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ERT for the Detection of Unmapped Underground Cavities

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SUMMARY

Electrical Resistivity Tomography was carried out in Vincennes Park, near Paris (France), above a former underground limestone quarry. One electric profile was placed on a well-surveyed zone of the quarry, and another on a reference zone thought as unexploited. On the former, a previously reported underground cavity (at 10 m depth) was found in our results. But in addition, a new larger cavity was identified on the reference section, illustrating the relevance of ERT for locating shallow cavities.

In this paper, we illustrate the application of ERT and the difficulties in data interpretation in a case where the geometry of the cavity is relatively simple and well known, at least in part: the abandoned limestone quarry located under the Vincennes Park, near Paris.

Introduction

Shallow underground cavities, whether of natural origin or abandoned mines, quarries and tunnels, constitute one major risk in built areas (e.g., Bell *et al.* 2000). To locate them, characterize their geometry and assess the risk of caving, classical engineering methods such as systematic drilling are time and cost-consuming. Electrical resistivity tomography (ERT) is particularly suited for this kind of civil engineering issues, as it is sensitive to resistivity contrasts. Indeed, underground cavities often exhibit well marked boundaries, and the resistivity contrast between the void volumes and the surrounding rocks can reach several hundreds or thousands of ohm.m in sedimentary contexts.

Survey site

The “Carrière de la Brasserie” is located under the Park of Vincennes on the East of Paris, France below an upper layer of marls embedding thin limestone bands, one finds about five beds of coarse limestone separated by three thin layers of marls over about six meters. The high quality of this limestone made it particularly suitable for building and carving. Interestingly, this quarry has not been filled up to prevent from caving in after its closure since the overlying area was not built-up, contrary to numerous other quarries under Paris. Only a few locations, located below a building structure, were reinforced. Note also that the voids are not flooded, the water table being about 24 metres below the ground surface.

A map of the underground quarries in Paris and suburbs was compiled by Tissier in 1947 (revised version in 1968), but it might be incomplete since some parts of the quarry could have been inaccessible due to collapsing of some galleries after the closure of the quarry (Moiriat *et al.* 2000; Perrier and Richon 2010).

Methodology

On December 18th and 19th 2013, we installed two ERT profiles in such a way that the first one crossed a known cavity to assess the quality of the resistivity inversion, whereas the second profile was set in an assumed undisturbed area to be considered initially as a “reference medium”, i.e. a zone supposed free of cavity on the quarries maps. First ERT line is roughly oriented from south-west to north-east and second ERT line is oriented west to east, both along an existing path next to a water-filled artificial canal. The topographic slope is negligible. The number of stainless-steel electrodes was equal to 64 and the spacing between each to 2.5 meters (profile length of 157.5 m).

We used a Wenner configuration (i.e., equally-spaced, in-line electrodes A, M, N, B with A, B for injection and M, N for potential measurement) because first, it has better resolution than Schlumberger or dipole-dipole despite its smaller penetration depth (e.g., Roy and Apparao 1971; Barker 1989); and second, from the analysis of its sensitivity pattern (see for instance Dahlin and Zhou 2004) it is recommended for characterization of horizontal or sub-horizontal structures such as a quarry ceilings. We used all the possible Wenner combinations for the quadripole AMNB, which led to 651 values of apparent resistivity. The continuous current (50 mA) was injected and the voltage differences were measured with a resistivity-meter Terrameter SAS1000 coupled to a multiplexer ES1064e (ABEM Instrument AB, Sweden).

Processing and results

Data were processed using Res2DInv software with “robust” inversion parameter. This way of drawing the results does not require smoothing which can produce artefacts and thus might lead to inappropriate interpretations.

On figure 1 (top), we can see low resistivities comprised between 20 and 40 ohm.m at shallow depths, corresponding to the water table associated to the very close water-filled canal presence. We can clearly identify a homogeneous zone of high resistivities superior to 130 ohm.m highly contrasting with the surrounding limestone rock on the right, perfectly correlated to the presence of the quarry mapped since 1947.

Figure 1 (bottom) shows the same kind of results, with a shallow low resistivity zone corresponding to the canal influence, and a high resistivity contrast deeper below 10 m depth due to an unmapped cavity. We cannot tell the cavity height though, because of equivalence principle.

Figure 1 ERT line 1 data inversion results (top), ERT line 2 data inversion results (bottom).

Conclusions

Using ERT, we were able to detect a probable part of the quarry of Vincennes that has not been mapped to date. This illustrates the usefulness of the method for such geotechnical problems. It also underlines the necessary reassessment of the risk in the Park of Vincennes, with a systematic geophysical study of the unmapped zones. The presence of previously unknown cavities to the East of the quarry is not incompatible with the known history of the excavation. Indeed, the Eastern part of the quarry remains largely unexplored, because the accesses were closed for safety reasons or blocked by caving in. Therefore, our study justifies the interest to image those remaining unmapped quarries and their extent to identify the remaining unconsolidated voids presenting a collapse risk.

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