CHARACTERIZATION OF THE VAUCLUSE KARST AQUIFER USING ELECTRICAL RESISTIVITY

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ABSTRACT

Electrical resistivity techniques were applied within the Vaucluse karst aquifer at the underground intersection with the LSBB gallery tunnel. Data were collected using electrodes inserted vertically along the tunnel floor and in five boreholes. 2D and 3D inversion-derived conductivity models of the data indicate resistivity variations including a lower resistivity zone that can be associated with a higher porosity/permittivity zone interpreted from borehole televiewer/structural and borehole GPR interpretation.

INTRODUCTION

Improvements in inversion modeling of electrical resistivity imaging (ERI/ERT) data provide a valuable tool for delineating geological structures in surface and underground environments [1]. We have been applying ERI techniques to characterize a karst aquifer as part of the interdisciplinary research program for Carbon Sequestration (ANR-HPPPCO2) in the 'gallery' of the Laboratoire Souterrain à Bas Bruit (LSBB). The research work is providing valuable calibration and comparison of geophysical measurements for characterization of the rock mass. The test site provides a low-noise environment and a control site for underground testing and development of 2D and 3D resistivity methodology. This ERI work is part of a spectrum of geophysical and borehole investigations that are undertaken at the gallery test site as part of the interdisciplinary program. The first phase of the ERI work reported here includes 2D and 3D surveys undertaken in the LSBB gallery in the area of test boreholes placed into the limestone fracture zone intersected by the gallery.

DATA COLLECTION

Data were collected using a multi-channel IRIS Syscal system connected to stainless steel electrodes placed in holes drilled in the tunnel floor. Specially designed borehole electrodes were placed in five 20 m vertical boreholes that had been drilled as part of the multi-disciplinary investigation. Data from two 48 electrode 2D ERI profiles were collected. On the right side of the drift, 48 electrodes at 1 m spacing were placed spanning both sides of the borehole array diamond to provide high resolution but with less depth penetration. Similarly, 48 electrodes were placed on the left side at 2 m spacings to increase the investigation depth. Dipole-Dipole and Wenner-Schlumberger array data were collected for both profiles.

For the 3D surveys in the gallery, borehole electrodes were placed in all of the five boreholes to provide additional 3D information for the data collection. Five electrodes were placed in each borehole at 4 m spacing starting from the bottom of each hole. In addition, 23 'surface' electrodes spanning the complete 94 m length of the 2D survey and using the 1m and 2m electrodes on both sides of the gallery were used in the 3D survey.

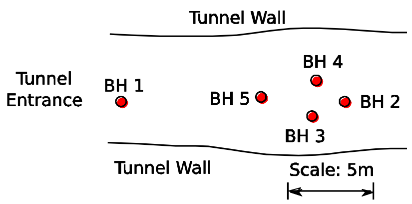

Fig. 1 Layout of the measurement area within the anti-blast gallery at LSBB. Only borehole positions are to scale.

An optimized sequence of current injection dipoles and potential measurement dipoles was measured providing relatively complete coverage of the available geometries of the electrodes. In total, 19,000 quadrapoles were measured and less than 10% were rejected for low signal strengths or high misfits. The UBC-GIF 3D DC resistivity interpretation package, DCIP3D, was used for 3D interpretation and a commercial inversion software, RES2DINV, was used for 2D data interpretation.

INVERSION

The inversion algorithm used in DCIP3D is the formulation of an objective function to be minimized, specifically:

$$\phi = \phi_d + \beta\phi_m$$

where φ is the objective function, φ_d is a measure of the data misfit, and φ_m is a measure of the model size and complexity. Initial inversions use a coarse discretization that is refined as the interpretation progresses, allowing parameters such as the regularization parameter, background model and standard deviations to be adjusted. The 3D nature of the data makes it difficult to apply traditional quality-checks, such as identification of poor data visually using a so-called 'pseudo-section'. In addition to rejectingspurious data perceived as being erroneous or unrealistic, data exhibiting very high misfits after the inversion are rejected, and we proceed in an iterative fashion. The inversion algorithm attempts to fit these high misfit data, resulting in overly complex and unrealistic conductivity models.

INVERSION RESULTS

The major resistivity variations are highlighted in Figures 2-4 with borehole televiewer data overlaid for comparison to structural geological interpretation. All figures are plotted with the gallery entrance, which is nominally south, to the left and the east side towards the viewer.

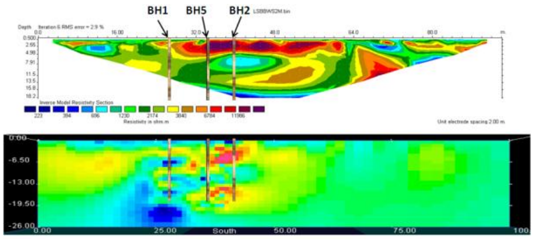

Fig. 2 Comparison of 2D (upper) inversion of Wenner-Schlumberger data and 3D inversion of complete data set on similar plane with borehole televiewer data overlaid.

Figure 2 indicates the lower resistivity/higher electrical conductivity zone below approximately 7 m depth that can be related to the higher porosity zone evident as the lighter-coloured sections of overlaid borehole televiewer data and delineated as a higher permittivity zone in borehole GPR interpretations in a related investigation [2]. The 2D and 3D ERI results are similar, however, the 3D results provide additional information showing extensions of the zones of low resistivity. Figure 3 shows an iso-surface highlighting the zones of low resistivity and Figure 4 shows a 3D colour rendition of the sampled volume in the area of interest. The ERI results indicate that the feature of interest dips to the south and west (into the figure) in agreement with structural and GPR observations. There is an extension to depth which may be related to higher water content and potentially porosity. Shallow near-surface features likely (4) represent wet tunnel floor.

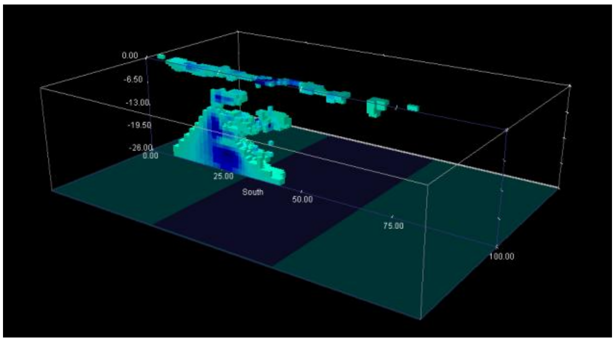

Fig. 3 3D inverse model with iso-surface cutoff highlighting low resistivity zones. Deeper structure is poorly constrained on the bottom face.

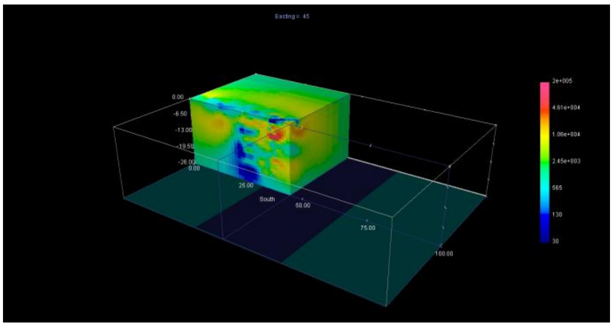

Fig. 4 3D inverse model sliced to highlight low resistivity/high porosity zone viewed from nominal NE direction.

CONCLUSION

Interpretation of 2D and 3D ERI investigations of the karst aquifer within the LSBB gallery indicate a zone of low resisitivity that is consistent with other borehole investigations. The ERI results show extension of low resistivity deeper to the south of the investigated volume which could be related to higher water content within the aquifer.

REFERENCES

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