Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Assessment of underground karst caves using geophysical tests: A case study for Lajamgir dam site, Iran

F. Jafarzadeh
Civil Engineering Department, Sharif University of Technology, Tehran, Iran

M.M. Shahrabi, M. Banikheir & N. Eskandari
Abgeer Consulting Engineers, Tehran, Iran

A.A. Garakani & H. F. Jahromi
Civil Engineering Department, Sharif University of Technology, Tehran, Iran

ABSTRACT: Karst features have caused serious problems in many engineering projects because of their permeability and high leakage potential; a clear example is Lar Dam, 84 km northeast of Tehran in which normal water level has never been reached since the filling of its reservoir in 1980. Sometimes conventional methods of studying karst features (e.g., borings and sampling) fail to precisely reveal their underground structure and this may result in inaccurate design, extensive leakage and creation of sinkholes. In the present paper, an under-study dam site in Lajamgir, Zanjan province, northern Iran is investigated. Ground observations indicated the possibility of presence of Karst caves while borings showed no such feature. Detailed studies by means of geoelectrical (Electrical Resistivity Tomography, ERT) and geo-radar (Ground Penetrating Radar, GPR) tests demonstrated what was claimed by site observations and proved that a simple group of geophysical tests can effectively help reveal the general condition of underground karst caves which can be followed by a set of dense borings to assess the details.

1 INTRODUCTION

Karst features are mainly formed in limestone and other dissolvable lithological units and they cover approximately 33% of the earth's surface (Milanovic, 1981). Surface karst features are distinguished through geomorphologic maps, whereas, underground features are extended from the uppermost layers of the ground surface to great depths and are not easily discoverable. Thickness of the underground features varies normally from a few decimeters to tens of meters (Klimchouk, 1996). Leakage is one of the main problems associated with cavities and gaps formed in karstic zones. Recurring drainage in the foundation of dams result in their malfunction as water storage structures, therefore, a thorough survey is needed in the primary phase investigations of any dam to avoid such problems.

Geophysical techniques have proven to be very useful to engineers and geologists in order to identify anomalies related to underground cavities and gaps and have developed recently. Among the most favored geophysical tests used for this purpose, one can name electrical resistivity tomography (ERT) or geoelectrical imaging and an electromagnetic survey referred to as GPR (Ground Penetrating Radar) or geo-radar test. In ERT method, electrical current is applied into the soil by means of two electrodes. The electrical potential generated in another pair of elec trodes is measured and the electrical resistivity (or its inverse electrical conductivity) of the subsoil is obtained. The electrical resistivity of the geomaterials can give a reasonable insight into their mechanical properties and is used to recognize different rock and soil formations, including the presence of caves and discontinuities. Various types of arrays are introduced for the purpose of geoelectrical testing including Wenner, Schlumberger, and dipole–dipole (Zhou et al, 2002).

GPR has also been widely applied to locate karst features (Robert and de Bosset, 1994; Grandjean and Gourry, 1996; Freeland et al, 1998; Doolittle and Collins, 1998; Cunningham, 2004; Kofman et al, 2006). It takes advantage of electromagnetic pulses that are produced by an antenna and received by another one which detects the changes in the dielectric permittivity of the subsoil. The method typically involves a systematic moving of both the generating and the receiving antenna in parallel lines in a way to entirely cover the surveying area. In the present paper, both ERT and GPR tests have used to detect the underground karst features at Lajamgir Dam site in Zanjan Province in northern part of Iran. Results obtained by both methods are presented followed by a discussion on the effectiveness and accuracy of geophysical tests as non-invasive investigations for detection of underground karst caves.

2 GEOLOGICAL SETTINGS

Lajamgir Dam is an under-study embankment dam located about 60 km west of the City of Zanjan in the Zanjan Province of Iran. The dam is planned to be constructed on the Lajamgir River, one of the main tributaries of Ghezel-Ozan River in a drainage basin with very high flooding potential. The study area is located in the Western Alborz-Azarbaijan structural zone with outcrops of sedimentary sequences from Oligo-Miocene to Miocene. The most important lithological units in the dam site include (old to new): (1) lower marl unit, (2) lower marly limestone unit, (3) middle marl unit, (4) upper limestone unit, (5) upper marl unit, (6) gypsiferous marl unit, (7) quaternary alluvial deposits. The upper limestone unit is underlain by a marl unit, has a thickness of 30-40 meters and is outcropped at the dam axis (Figure 1). As shown in Figure 1, this unit contains several dissolved karst caves and has a great potential for leakage. As a consequence, several geoelectrical and georadar tests were planned to be conducted on the axis of dam, on the river stream route and on the abutments of the dam. Figure 2 demonstrates the geological section of the dam foundation based on previous geotechnical investigations. It is clearly shown that sequences of limestone and marly limestone exists under the axis of the dam, proving the necessity of further underground investigations to locate any cavities and gaps and consider required measures to prevent leakage from the foundation and abutments.

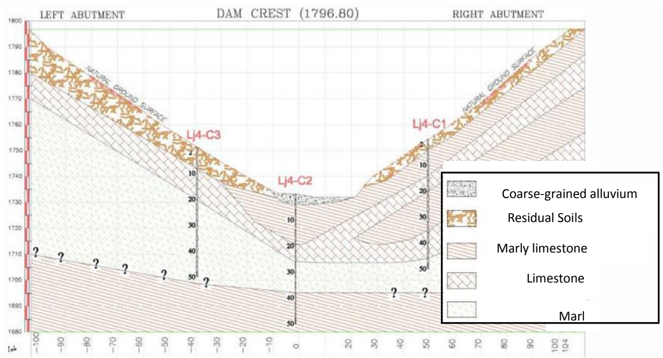

Figure 2. Geological section of the dam foundation under the axis

3 FIELD INVESTIGATIONS

A total of 23 georadar arrays and 9 geoelectrical arrays (1 Schlumberger and 8 dipole-dipole) were designed on the axis of dam, on the river stream route and on the abutments of the dam as depicted in Figure 3.These investigations were concentrated mainly in locations where the possibility of the presence of underground karst features was the most. In order to improve the effectiveness and efficiency of the georadar method, multiple arrays were planned and performed in which the distance between the emitter and the receiver is varied.

In the dam site under study, the Schlumberger array for geoelectrical testing was feasible only on the river bed (array No. 10). A total number of 12 vertical sockets were placed at every 25 meters, perpendicular to the dam axis. The achieved processed section is shown in Figure 4(a). Anomalies which may be attributed to the dissolving karst caves are shown in circles. However, for a more accurate assessment, these anomalies should be compared to those achieved by georadar tests. The sections obtained by dipole-dipole arrays were also processed and two sections are shown as examples in figures 4(b) and 4(c). Lithological units, fractures and anomalies (marked with circles) can be seen through these sections.

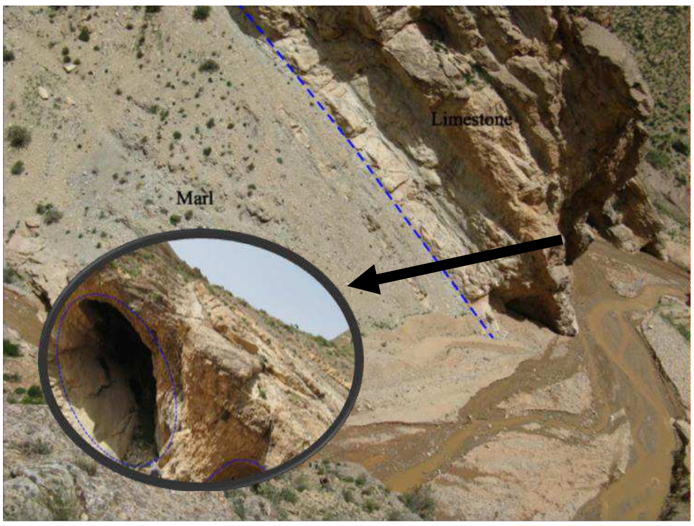

Figure 1. Limestone outcropping on the axis of Lajamgir Dam (large dissolved karst caves)

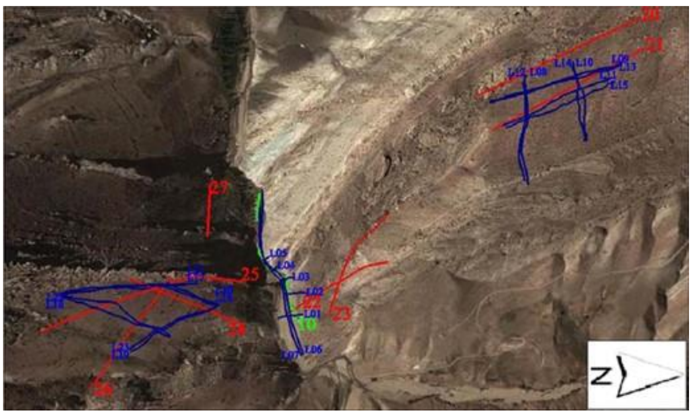

Figure 3. Location of geophysical arrays at the dam site, georadar arrays (L01-L23), geoelectrical arrays, dipole-dipole (1-9) and Schlumberger (10).

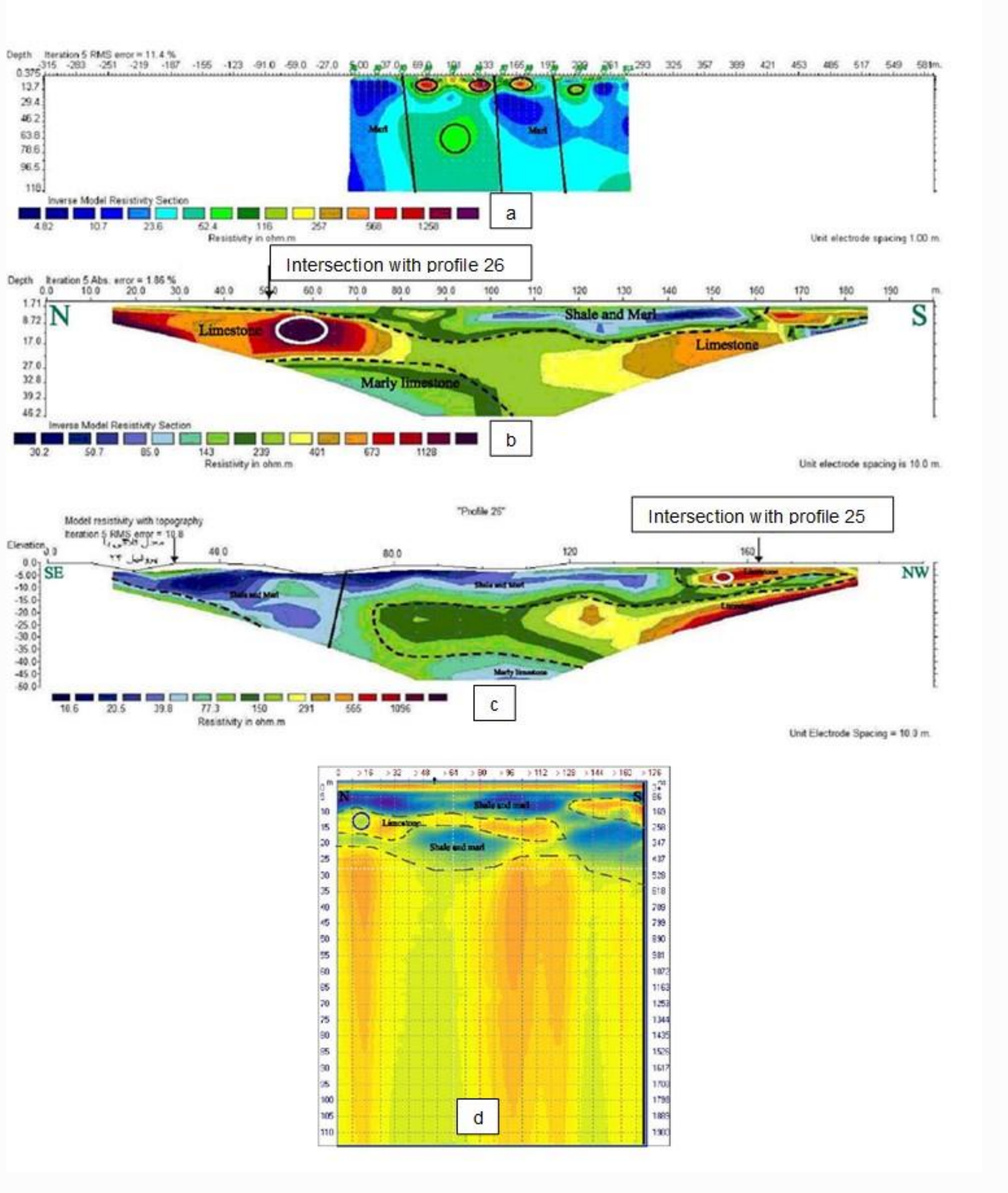

Figure 4. Typical results obtained by geoelectrical tests and Georadar tests; (a) Schlumberger array No.10, (b) dipole-dipole array No.25, (c) dipole-dipole array No.26, (d) georadar array No.L17.

Figure 5. Location of geophysical arrays at the dam site and the observed anomalies (shown in circles)

By comparing figures 4(b) and 4(c), it is observed that at the intersection of arrays No.25 and 26, an anomaly exists showing a very small electrical resistivity that can be ascribed to a karst cave.

For georadar testing, 27 arrays were designed on the river bedding, right and left abutments. Typical result obtained from the array No. L17 is shown id Figure 4(d). The section clearly defines different lithological units and the observed anomalies (marked with circles). As mentioned before, not all the anomalies detected through georadar tests are caused by karst features. Therefore, a detailed comparison should be made between the results obtained by geoelectrical and georadar tests to better prove the presence of any karst cave in the dam site.

All of the surveys demonstrated that at Lajamgir Dam site, anomalies are limited to depths of less than 20 meters. The results obtained by both geoelectrical and georadar tests prove that although anomalies are spread at the river bedding, left and right abutments (shown by circles in Figure 5), most of them are concentrated at shallow depths smaller than 5 meters under the river bedding. In general, it was observed that both methods provide valuable information on the present underground anomalies especially at shallow depths (<40 m), however, the results of geoelectrical tests are more reasonable in terms of accurate interpretation. Therefore, it is suggested that geoelectrical tests may be used solely for determination of underground karst features at dam sites and that georadar tests should be followed by a set of geotechnical borings to achieve a complete perception of underground lithological formations.

4 CONCLUSIONS

Lajamgir Dam site is located near the City of Zanjan in the Zanjan Province of Iran on the Lajamgir River, a tributary of Ghezel-Ozan River. The presence of limestone in the river bedding and the resulting leakage potential is an important issue about the Lajamgir Dam site studied in this paper. Two mostly used geophysical tests (geoelectrical and georadar) were performed to assess the underground lithological units and obtain information on karst features. In total, 23 georadar and 9 geoelectrical (1 Schlumberger and 8 dipole-dipole) tests were designed and performed on the axis of dam, on the river stream route and on the abutments of the dam. Surveys showed that most anomalies are shallow and mainly concentrated under the river bedding below the axis of the dam. Both georadar and geoelectrical approaches were proved to give reasonable information on presence of anomalies at small depths (<40 m). Nevertheless, it was observed that georadar tests were less accurate than geoelectrical tests and they need to be followed by a set of geotechnical surveys (boreholes) to better evaluate the presence of underground karst caves.

5 REFERENCES

Zhou, W., Beck, B.F. & Adams, A.L. 2002. Effective electrode array in mapping karst hazards in electrical resistivity tomography. *Environmental Geology* 42: 922-992.

Robert, A. & de Bosset, C. 1994. Application du géoradar à la localisation de cavités, de nids de gravier et de zones karstiques. *Journal of Applied Geophysics* 31 (1–4): 197–204.

Grandjean, G. & Gourry, J.C. 1996. GPR data processing for 3D fracture mapping in a marble quarry (Thassos, Greece). *Journal of Applied Geophysics* 36 (1): 19–30.

Freeland, R.S., Yoder, R.E. & Ammons, J. T. 1998. Mapping shallow underground features that influence site-specific agricultural production. *Journal of Applied Geophysics* 40(1–3): 19–27.

Doolittle, J.A. & Collins, M. E. 1998. A comparison of EM induction and GPR methods in areas of karst. *Geoderma* 85(1): 83–102.

Kofman, L., Ronen, A. & Frydman, S. 2006. Detection of model voids by identifying reverberation phenomena in GPR records. *Journal of Applied Geophysics* 59(4): 284–299.

Cunningham, K. J. 2004. Application of ground-penetrating radar, digital optical borehole images, and cores for characterization of porosity hydraulic conductivity and paleokarst in the Biscayne aquifer, southeastern Florida, USA. *Journal of Applied Geophysics* 55(1–2): 61–76.

Milanovic, P.T. 1981. *Karst Hydrogeology*. Water Resources Publications, Colorado, U.S., 434pp.

Klimchouk, A. 1996. Hydrogeology of gypsum formations. Gypsum karst of the world. *International Journal of Speleology* 25: 83-89.