GSS GEOPHYSICS TECHNICAL NOTE

Application of 2D/3D Electrical Resistivity Imaging for the Delineation and Mapping of Subsurface Karst Geology

April 2023

Introduction

Subsurface voids, caverns, sinkholes, and other similar structures common in Karst regions represent serious engineering and environmental geohazards for land development projects, foundation engineering for roadways, buildings, tunnel construction, and other infrastructure. To minimize the hazards and risks of catastrophic and/or gradual subsidence associated with Karst structures in limestone and dolomite rock formations, it is imperative that a comprehensive soils and rock geophysical and geotechnical site characterization study be conducted to assess site conditions for engineering and environmental projects planning.

Undetected Sinkhole - Florida (2004)

Clearing sites using only the single geotechnical investigation method proved to be disastrous for engineers building a new elevated highway in Tampa, Florida. Geotechnical soil tests performed only at support column locations detected no sinkholes. The collapse sinkhole was actually deeper than the geotechnical borings, and located within underlying the limestone rock formation.

While geotechnical investigations provide much needed critical information regarding near surface soil physical properties, it is not always practical or cost effective to use borings alone to determine if any unknown sinkholes, or other subsurface Karst features are present. Karst geology develops vertically and horizontally in the subsurface, along interconnected carbonate rock fractures, fissures, dissolution zones and void structures. Depressions observed at the surface are typical indications of previous collapse of unexposed subsurface sinkholes, but such depressions are not always present where collapse has not yet occurred. Moreover, the setting of support columns, and/or mass loading at the surface with the installation of buildings and other structures, can initiate sinkhole collapse. To investigate the presence of hazardous subsurface Karst structures, it is recommended that geophysical methods be used in advance of a geotechnical boring program. Although there are several geophysical methods that can be used for Karst site characterization, one of the more effective methods is 2D and 3D Electrical Resistivity Imaging (ERI).

Electrical Resistivity Imaging is a method that utilizes continuous profile resistivity data acquired from a multi-electrode spread. The method measures and maps the horizontal and vertical distribution of apparent resistivity of soil and rock formations. Because the ERI method is very sensitive to variations of electrical properties associated with subsurface Karst features, it is a very powerful geophysical imaging tool for locating and mapping voids, caverns, carbonate rock fracture and water channel systems, depth to bedrock, and other Karst geologic structures.

When used as an initial reconnaissance survey method, the data can be used to assess potential site Karst geohazards, and to develop a more effective and valuable geotechnical investigation program. The integration of ERI and geotechnical data can provide site development planners, engineers, and environmental scientists with a more comprehensive understanding of the subsurface Karst geology.

<u>Case Study – 2D and 3D Resistivity Imaging for Karst Geology Characterization</u>

A multi-line Electrical Resistivity Imaging survey was conducted at a power plant facility located in North Georgia, USA. Plant engineers initially used geotechnical borings to assess soil properties, and to determine depth to competent bedrock across an area where plant expansion is planned. Data from the geotechnical investigation indicated variable depth to bedrock, and void structures across the proposed plant expansion area. Because of the geologic complexity, data from a grid of 2D resistivity profile lines was acquired to image dissolution zones, locate voids and caverns, and to define the overall site geologic structure. The survey grid geometry consisted of 12 inline and crossline 56-electrode survey lines, with an electrode stake interval of 10 feet. Figures 1 and 2 represent two parallel resistivity inversion sections (20 ft line separation) that show large low resistivity zones, indicating the location, depth, and approximate dimensions of the dissolution and large cavity structures.

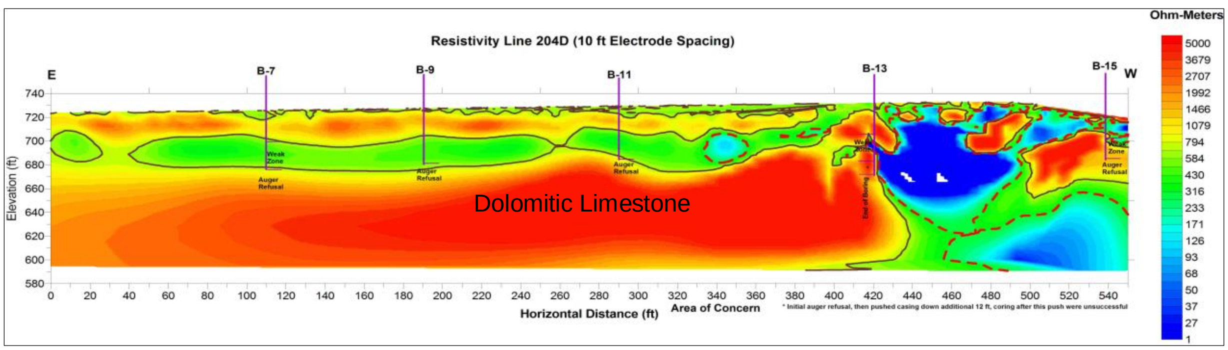


Figure 1 – Line 204D resistivity inversion section

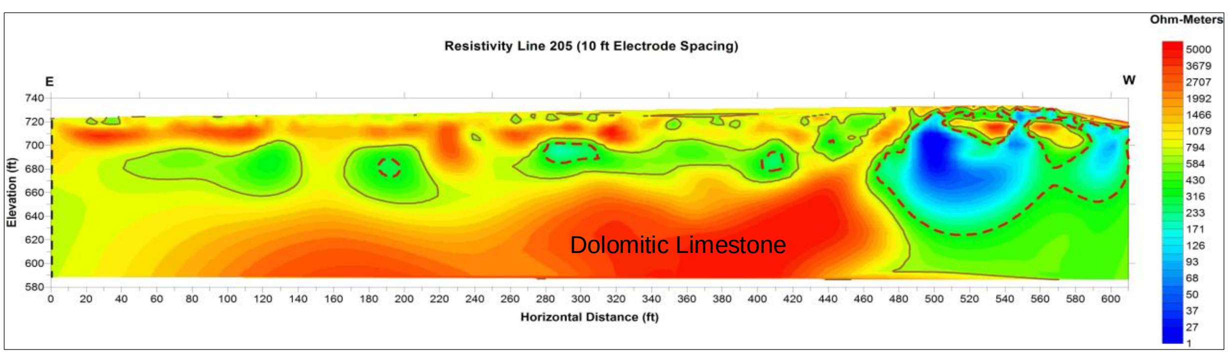
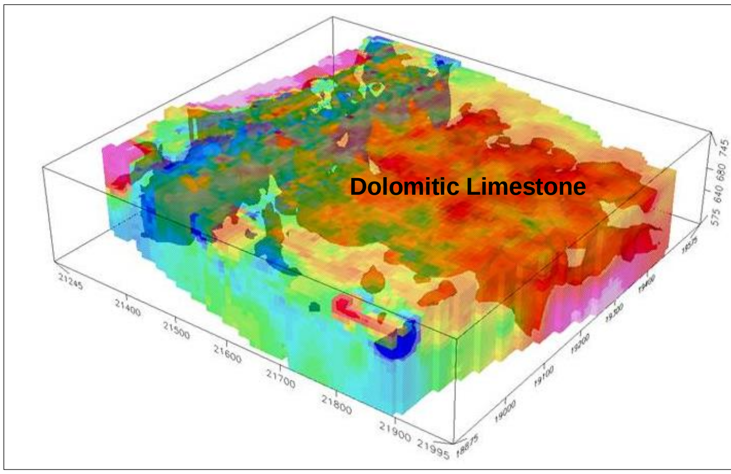


Figure 2 – Line 205 resistivity inversion section

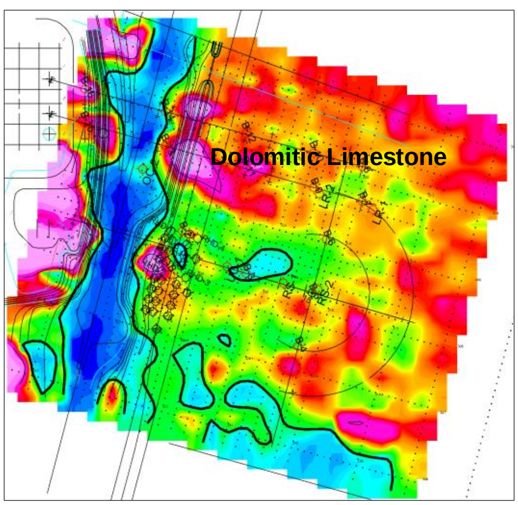
1 – 175 Ohm-m : Represents open or partially filled subsurface cavities
200 – 1000 Ohm-m : Represents dissolution zones
2000 – 5000 Ohm-m : Represents competent dolomitic limestone (weathered, fractured)

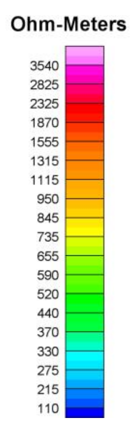


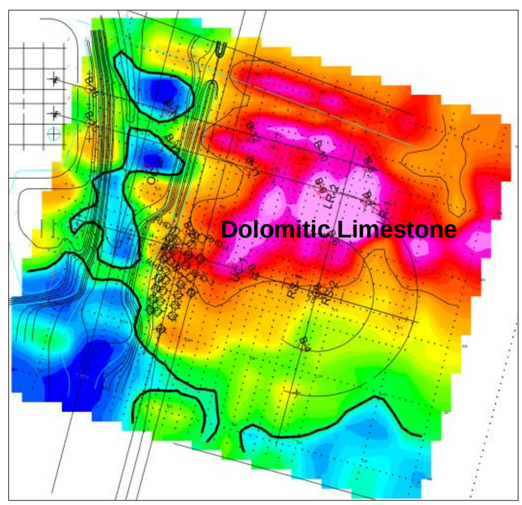
3D Resistivity Imaging

The grid of 2D resistivity profile lines is used to build a 3-dimensional data volume. Using a 3D graphics program, a 3D image of the resistivity site survey is presented to show zones of competent limestone rock, cavern, and dissolution zones. The 3D image, which is surface geo-referenced, can be used to determine the relative total volume of the subsurface voids, and to plan barrier injection grouting operations to in-fill the caverns.

Foundation engineers use the geo-referenced 3D resistivity image to plan excavation, and to change the locations of surface structures, trench routes for pipelines, and support pile locations. Orange-red color indicates competent limestone rock, whereas the light blue-blue color zones indicate the locations of open and partially filled subsurface voids. It was determined from analysis of geotechnical core sample data that the intermediate green-yellow regions indicate subsurface dissolution zones that are permeable and highly porous altered and fractured limestone. Using the 3D resistivity data volume, individual depth-slices (x,y plane) can also be generated at any depth interval to examine how the Karst structures change with increasing depth.







Depth-Slice A – 20 feet BGS

Depth-Slice B – 80 feet BGS

Depth-Slices A and B represent the extraction of the variation of horizontal resistivity in the x,y plane at depths of 20 and 80 feet below ground surface. At 80 feet, the region of competent limestone rock is increased relative to the 20 ft depth-slice. Also, the void and dissolution regions are significantly decreased in size and distribution. Using depth-slice analysis at a 10 ft depth interval, the 3D imaging allows geophysicists and engineers the opportunity to determine the depth at which soil and/or rock composition uniformity is located, and to accurately isolate potential geohazard zones.

Results from the 2D and 3D resistivity imaging project were used by geotechnical and site construction engineers to plan a follow up drilling program to confirm the location of discovered voids, property data within the dissolution zones, and to design a barrier injection grouting strategy for in-filling and stabilizing subsurface regions at locations where surface structures are to be installed, and for selecting the type and installation depth of pile footings.

The Karst geologic characterization project demonstrates how valuable the combination of geophysical and geotechnical data is for assessing subsurface geohazards, and for designing site remediation and foundation preparation plans prior to excavation and construction work. While the comprehensive integrated approach to site investigation may not always be necessary, Karst regions are particularly complex and do present a wide range of engineering and environmental problems. For Karst characterization, neither the geophysical or geotechnical methods of investigation alone should be used to adequately assess potential geohazards. Full characterization of subsurface Karst geology requires the analysis and integrated interpretation of both geophysical, geologic, and geotechnical data.

Other Applications

In addition to characterization of subsurface Karst geology, the 2D and 3D resistivity data acquisition and image processing methods can be used for other types of site investigation projects. These include, but are not limited to:

1. Archaeological investigations where the 3D and depth-slice imaging can be used to delineate ancient buried foundations, especially in regions where ground penetrating radar (GPR) does not work because of soil conditions.

2. Mapping of shallow fault systems, depth to bedrock, and water saturation zones.

3. Mapping of soil contamination zones.

4. Shallow minerals and rock bodies for mining.

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For more information concerning the application of 2D and 3D electrical resistivity imaging or other geophysical survey techniques for engineering and environmental site characterization projects, contact:

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