GEOPHYSICAL CHARACTERIZATION OF URBAN UNDERGROUND OF THE AVIGLIANO TOWN (SOUTHERN ITALY)

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Introduction. An renewed awareness of the urban subsoil as energy resource or as a space for hosting infrastructures has recently been growing (Mielby *et al.,* 2016). Improved exploration, characterization and modelling approaches are required in line with this view (Showstack 2014). Thanks to the diverse range of mature exploration methodologies, applied geophysics holds a valuable potential for the collection of spatially distributed data that can be both combined with each other and with data derived from direct surveys. A wide variety of environmental and engineering issues has already been tackled and solved by means of geophysical-based approaches, especially in rural areas. In fact, the urban environment imposes strong constraints not only on invasive direct surveys, which still provide valuable indications although limited in terms of spatial scale (Lapenna 2017), but also on geophysical surveys, in terms of data quality deterioration and logistics. Nevertheless, geophysics has already been applied in urban contexts to assess site amplification effects (Mucciarelli *et al.,* 2011), to estimate the fundamental frequencies and damping of buildings (Gallipoli *et al.,* 2009), to detect shallow cavities in historical areas (Piscitelli *et al.,* 2007), to delineate fracture zones (Mehta *et al.,* 2017), to detect causes of subsidence effects (Solari *et al.,* 2017) and to monitor subsurface leakage in industrial/nuclear areas (Kuras *et al.,* 2016).

In the framework of an agreement between the Institute of Methodologies for Environmental Analysis (IMAA) of the Italian National Research Council (CNR) and the Soil Protection Office of Basilicata Region, a methodological approach successfully applied by other authors in rural context (Perrone *et al.,* 2006) is here tested in a urban environment with the aim to support the diagnostic and monitoring of instability phenomena affecting the Avigliano (PZ) town (Basilicata Region, southern Italy). The approach is based on a top-down philosophy where satellite and ground-based techniques are applied in a coordinated way.

Materials and Methods. The urban area of Avigliano and the surrounding areas are heavily affected by ancient and recent multiple and complex roto-translational-earthflows, periodically undergoing to partial or total reactivation. Moreover, heavy damages to buildings and facilities in the urban area are caused by significant instability phenomena affecting the most superficial and altered layer of sands formations or slope debris layer abundantly reported the area. In this paper the focus is on the sector located near Via Roma (40.729608 N, 15.719757 E) which has long been affected by such phenomena, due to differential failures of detrital nature of the material used to fill an old channel (Fig. 1).

In order to achieve a characterization of the site as accurate as possible, a top-down approach was applied by using a suite of geophysical methods. Firstly, satellite SAR data, for the period march 2012-september 2015, were analyzed by means of the Small BAseline Subset (SBAS) differential interferometric (DInSAR) algorithm (Bonano et al. 2012) to highlight the superficial deformations at a larger scale. Then, between June 2016 and February 2017, the following in-situ geophysical survey methods were applied (Fig. 1):

- N. 5 Electrical Resistivity Tomographies (ERT) using a Syscal Pro geo-resistivimeter (IRIS Instr.);
- N. 1 refraction seismic profile using a seismograph (Geometrics) with 14 Hz geophones (Geospace);
- N. 1 active seismic array Multichannel Analysis of Surface Waves (MASW) using a Geode seismograph (Geometrics) and 4.5 Hz geophones (Geospace);

Fig. 1 - [a] Sketch map of geophysical and geotechnical survey locations superposed to the geological map of the urban area of Avigliano (PZ). [b] accelerometer (SARA-Electronic Instruments SL06) used in the 'palazzo Mancusi' (AV2) along with photos of structural damages.

- N. 1 bi-dimensional passive seismic array, using a Geode seismograph (Geometrics) and 4.5 Hz geophones, processed with Extended Spatial Auto-Correlation (ESAC) technique;
- 15 single station seismic ambient noise measurements acquired by a 24 bit digital tromograph Moho-Tromino and analyzed with the Horizontal-to-Vertical Noise Spectral Ratio (HVNSR);
- local and regional earthquake recordings by accelerometers (SARA-Electronic Instruments SL06 with 1g full scale) in two sites analyzed by means of Horizontal-to-Vertical Spectral Ratio (HVSR).

A detailed description of the methods used is given elsewhere (Calamita *et al.*, 2018).

Results and discussions. From a qualitative viewpoint, the full resolution COSMO-SkyMed (CSK) SBAS-DInSAR velocity map (Fig. 2) do not show any significant deformation pattern, thus revealing a general stable behaviour of the entire urban area in the investigated period. However, some localized displacements of 3-4 mm/year are detected for some buildings and

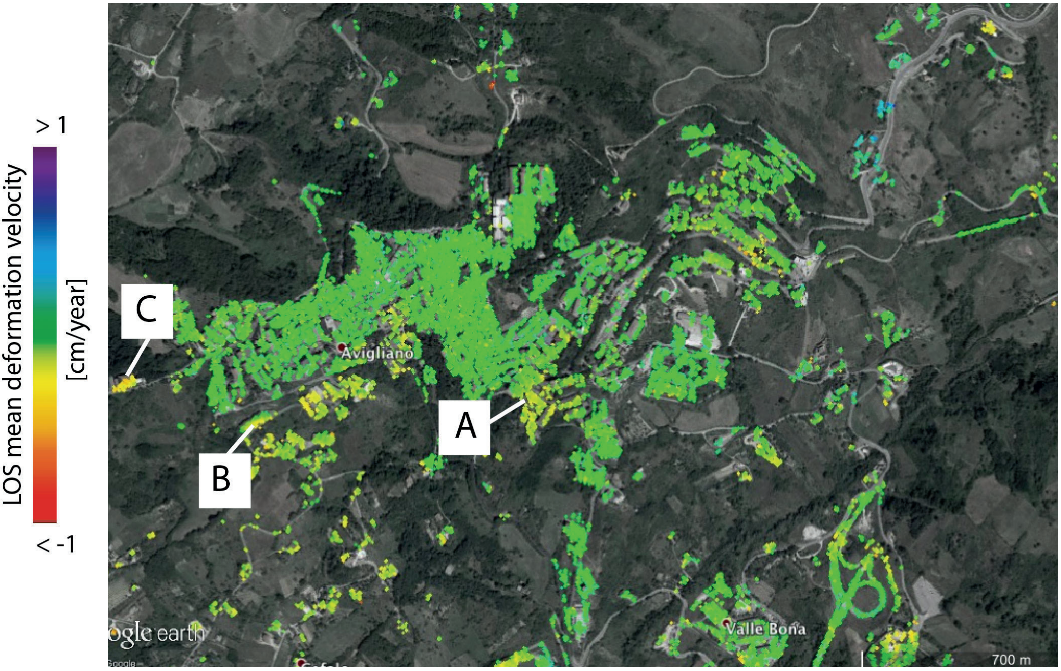

Fig. 2 - Full resolution SBAS-DInSAR processing of the X-band SAR dataset collected by the COSMO-SkyMed (CSK) constellation acquired from descending orbits between March 2012 and September 2015. Line of sight (LOS) deformation velocity map superimposed on an optical image of the investigated area.

isolated edifices located to the SE and SW of the urban centre (named A, B and C). A zoomed view of the full resolution deformation velocity map and the corresponding CSK deformation time series of the above mentioned area show a maximum deformation rate of ~5mm/year.

Geoelectrical (ERT) and seismic (active and passive) methods were applied in the deformed area A with the aim to reconstruct the litho-stratigraphic setting and to verify the geophysical characteristics of the subsoil in this urban sector. Although bentonite and salty water were used to improve the contact resistance of electrodes, preliminary analysis of the ERT highlighted the poor quality of the data due to the noise conditions typical of the measurements carried out in urban areas. Furthermore, the presence of underground services and man-made structures could have influenced the electric signal path, distorting the electrical field and providing some artefacts on resistivity distribution. The inversion of apparent electrical resistivity data of the ERT1, after a careful filtering, (Fig. 3) shows the presence of a concave shaped material with a relatively higher electrical conductivity (ϱ< 25 Ωm) in the shallow subsoil resting on a more resistive material (ϱ > 60 Ωm). While the relatively more conductive material exhibiting a thickness of about 15 m can be attributed to debris accumulation material (D) the underlying more resistive material is attributable to fine and silty sands, as described in the geological map (Fig. 1).

The litho-stratigraphic setting inferred from the ERT1 is confirmed both by the stratigraphy of the D10 survey and by the Vs profile, estimated by the inversion of dispersion curve provided by MASW (Fig. 3). Similarly to the electric contrast in the ERT1, the Vs profile shows an impedance contrast at about 15 m, i.e. between the debris accumulation material (Vs about 320-380 m/s) and the underlying sandy-silty unit (Vs about 620 m/s).The HVNSRs show two resonance peaks, at about 1.5 Hz and 2.5 Hz. As these resonance frequencies are present in all the estimated HVSR functions, both inside and outside the area affected by failure, it could be said that those constitute litho-stratigraphic properties of the investigated site. This suggests that

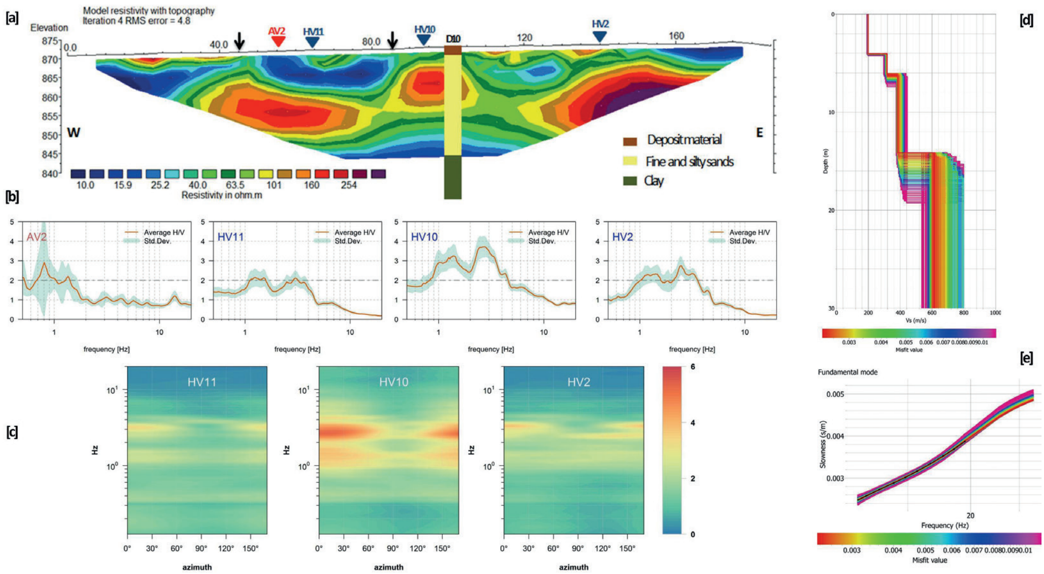

Fig. 3 - [a] ERT1 (first and last electrodes are located at 0 m and 185.5 respectively) with stratigraphic data (D10); [b] mean HVNSR (HV11, HV10 e HV2) and HVSR (AV2); [c] directional HVNSR, [d] the depth Vs profile and (e) the dispersion curve obtained by the MASW survey along Viale della Vittoria in the urban center of Avigliano (PZ, Italy). Black arrows point to the limits of the differential failures.

the 2.5 Hz frequency could be due to the contrast between the sands and underlying clays while the 1.5 Hz frequency could be originated by the clays and the bedrock which is characterized by the conglomerate unit. The directional analysis of the three HVNSR functions shows that both resonance peaks of the deformation phenomenon have a directionality of approximately 30° respect to the main axis of the deformation area. The HVSR function estimated in the area of the failure (AV2 in Fig. 3), from the analysis of earthquake recordings on the ground floor of the building affected by the structural damage, do not show any particular resonance peaks. It is therefore assumed that the presence of substructures and containment works in the area below did not allow a correct estimate of the site seismic response.

Conclusions. The approach proposed is based on the integration of satellite and in-situ geophysical techniques. The top-down philosophy adopted proved to be suitable to locate sites affected by ground deformation and to reconstruct the litho-stratigraphic and geometrical details in the investigated area. Minimum invasiveness, low costs and rapidity of the measures represent an added value of the proposed approach. The lack of indications regarding the possible causes of the processes causing the ground deformation made not possible to verify whether the deformation was due to the compaction of filling material or to a hydrogeological phenomenon. A better understanding of the processes involved would require the acquisition of additional information, such as piezometric and inclinometric measurements, rain-gauge data, etc.

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