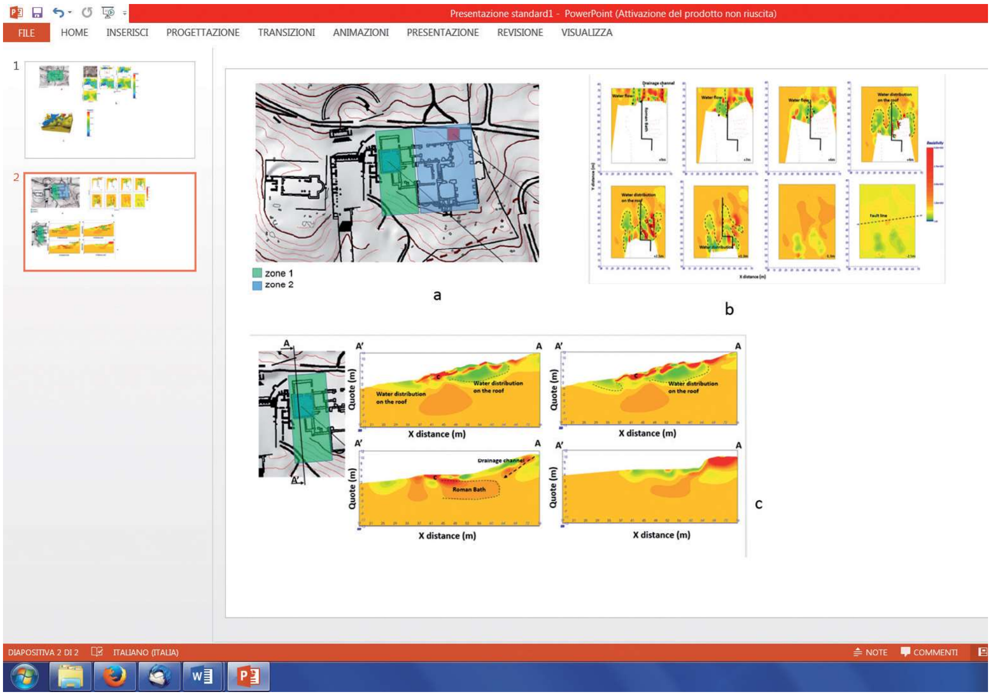

Fig. 2 – a) ERT surveyed areas; b) 3D electrical resistivity distribution in the subsoil; c) 3D electrical resistivity distribution crossing the roman bath.

results show zones on the vault where the water stagnates. In these zones, the stability analysis showed a probability of collapse that could occur within 2 years.

Given the low values of the self potentials, the water flow velocity is fairly reduced. The flow velocity likely increases during the rainy season thus increasing the danger of collapse. Another problem linked to the presence of water is related to the formation of ice during the winter. In the zones of water stagnation, this phenomenon leads to an increase in the volume of water and consequently to an increase of the probability of collapse.

NEAR SURFACE SEISMOSTRATIGRAPHIC MODELLING OF THE BANDITA PLAIN IN PALERMO TOWN (ITALY) FROM INTEGRATED ANALYSIS OF HVSR AND STRATIGRAPHIC DATA

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Introduction. The Horizontal to Vertical Spectral Ratio (HVSR) noise method (Nakamura, 1989) is nowadays widely used to estimate the resonance frequencies of geological structures (Bonnefoy-Claudet, 2006). However, often HVSR is also used to obtain information on the depth of the seismic bedrock and on thickness and seismic velocity of the process overburden deposits, using inversion techniques of the H/V curve (Fäh *et al.*, 2003). This nevertheless produce results with large uncertainty intervals of parameters, and then must be necessarily constrained by detailed stratigraphic information. An application of HVSR inversion is presented in order to verify the effectiveness of this technique for purposes of reconstruction of the buried geological setting where stratigraphic constraints are available.

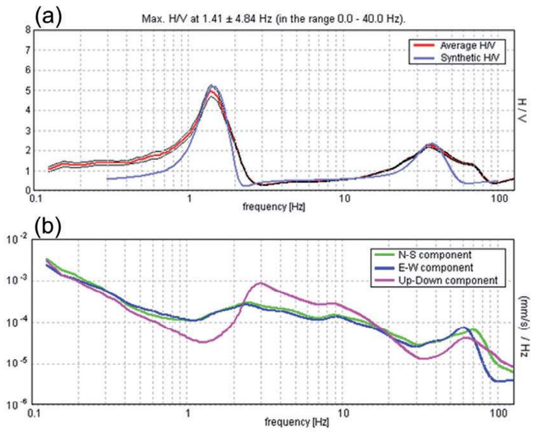
The study area lies in the south-eastern zone of the Palermo plain, known as “Bandita”. It falls within the geological context of the Monti di Palermo (Abate *et al*., 1978), resulting from the superposition of structural-stratigraphic units arising from the Miocene compressive deformation of limestone and dolomite shallow-marine deposits (Panormide Platform), and Mesozoic limestone and siliciclastic deep sea deposits (Imerese Basin), with overlying Oligo-Miocene terrigenous covers (Numidian Flysch).

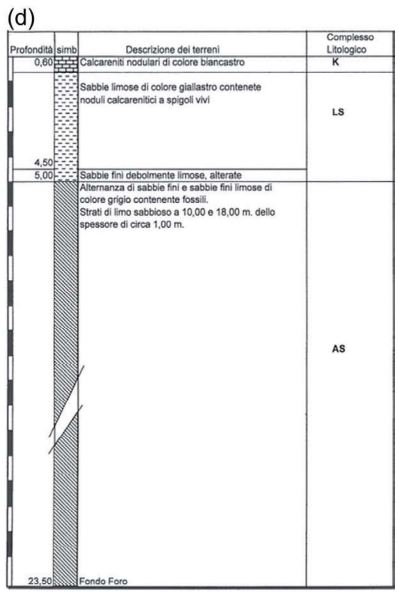
Specifically, the reconstruction of the stratigraphy in the studied area has been obtained by a seismic-stratigraphic three-dimensional modelling. This allowed for geophysical and geognostic data derived from surveys carried out during this study, as well as previously by the municipality of Palermo.

Lithostratigraphic characterization by geognostic drillings. The reconstruction of the lithostratigraphic successions was based on previous knowledge arising from 93 available stratigraphic logs, randomly distributed in the zone, with maximum depth of 30 m below ground level.

The analysis of this information allowed to define the quite articulate geological and lithostratigraphic setting of the area. This is characterized by the extensive presence of calcarenite-sand complex of the lower-middle Pleistocene, (Calcarenite di Palermo). This in the western sector rests on gray-blue clays of the Lower Pleistocene and in the eastern sector discordantly on the Numidian Flysch.

By analyzing the collected stratigraphy, a reclassification of lithological samples was made, considering five main groups: sands and limestones (K+S), silts and sands (As), sands and sandy gravels (Ls), backfill (Dtr), marl and clay (FN). The pre-Pleistocene sedimentary basement, characterized by Numidian Flysch is not evenly distributed throughout the area. The roof of the flysch deposits is found at depths varying from 15 to 30 m. Particularly in the eastern part the depth is considerably greater near the coast than the inland areas. In the western part instead,





(c)

Depth bottom [m]	Thickness [m]	Vs [m/s]	Poisson ratio
1.50	1.50	220	0.39
5.30	3.80	425	0.38
71.30	66.00	390	0.40
inf.	inf.	930	0.35

Fig. 1 – Example of inversion of HVSR curve, constrained by a lithological drilling: (a) theoretic and experimental HVSR curve; (b) three component velocity spectra; (c) interpretative geophysical model; (d) lithostratigraphic data.

there is no evidence of the flysch complex, probably because its depth in this part would be greater than those of the stratigraphic logs. In that sub-area, the prevailing lithology achieved by drilling are the Pleistocene grey-blue clays, present in almost all considered logs, except for those located in a restricted eastern area (Catalano *et al.*, 2013).

Execution and interpretation of HVSR measures. Between December 2015 and January 2016, 49 single-station microtremor measurements were carried out, in coincidence with or in the immediate neighborhood of the stratigraphic surveys, so as to link the HVSR inversion to the thicknesses of layers investigated by logs, allowing to characterize the seismic velocity of near surface deposits (Fig. 1). Most of the HVSR curves have clearly identified peaks, according to the SESAME criteria (SESAME, 2004). Anyway some curves have not entirely clear peaks (H/V ratio not higher than 2) but they are however considered likely to occur resonance effects, starting from a comparison with the log stratigraphy.

Near surface stratigraphic and seismic modelling. The stratigraphic and seismic modelling was carried out with the help of Rockworks 15 software, by creating a geo-referenced database of lithological and seismic data relating respectively to geognostic logs and inverse models from HVSR curves. The data thus organized were interpolated with geostatistical analyses to build discrete 3D models, represented successively by means of sections and fences (Figs. 2 and 3). The parameter used for the seismic modelling (2D and 3D) is the shear waves velocity Vs. For the lithological modelling instead, the lithological data were considered according to the above cited reclassification. In particular, the 3D model of Vs velocity was used to derive vertical sections with depth of 150 m b.s.l. but also more detailed sections till a more limited depth of 30 m.

Discussion of results. To verify the reliability of the 3D models developed, 2D sections were extracted in areas with large numbers of data in order to create a highly reliable distribution of the various layers. Two of these sections are parallel to the coastline in approximately ENE-WSW direction and two ones are transversal.

From comparative analysis of the 3D models we note that the most superficial portions (1.5-2 m) in the western zone are characterized by seismic layers with low density and poor mechanical properties. This is confirmed by low shear waves velocity values (about 200 m/s). This first seismic layer is attributable to the overburden. Stratigraphic data confirm that approximately at depth of 2 m there is the transition between the incoherent deposits represented by the overburden and the calcarenite-sand complex, characterized by Vs about 350-430 m/s. In the western area at about 8-10 m depth from the ground level is evident a decrease of Vs characterizing the transition to a less rigid lithotype. This limit corresponds to the transition

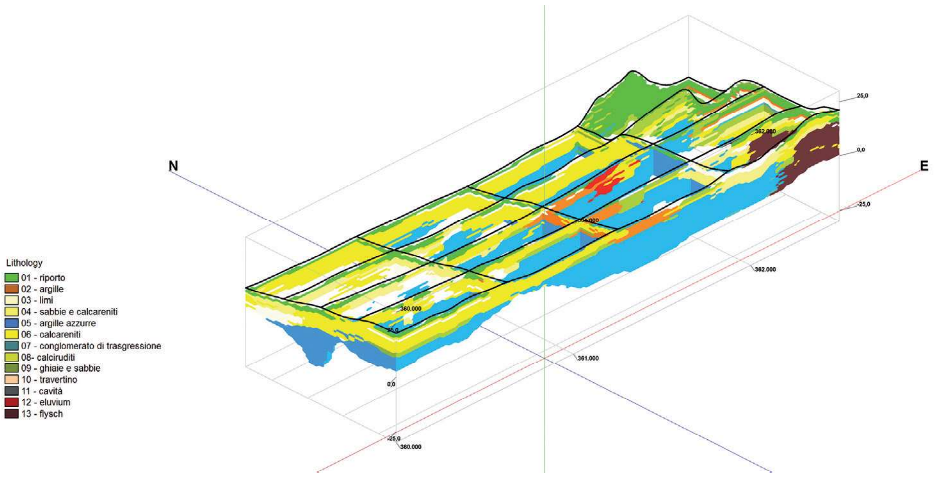


Fig. 2 – Representation by vertical fences of the lithological model of the Bandita plain (Palermo).

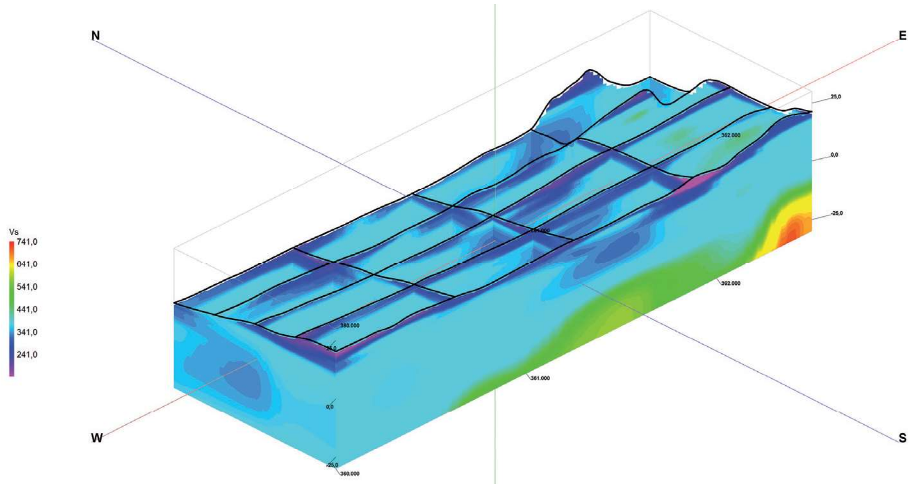


Fig. 3 – Representation by vertical fences of the shear waves velocity model of the Bandita plain (Palermo).

between the lithological calcarenite-sand complex and underlying grey-blue clays. In the eastern area, in contrast, there is a greater lithological variability demonstrated by the marked changes of Vs values. In particular, under the low velocity near surface layer Vs amounts to about 350-450 m/s. This can be attributed to the calcarenite. The underlying layers instead, are characterized by moderately higher Vs values (500-550 m/s), corresponding to Numidian Flysch. In this sector it is well evident the tectonic boundary between the grey-blue clays, present in the western zone, and limestone and flysch, in the eastern one.

For more details on seismological analysis, seismic sections spanning a greater depth range (150 m depth under sea level) have been extracted from the 3D seismic model. These seismic sections show a high increase of the shear wave velocity Vs in depth, interpreted as the presence of a seismic bedrock (Vs>800 m/s) due to the underlying Triassic carbonate formations.

Conclusions. Shear waves velocity values have been estimated by the HVSR inversion constrained by thickness of the near surface layers detected by lithological logs. The constrained 1D inversion of HVSR curves and bi- and tri-dimensional seismic and lithological modelling by interpolation of geophysical and lithological data allowed to obtain for each seismic layer the variability of shear waves velocity Vs related to the physical-mechanical properties.

This process of joint correlation and interpretation has therefore allowed to obtain a high detailed seismostratigraphic model of the studied area.

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