The Combined Use of Different Near Surface Geophysics Techniques and Geotechnical Analysis in Two Case Histories for the Advanced Design of Underground Works in Urban Environment: Rome Metro B and Torino-Ceres Railway

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Abstract

In the urban context of the Italian towns, both historical remnants (archaeological items, man-made cavities, buried walls, etc.) and underground geotechnical "anomalies" (cemented layers, pockets of low-density soils, presence of big boulders, etc.) can strongly increase the hazard risk associated to underground excavation in urban context (as collapse, surface subsidence, interference) or inappropriate choice of the excavation method. This consciousness has led the writers to work out a site-specific multi-investigation method, hereinafter explained through a couple of case histories. The first one considers the reconstruction of a man-made cavities map distribution along the anticipated alignment of the extension of Rome Metro B Line, with the use of GeoRadar and geoelectrical methods, calibrated through boreholes. The second case history is related to the recognition of poor-quality soils and possible cemented layers along the alignment of a new urban railway line in Turin, using a MASW survey and a seismic refraction tomography survey, both coupled with geotechnical investigations. In both cases, the combined use of geophysical and geotechnical investigation has guaranteed the identification of the possible main geohazards, fundamental basis for an appropriate tunnelling design and assessment of the related risk.

Keywords

Geophysics • MASW • Geotechnical investigations • Geohazards • Risk

190.1 Introduction

Too often project main goal and time-related concerns may distract designer and client from the boundary value problems, potentially leading to an underestimation of the so-called minor issues that in the end may turn out in major ones. In this sense, the knowledge of the geological–technical context must be intended as a key of success of the Design phase and not as an annoying formal step only because required by contract specifications or rules. As a consequence, the definition of the Design Geological and Geotechnical Model (DGGM) is the first and inevitable design goal, by which it is possible to achieve high level of sensibility about the underground space and to propose mitigation measures for the risks associated, both during the construction phase and during exploitation. Actually, geological uncertainties and the resulting risks in construction of great civil infrastructures are well understood. However, the use of a step-wise investigation approach in reducing these risks not always receives the deserved emphasis. In particular, a well-planned preliminary investigation can identify the possible hazards and thus deliver a high ratio of benefit to cost. In many designed works, which met severe problems during construction, it was found that often an inadequate model of ground conditions had been used, either because some geological features had been missed or overlooked during investigation or because its significance had been underestimated. This is especially true in case of

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underground works in urban areas where the interaction between the geological and geotechnical context with the excavation is dramatically critical and therefore more detailed studies are necessary.

Besides, it must be noted that common geo-investigation methods usually deal with single survey technique at once, both for practical reasons and costs control. In our experience, this approach has turned out to achieve benefits only in the short-term, as immediate saving of time and money. On the other side, in the long-term, this is not a pay-back winning strategy, because of the uncertainties left behind and possible unidentified geohazards that could lead to additional cost and time consumption higher than early savings.

For this reason, a multi-approach investigation method has been worked out, refined in the course of time, on the account of several past experiences, with the aim to achieve the best compromise among all the above listed aspects. Current results show, in short, that coupling geotechnical investigations and geophysics surveys, conveniently integrated in terms of mutual placing in space and time allows gaining high satisfactory level of geological-technical knowledge and time/cost optimization.

The illustrated approach has been consolidated from the experience of many successful completed projects, and has become a standard practice, as well explained by the two following case histories.

190.2 Case A—Rome Metro B Extension

The case history A is related to the definitive design of underground Metro Line B extension, in Rome, between Rebibbia and Casal Monastero. The metro line extension has involved the realization of three new underground stations and the C&C excavation of a double tracks single tunnel, 3,000 m length, between diaphragm retaining walls.

190.2.1 Geological Settings and Geotechnical Investigations

From a geological-technical point of view, superficial deposit are represented by recent alluvial and anthropic soils, with heterogeneous grain size distributions and maximum thickness of 24 m, overlying pyroclastic deposits mainly composed by aches and lapilli of volcanic origin. Into all the pyroclastic sequence gas pockets (also radon), as well man-made cavities are possible; specifically, Roman Age underground pits for building materials extraction can be expected in the *Tufo Lionato* and *Pozzolana* units (Funiciello et al. 2005; Ventriglia 2002).

Beside this, presence of archaeological ruins must be taken into account when excavating in Rome subsoil; previous bibliographic information highlighted from the beginning the possible presence of Roman ruins near the alignment sector, such as old road network, underground services (ancient sewers), cemeteries and thermal baths (Funiciello 1995).

Due to these main anticipated geohazards, all the entire design process has been eventually driven by the associated knowledge and consequent management, conferring to the investigations-based DGGM a key-role in case of high-stakes choices.

Geotechnical investigations, which the DGGM has been based on, consisted in boreholes, CPTUs (Seismic Piezocone penetration test) and lab tests, assuring complete geotechnical characterization and punctual stratigraphical recognition; on the other side, spatial continuity was missing, as well the possibility to identify cavities or ancient remains if not directly intercepted by boreholes. This is where integration with geophysics came in handy.

190.2.2 Geophysical Survey and Discussion

Geophysical survey have been carried out with the aim to map the subsoil in terms of anomalies that might be led back to possible cavities or buried remains, using the previous boreholes and CPTUs as calibration network, thus avoiding false positives, on one hand, and assuring continuity in stratigraphical reconstruction, on the other one. Two techniques have been adopted: Ground Probing Radar (GPR), with different antennas (with frequency of 25, 100, 200 and 600 MHz), specifically oriented to ancient remains detection within the very first meters below ground level (4–5 m), and Electrical Resistivity Tomography (ERT), more oriented toward cavities identification. In order to best address the ERT survey, a preliminary calibration test was conducted in a similar area in presence of a known cavity (archaeological park in Rome). The test was performed with the aim of get the typical resistivity values of the void in the tuff materials (the so-called digital signature) in order to easily recognize similar anomalies along the Project alignment. The test pointed out a strong contrast between the resistivity value of the tuffs (ranging from 100 to 200 ohm.m), and the resistivity values of the test cavity (>800 ohm.m,).

Speaking of specifications, GPR survey was conducted on the account of a regular grid all along the metro anticipated alignment, using three different antennas (100, 200 and 600 MHz). The clayey shallow deposits have slightly conditioned the survey results (strong attenuation on the radar signal), but on the whole the survey was able to reveal a lot of structures down to a depth of 4–5 m with the lower frequency antenna (i.e. 100 MHz). All the founded structures (detected in two directions) have been mapped and cross check with known underground utilities or with opening of nearby gutters. After this comparison, all the underground structures have been mapped as underground utilities or underground tanks and no archaeological remnants have been detected. These results have been critical in defining the final boreholes location to avoid unwanted interference with underlying utilities.

ERT survey was carried out all along the future metro path, with a longitudinal line of 3 m-spaced electrodes and overlapping among consequential lines (roll-along technique). The obtained results have always revealed very low resistivity values (lower than 200 ohm.m.) that can't be referred to cavities presence. The only relevant "anomalies" have been identified in alluvial deposit, in terms of high contrast resistivity (80–100 ohm.m spot compared with the surrounding 10–30 ohm.m average). Again, the geophysical survey has proved to be unique for preliminary assessment of the specific areas to be directly investigated through boreholes; in this sense, the resistivity anomalies turned out to be soil pockets of very loose silty sand (SPT = 1) then correlated to piping phenomena in alluvial soil underlying the main gullies.

190.3 Case B—Torino-Ceres Railway

190.3.1 Geological Settings and Geotechnical Investigations

The case history B concerns the Definitive Design of a metropolitan underground rail junction between Turin Rebaudengo existing station and Caselle Airport located in the North city area. The Project involves a new 2.5 km long tunnel, single tube, double tracks, with a section area of 54 m^2, to be excavated in C&C between diaphragms hydromill-excavated. From the geological point of view, the Project area is underlain by glaciofluvial deposits of *Rissian* age (Quaternary), mainly composed by sandy gravels, cobbles and blocks, occasionally with clayey or silty sand layers.

Even if apparently plain, yet Turin subsoil can present frequent anomalies, as highlighted in past experiences such as *Metro Torino Line 1* or the *Passante Ferrioviario*, namely:

- the cementation of glaciofluvial deposits, and its variability, relevant to excavation technique choice and cutters wearing in case of TBM or hydromill excavations;
- the presence of big blocks (diameter >1 m), hence difficulties during excavation;
- presence of very loose sandy, supposedly affecting the stability of nearing existing building and road, as well the safety conditions of the site equipment, machinery and vehicles, during the excavation.

Considering the possible geohazards listed above, geotechnical investigation have been planned consequently; specifically, common boreholes have been coupled with DAC tests, that is the automatic measurement of drilling parameters to evaluate the mechanical properties of soils, and namely the level of cementation, to be correlated to the soil shear resistance.

Again, in order to better address the investigation plan, final location of tests have been derived from the geophysical results, as showed below, with the aim to limit the number of drillings and placing them right where most effective.

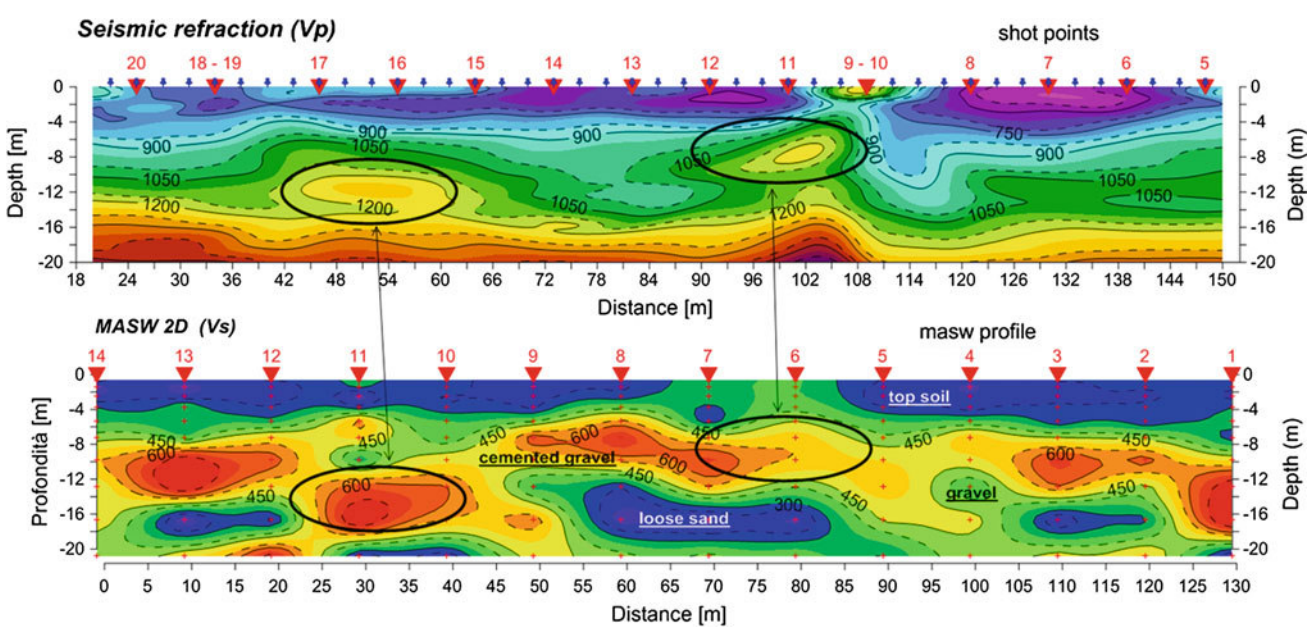

Fig. 190.1 Comparison between seismic refraction and MASW 2D section

190.3.2 Geophysical Survey

According to the objectives of the survey (subsoil profiling to locate cemented layers and loose sand pockets), two different geophysical methods have been applied: P-wave shallow seismic refraction and Multi-channel Analysis of Surface Waves (MASW) continuous profiling (2D section-shear wave velocities) (Park et al. 1999). The combined use of two different seismic methods provides both P-waves and S-waves velocities to estimate the main elastic properties of the soil and a cross-check to reduce the interpretative ambiguity for the DGGM. The results of the survey have provided a very detailed "image" of the subsoil, with some differences between refraction seismic and MASW 2D.

For the irregular distribution of low velocity and high velocity materials, the refraction seismic tomography method does not reveal correctly the geometry and morphology of the sedimentary lenses, while MASW2D methods provides a better resolution of the geometry of the alluvial sedimentary sequence (Fig. 190.1).

190.4 Conclusion

Owing to the anticipated subsoil peculiarities, neither single investigation tests nor separate geophysical surveys would have solved efficiently the risk associated to the possible geohazards affecting the designing of the urban underground works here described. For this reason, an integrated investigation survey has been worked out, coupling traditional geotechnical boring and tests with advanced geophysical surveys, compensating the reciprocal limits, in a complementary way: boreholes and CPTUs has reached the desired investigation depth assuring direct visual recognition and soil geotechnical testing; geophysical survey have fixed the gap between single site tests, which have act meanwhile as calibration point, improving the overall continuity and reliability of the DGGM.

This is how it works: reducing costs while increasing design quality and achieving final Project goals: a methodological approach that has become, for us, common practice.

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