor is equal to 1. Fig. 2c and d illustrates the pseudo-depth distribution of data points for the Wenner and Wenner-Schlumberger configurations.

Resistivity field data collected using the Wenner-Schlumberger array from individual survey lines were inverted individually using RES2DINV Software proposed by Loke and Barker (1996) to generate 2D Wenner-Schlumberger resistivity models. An initial model is produced, from which a response is calculated

and compared to the measured data. The starting model is then modified in such a way as to reduce the differences between the model response and the measured data; these differences are quantified as a Root-Mean-Square (RMS) error value. This process continues iteratively until the RMS error falls to within acceptable limits, usually below 5%, or until the change between RMS values calculated for consecutive iterations becomes insignificant.

RESULTS AND DISCUSSION

Analysis of high-resolution gravity results: The results of the Bouguer gravity data collected over the site were processed and contoured at 0.02-mGal contour interval (Fig. 3a). The Bouguer gravity anomaly map over the investigated site is dominated by small variations, appreciably negative, of the order of -10.62 to -10.28 mGal, a difference of 0.34 mGal. The Bouguer gravity map was incorporated into a 3D data volume with coordinates of horizontal position and gravity anomalies (Fig. 3b).

The 3D data volume of the Bouguer anomaly map (Fig. 3b) indicates a fluctuation (high density) over the limestone members, while there are only negligible scatter anomalies (low density) in the part of the chalky marl rocks. Because of these significant gravity changes over the study site, the 3D surface (Fig. 3b) appear to have mapped, in remarkable detail subsurface three zones with different properties: the first zone has about 20 m wide in the E-W direction, extending from 10E to 30E and has about 70 m long in the N-S direction, extending from about 0N to 70N. The second zone has about 25 m wide in the E-W direction, extending from

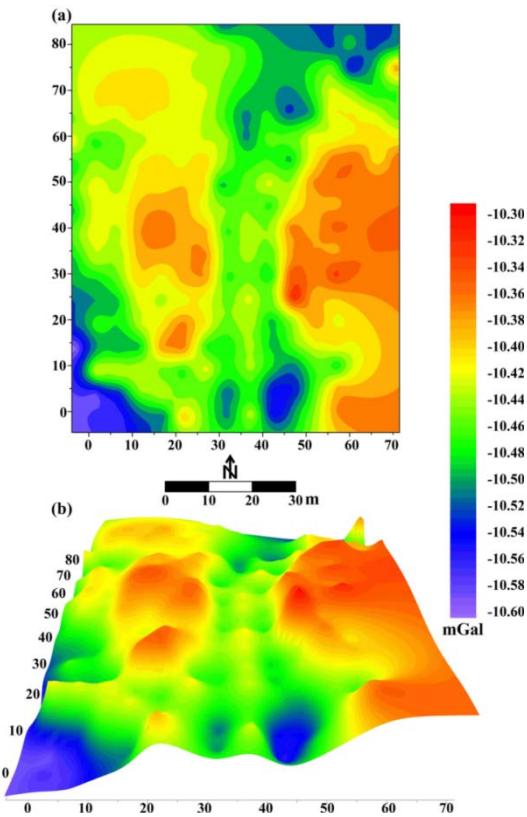


Fig. 3: Bouguer gravity anomaly map with 0.02 mGal contour interval for the investigated site

45E to 70E and has about 70 m long in the N-S direction, extending from about 0N to 70N. As seen from Fig. 3b, the first zone shows high gravity values in the range -10.42 to -10.34 mGal, considered to have been caused by marly-marly limestone rocks at shallow depths. In the second zone the range is from -10.40 to -10.30 mGal, considered to have been caused marly limestone rocks.

An elongated N-S trending gravity anomaly, third zone, about 15 m wide in the E-W direction, extending from 27E to 43E and has about 80 m long in the N-S direction, extending from about 0N to 80N was recognized. This zone shows moderately lows gravity values in the range -10.56 to -10.42 mGal, considered to have been caused by chalky marl rocks.

A pronounced N-S trending gravity anomaly lows about 12 m long and 10 m wide was recognized in the southern central part of the study area. The registered gravity value for this anomaly is -10.57 mGal. In addition, anomalies low covers considerable parts at the extreme north and northeast of the site was also recognized. These anomalies registered gravity values in the range -10.57 to -10.52 mGal. Subsequent excavations carried out by the group of this survey

revealed the existence of a paleochannel filled with low materials hosted in more dense rocks. Paleochannel were observed for the first time in Jordan within the Upper Cretaceous rocks in the Rasen Naqab area, south Jordan (Batayneh and Barjous, 2003).

The lowest prominent gravity anomaly feature, -10.60 mGal, is recognized in the southwestern part (Fig. 3b). The anomalous areas are about 5 m wide. The lowest gravity anomaly in the southwestern corner is attributed to the sewer hole which is belonging to the southwestern house (Fig. 1). This hole can be seen to the northwest of the house at the surface.

Wenner-Schlumberger resistivity inversion results: Figure 4 shows the results from the 2-D inversion of the field data along the thirteen Wenner-Schlumberger profiles. For the first level of measurements, $n = 1$, corresponding to shallow depths of investigation from the surface down to a depth of 1.1 m (Fig. 4a), the distribution of the resistivity indicates the presence of two zones with different properties. These zones were defined in terms of the expected overburden thickness. Overburden is generally, although not always, more conductive than the underlying bedrock. This is due to the higher porosity and, hence, higher water content and to a generally higher content of electrically conductive clay minerals relative to the bedrock. The first zone that mainly covers the northern and eastern parts shows resistivity values in the range 60-180 ohm-m, considered to have been caused by the alluvial sediments at the top underlain by chalky marl rocks at 0-1 m depth. In the second zone that mainly covers the southern central and western parts; the range is from 180-400 ohm-m, considered to have been caused by marly limestone rocks at the surface. With $n = 2$ level (Fig. 4b), corresponding to a depth of 1.1-2.2 m, the detail obtained indicate that the majority of the mapped area (about 75%) shows resistivity values in the range 60-180 ohm-m, considered to have been caused by chalky marl rocks. The rest that mainly covers the southern central part shows resistivity values in the range 180-400 ohm-m, considered to have been caused by marly limestone rocks.

The results obtained for the $n = 3$ and 4 levels (Fig. 4c and d), corresponding to a depth of 2.2-3.3 and 3.3-4.4 m, respectively indicate less lateral resistivity variations compared with the levels 1 and 2. This may be ascribed to fewer changes in physical properties with greater depth. The resistivity maps for $n = 5$ and 6 levels (Fig. 4e and f), corresponding to a depth of 4.4-5.5 and 5.5-6.6 m, respectively are characterized by moderate high-to-low resistivity values. The obtained values are ranging between 60 to 300 ohm-m.

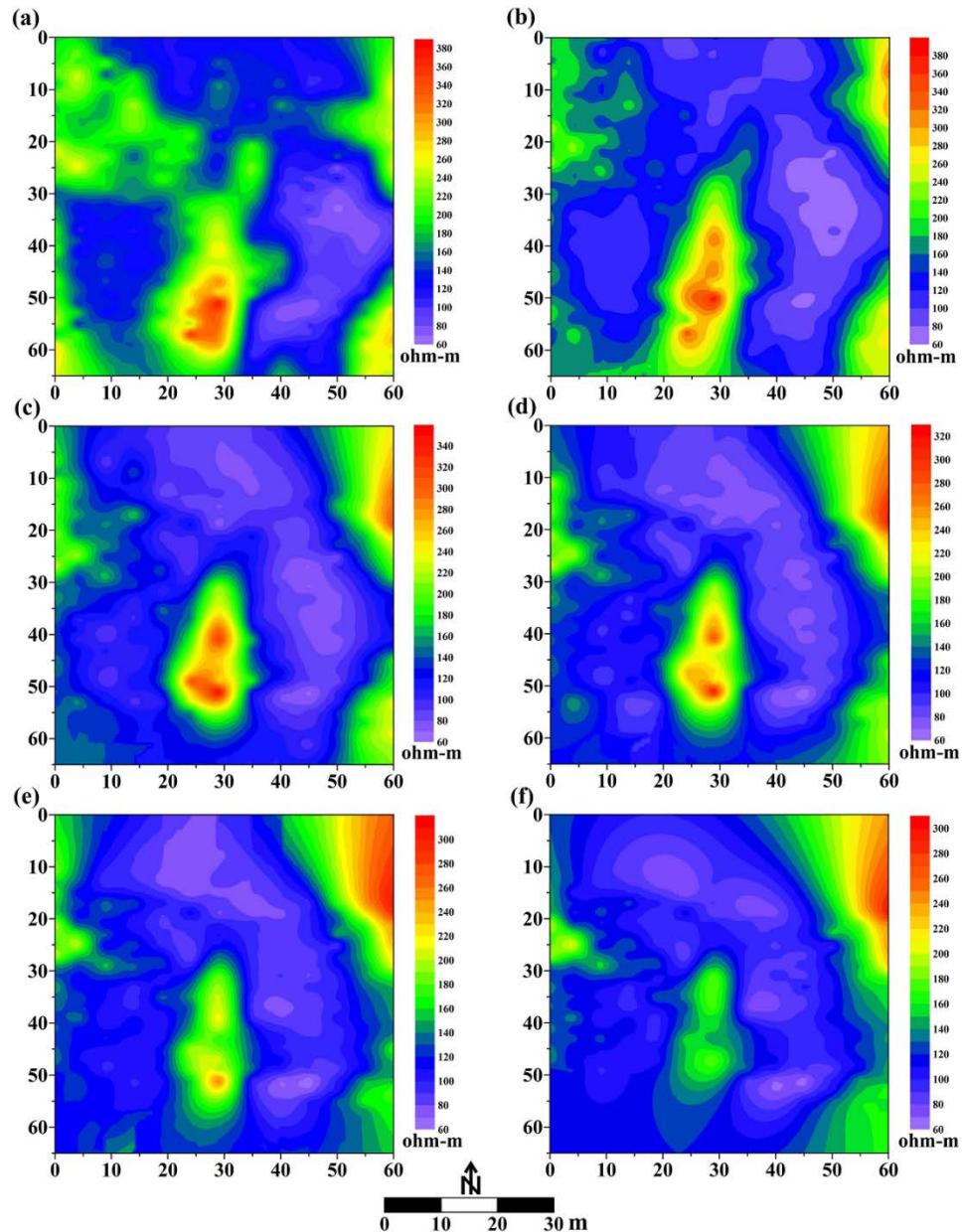


Fig. 4: Resistivity maps measured along 13 resistivity profiles spaced 5 m apart (a) n = 1 corresponding to 0-1.1 m of depth, (b) n = 2 corresponding to 1.1-2.2 m of depth, (c) n = 3 corresponding to 2.2-3.3 m of depth, (d) n = 4 corresponding to 3.3-4.4 m of depth, (e) n = 5 corresponding to 4.4-5.5 m of depth, (f) n = 6 corresponding to 5.5-6.6 m of depth

This decrease in resistivity values from about 400 ohm-m on the surface to about 300 ohm-m at 6.6 m depth can be explained by the more homogenous chalky marl of the Shu'ayb sedimentary rocks.

CONCLUSION

The case presented here clearly illustrates that the high-resolution gravity and DC-resistivity geophysical

techniques are reliable, rapid and economical methods for mapping shallow subsurface sediments and assessing their lateral and vertical physical properties. The thickness of the sediments can be reliably mapped at a field site where subsurface geology is not too complex and where changes in subsurface physical properties are associated with lithology changes.

At the Jarash City, north Jordan, high-resolution gravity technique gives the variations in the

gravitational field at the ground surface, which corresponds to density changes in the subsurface. Based upon the lateral gravity changes, high-resolution gravity data provided useful information in detecting near-surface channels when the host rock has different physical properties. The DC-resistivity surveys allowed the determination of the specific resistivity down to a depth of about 6.5 m. The results indicate zones of chalk, marl and chalky marl with limestone intercalation with low resistivity values in the range of 60-180 ohm-m. The moderately high resistivity values (180-400) were attributed to the presence of marly limestone sedimentary rocks.

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