

## ENGINEERING AND URBAN GEOPHYSICS TO MONITOR REINFORCED CONCRETE STRUCTURES

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**Introduction.** The use of reinforced concrete (RC) technologies into the engineering field of the building and civil infrastructures represent probably the most important discovery of the 19th century. At the same time the RC technology represents an economic way to realize building and for this reason in a large number of country has become the most used technology. In Italy, in the last decades, the structures realized with RC technology have exceeded those realized with technologies based on use of brick and stone masonry [1]. However RC technology is affected by very dangerous degradation phenomena that could be reduce strongly the life time of engineering structures. The real cause of this problem involving all the RC structures is due to heterogeneity of the material characterized by a mixture of concrete where steel rebar are placed depending on the need imputable mainly to mechanical stresses. So the interaction between steel and concrete is one of the causes that generates degradation. Among the different causes three are the one most detected and recognizable: a) corrosion for flow of chloride ions, b) cracks, fractures or delamination induced by mechanical stresses, c) voids or carbonation due to water or moisture (Apostolopoulos, C.A. *et al.*, 2013).

In addition to the degradation mechanisms (definable for simplicity as local problems) that involve the RC structures, other effects that could cause fails for the structures interesting the global behaviour of all engineering buildings included precast or realized in situ RC structures. This is the case of settlement foundations or seismic vulnerability or low bearing capacity of structures for obsolescence or age (Breyse 2012).

Geophysics can offer effective tools to aid engineers and public stakeholders to monitor and verify the state of conservation of RC elements subjected to “local” or “global” mechanisms of degradation. A novel sub-discipline, called Urban Geophysics, has recently been developing in the field of geophysics for analysing limits and potentialities of well-known geophysical techniques in urban and industrialized areas. The urban geophysics represents, most likely, the only way to characterize the subsoil ensuring a good resolution for the obtainable information and interfering little or nothing with the life of the investigated area. Unfortunately, not all the geophysical techniques are applicable in urban areas for the strong noise due to the presence of metallic structures or highly insulating layers (i.e. asphalt) that often limit the use of electrical and electromagnetic methods. However, good results are achievable with applications of electrical resistivity measurements and ground penetrating radar so much to investigate structural elements as to monitor the stability of civil structures (Capozzoli and Rizzo, 2016).

The paper presents some real cases where electric and electromagnetic geophysical tests are applied in combined mode to identify the possible cause of degradation of structures and some laboratory experiences where the usefulness of geoelectrical measurements (performed without use of classical and invasive electrodes) and ground penetrating radar has been tested to identify their effective contribution among non-invasive tests.

**Electrical resistivity technique and Ground penetrating radar for civil engineering issues.** ERT is a geophysical active method belonging to the resistivity techniques and is based on the introduction of direct current with a couple of electrodes inserted in the ground and the subsequent recording of the potential difference generated in the soil thanks to the passage of the electrical current. The theoretic basis of this well-known technique lies with the Ohm’s law and the target of this method is the localization of the electrical resistivity variations of the subsurface materials induced by the presence of anomalous bodies into the soil. Generally, a switched square wave is the current waveform used (Binley and Kemna, 2005) and an advanced “multimeter” called georesistivimeter is used to implement particular sequence for generating

the electrical. The data acquired are expressed in form of apparent resistivity ( $\rho$ ) and then they are interpreted in terms of real resistivity and depth by means of inversion software. The aim of the inversion procedure is to compute the 'best' set of resistivity values, which satisfies both the measured dataset and some a priori constraints, in order to stabilize the inversion and constrain the final image (deGroot-Hedlin and Constable, 1990).

GPR is an active geophysical technique based on the introduction of electromagnetic (EM) waves that, in presence of variation of EM impedance of the investigated medium, is able to identify scattering phenomena occurring in the subsoil. In detail variations of physical properties of the investigated medium as dielectric permittivity ( $\epsilon$ , F/m), electrical conductivity ( $\sigma$ , S/m) and magnetic permeability ( $\mu$ , H/m) are recorded as reflections characterized by a particular amplitude or phase. Variations of physical properties influence strongly the velocity of propagation of e-m waves and energy attenuation. Analyses of variations of velocity are used to create permittivity map according to the fundamental relationship for non-dispersive medium

$$v = c/\sqrt{\epsilon}$$

Where  $v$  in the propagating velocity of the material,  $c$  in velocity of em wave into the void ( $2.998 \times 10^8$  m/s) and  $\epsilon$  represents the relative permittivity of the material (Annan, 2005).

**Study Cases.** Two precast concrete buildings affected by settlement phenomena are studied with electric and electromagnetic techniques. In particular, in the first case 3D-ERT and GPR 2D radargram are used to identify the possible causes that have induced the deterioration of façade panels. In the second case, the use of only GPR and ERT 2D data has allowed to identify the possible cause of a settlement phenomena of a precast concrete bus garage. All the obtained data are constrained with direct measurements and have supported the interpretation of the geological models as showed for one study case in figure 1.

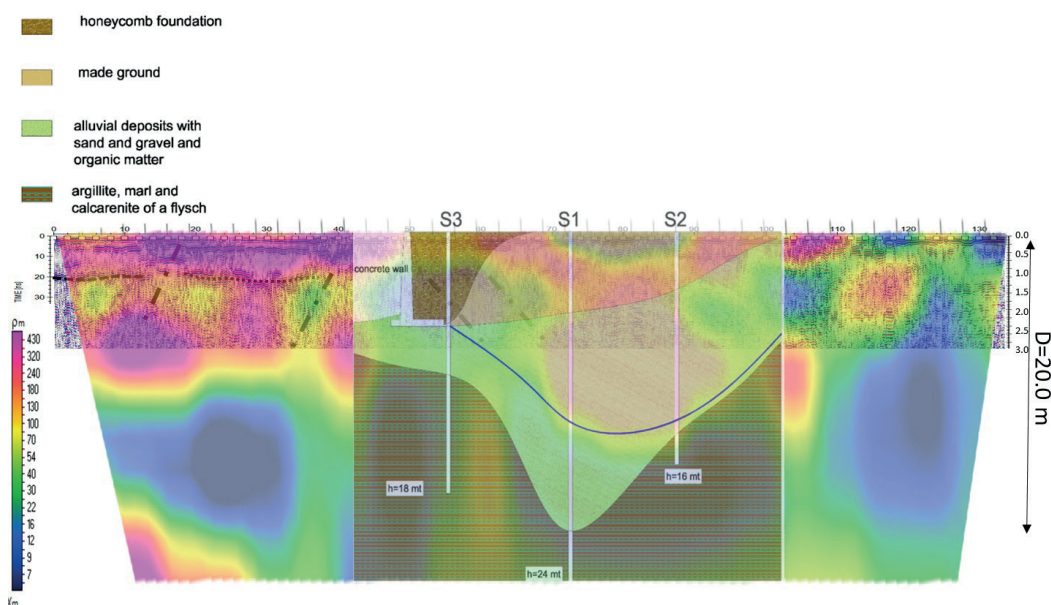


Fig. 1 - GPR and ERT corendered representation with overlap of geological model.

Geophysical investigations were realized with a multichannel georesistivimeter ABEM SAS-1000 that has provided to make acquisitions using maximum 64 electrodes distributed along 4 cables. An external source (a battery of 12 V) was adopted for the measurements. Further, to monitor real study cases, a series of drillings in the asphalt layer was performed before to insert the electrodes. For reducing the contact resistance between the electrodes and

ground and enhance the quality of measured data, the holes are also filled with a electrically conductive solution composed by clay (i.e. bentonite) and water. GPR radargrams were acquired near to the façade panels with a SIR3000 (GSSI Instrument) coupled to survey wheel and 400 MHz antenna.

Moreover, the uncertainties related to the geophysical data interpretation has pressured to reconstruct real elements of civil engineering RC structures to evaluate, in laboratory conditions the possibilities offered by GPR and ERT to reconstruct the behaviour of RC elements. With these purposes, two RC panels of limited size (1x1m) and a common RC structure composed by columns and beams with foundations (fig. 2) are realized and investigated with geophysical approach. A georesistivimeter Syscal Pro (IRIS-Instruments) connected to self-made cables was used to monitor RC structures and support GPR information acquired with antennas operating at different frequencies. The resistivity data measured in field are inverted with ERTlab and Zondres software while GPR data are processed with Reflex-w. Different types of electrode systems are used to minimize the invasiveness of the method and the results obtained have demonstrated a good capability of ERT for reconstructing engineering structures and supporting GPR results.

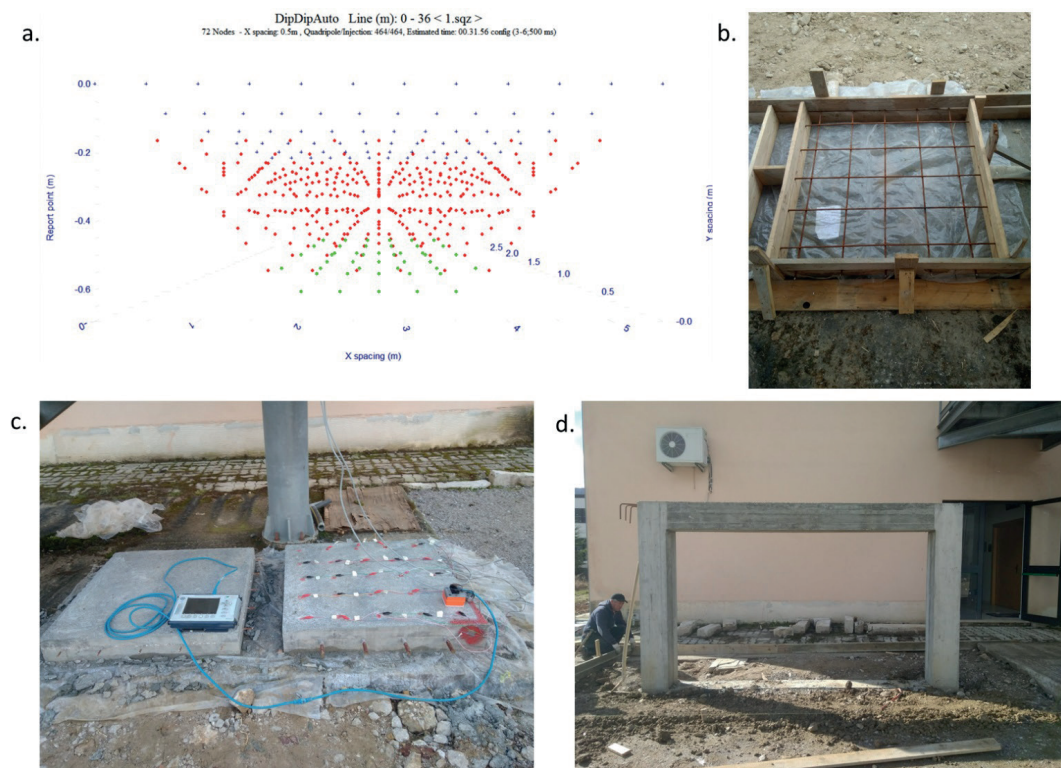


Fig. 2 - Laboratory tests investigated with a dense grid of resistivity measurements (a); a picture of the steel mesh used for reinforcement of the panel (b), where GPR and ERT measurements are achieved (c); finally the real scale RC structure realized at the Hydrogeosite IMAA-CNR Laboratory (d).

**Conclusions.** For the real cases analysed, results have identified some geophysical anomalies due to discontinuities of the subsoil or a different water content of the subsoil able to generate displacement for foundation structures or not structural elements. The results obtained in laboratory experiences have showed the difficulties for the reading and interpretation of geophysical results, inherent to the electrical and electromagnetic complexity of the behaviour

of concrete structures. However, the comparison and integration of the two techniques have anyway demonstrated the capability and the effectiveness of the adopted techniques to investigate reinforced concrete structures and phenomena occurring during the phase of hardness.

Engineering Geophysics represents a valid support to characterize RC structures. Among the various type of techniques, electric and electromagnetic methods can give a optimal contribute for identifying defects and degradation phenomena without interrupt building operability. In the investigated cases, real and laboratory case studies, the integration of GPR and ERT have effectively provided to monitor buildings affected by settlement phenomena. As regarding real cases, presence of high conductive and highly e-m energy attenuating zones have confirmed the presence of not compacted areas and not operating drainage systems. Further, the laboratory experiences have unequivocally showed the great possibilities to analyse RC structures with resistivity methods.

In the future corrosion induced artificially thanks to the use of electric generator will be analysed with use of GPR and ERTs supported by other resistivity techniques able to describe physical variation due to decay phenomena.

### References

- [1] XXV RAPPORTO CONGIUNTURALE E PREVISIONALE CRESME, Lo stato del territorio italiano -insediamento e rischio sismico e idrogeologico per gli anni 2012-2013-2014
- Annan A P (2005), Ground-Penetrating Radar. Near-Surface Geophysics: pp. 357-438. Eisbn: 978-1-56080-171-9 print ISBN: 978-1-56080-130-6 <https://doi.org/10.1190/1.9781560801719.ch11>
- Apostolopoulos, C.A., S. Demis, V.G. Papadakis Chloride-induced corrosion of steel reinforcement – mechanical performance and pit depth analysis Constr. Build. Mater., 38 (2013), pp. 139-146
- Breyse D. (ed.), Non-Destructive Assessment of Concrete Structures: Reliability and Limits of Single and Combined Techniques, RILEM State-of-the-Art Reports, DOI 10.1007/978-94-007-2736-6\_1, © RILEM 2012
- Capozzoli L, Rizzo E, Combined NDT techniques in civil engineering applications: Laboratory and real test, Construction and Building Materials, Volume 154, 15 November 2017, <https://doi.org/10.1016/j.conbuildmat.2017.07.147>
- deGroot-Hedlin, C. and Constable, S. (1990), Occams' inversion to generate smooth, two-dimensional models from magnetotelluric data, Geophysics, Vol. 55, No. 12, p. 1613-1624.