Scientifica Acta **2**, No. 2, 39 – 43 (2008)

Earth Sciences

The use of single station microtremors for the local seismic hazard assessment: an example in northern Apennine

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In this work are shown different phases needed for the local seismic hazard evaluation of test site of Varzi, northern Apennine, Italy. This area has been divided in a preliminary step into morphologic units through photo interpretation and direct survey. Than, the subsequent collection of subsurface data and accurate terrain survey has permitted to discriminate different engineering-geologic homogeneous units. A 3D model of the subsurface has been than created through specific software. In association to this phase several surveys of ambient noise has been made in order to define the proper frequency of soils, and to verify the applicability of this technique to the geological context of the area, other than define possible correlations with classical probing methods.

1 Introduction

Shallow soil deposits can have a great influence in ground motion amplification and it is necessary to include such effects in earthquake scenarios [1]. In the same context, the fundamental resonance frequency of the soil is an important parameter in these studies as the vulnerability of buildings and infrastructures is directly connected with their own resonance frequency.

The aims of this work were to verify the applicability of microtremors technique in the Apennine geological context, to compare this technique with classical geological and geotechnical methods of survey, and to estimate the local seismic hazard.

Ambient noise recordings and numerical analysis of the ground. were used to estimate the local ground response in terms of fundamental resonance frequency and the amplification of the shallow soils.

2 Geological setting

The urban area of Varzi, located in the Oltrepo Pavese (Northern Italy) was chosen as test site and it can be considered as geologically representative of a large part of the Northern Apennines. The downtown of the city has an area of 4.5 km^2 and is mainly located on the right side of the Staffora River (tributary of the Po river). The most important tectonic structure is the Villalvernia-Varzi Line (VVL). The VVL, defined as a dextral transpressive system [2], separates two structurally quite different areas. In the south, the Tertiary Piedmont Basin (TPB) is represented by upper Eocene - lower Miocene sedimentary sequence with a synclinal structure. In the north, where is located the urban area of Varzi, the Voghera Apennine is characterised by the presence of deformed sedimentary sequences of lower Cretaceous to Pliocene age. The VVL is probably connected to past tectonic activity [3]. The most important seismic sequences (1828 and 1945), are between 5th and 8th grade of intensity on MCS scale. The geomorphologic setting of the area is controlled by the geological and structural conditions and the landscape evolution is essentially controlled by mass-movements (translational and rotational slides evolving into earth flows). The bottom of the valley shows three levels of alluvial terraces and fossil alluvial fans belonging to the main tributaries of Staffora River. The thickness of the alluvial deposits varies from about 2 m to 15 m. Silty clay and clayey silty deposits constitute the first layer of alluvial deposits; the underlying layers consist, from top to bottom, of gravel and Tertiary bedrock (Chaotic Complex in the western sector and flysch formations consisting of alternating layers of clay shales with calcareous arenaceous marls in the eastern sector). Slopes in the argillaceous and marly successions are mantled with clayey colluvial deposits varying between 1 and 6m in thickness. Additionally, anthropogenic deposits up to 1-2 meters are somewhere present.

3 Subsoil geological model

The thickness of shallow sediments (colluvial and alluvial soils) could largely influence the site response in case of an earthquake. Therefore a detailed knowledge of ground conditions is essential to compute and analyse the site response. Data regarding the geology, geomorphology, hydrographical network, urban development and history of the town were used to develop a geological/geotechnical model of the subsoil of Varzi. In the first step the landforms (alluvial terraces, alluvial fans, landslides, etc.) were mapped from aerial photographs. In the second step each landform was investigated through the collection and analyses of geological, geotechnical and geophysical data (boreholes, water wells, trench pits, CPT, DCPT tests, geophysical data), in order to subdivide the landforms in homogeneous engineering-geological units (areas that may be regarded as homogeneous from the geomorphologic and engineering geological point of view). The following criteria have been used for discrimination of such units: lithology of the bedrock, (lithology, thickness, structure, hydrogeological and geotechnical characteristics of the colluvial and alluvial soils), the geometry (thickness of the different soils, spatial relation between the strata, etc..). Landforms with large variation of these properties were subdivided in engineering-geological units; landforms with a certain degree of homogeneity became directly engineering-geological units. 13 different engineering-geological units were identified, for each of them representative lithological profiles were constructed (Figure 1).

The validated and simplified data were implemented in GSI3D™, a program for 3D modelling and visualization of subsurface. GSI3D™ utilizes a Digital Terrain Model, geological surface linework and subsurface data to construct regularly spaced intersecting cross sections by correlating probes and the outcrops-subcrops of units (in our case, homogeneous engineering-geological units boundaries) to produce a geological fence diagram of the area (Figure 2).

Only some of the most representative units were also geophysically investigated through MASW survey. The amplification factors were estimated both by abacuses and by the numerical code SHAKE. Values obtained are ranging between 1.3 and 2.1 demonstrating that also even in presence of shallow covers is possible to find significant values of amplification.

4 Microtremors survey

Three survey campaign with a tromograph (Tromino®) provided by “Protezione Civile Nazionale”, (the national organism for civil protection) were made during different periods of the year, in order to derive a map of the fundamental frequency of resonance of the ground from single station recordings of ambient vibrations at first. The measured values were used in order to make a comparison with the subsoil model, assuming that resonance frequency values of site can give a qualitative idea of cover thickness.

It is a rather cheap method, relatively easy to set up in urban area and really low time consuming. Ambient noise is a low amplitude ground motion coming from artificial surface sources as traffic and human activities, but also from natural sources as wind-structure interactions and longer period oceanic waves and currents. There are different methods to use ambient noise, but the most useful and reliable is the H/V method [4]. The ratio between horizontal vs. vertical component of noise motion, is recognized between scientific community to be a reliable tool to determine the main resonance frequency of a site. The measurements have duration of 20 minutes each at a sampling rate of 128 Hz [5].

Results of the first campaign, had been sometimes quite unclear and difficult to understand. In fact, only after the third campaign and many measures (about 85) it had been possible to recognize some peculiar behaviour of different geologic units. It was rather clear that the difficulty in interpretation of some signals,

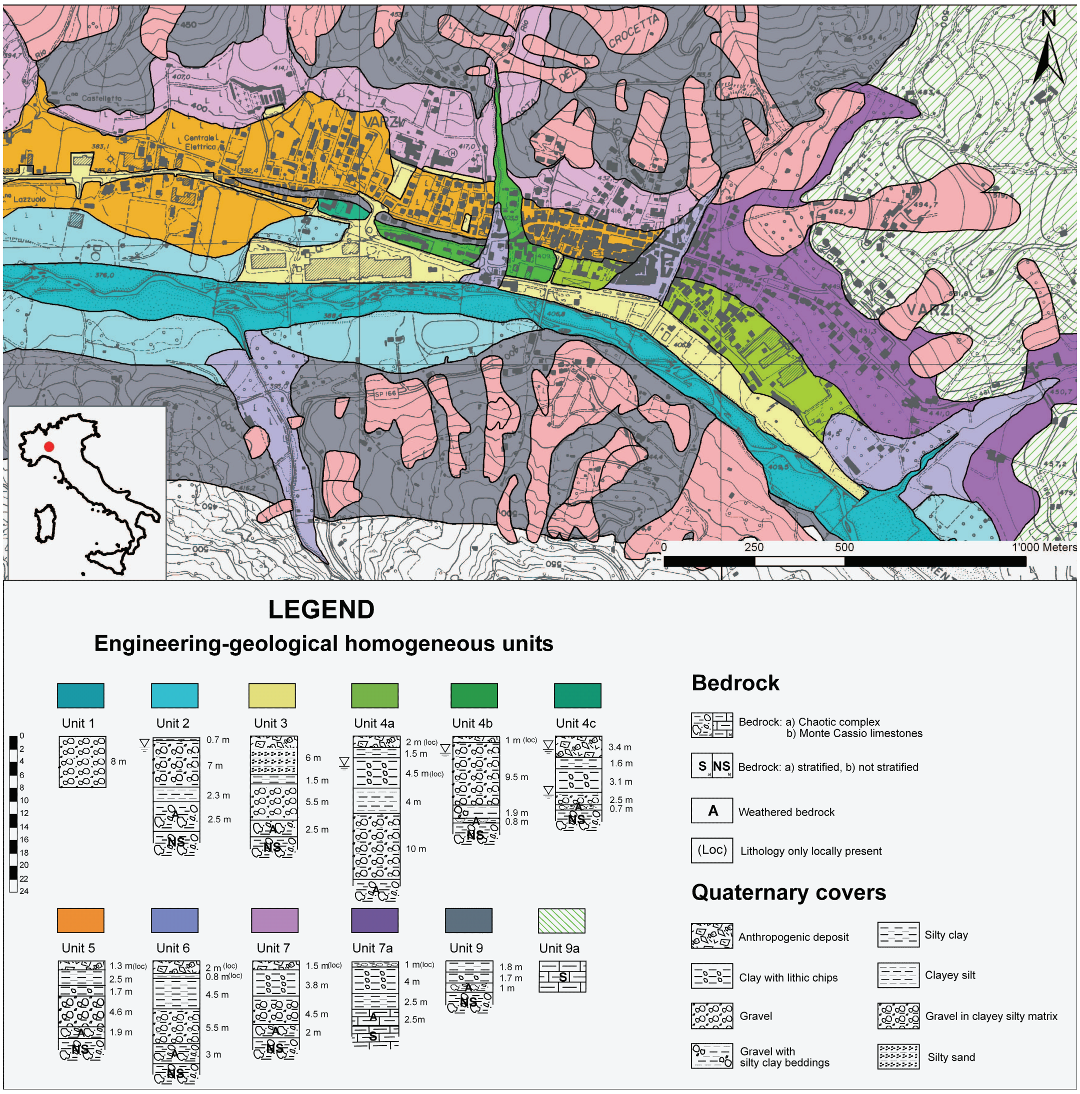

Fig. 1: Subdivision of Varzi municipality into engineering-geological homogeneous units and relative legend.

was due to the nature of the two different bedrocks characterizing the whole area. Unclear signals were almost surely due to a low impedance contrast of the bedrock known as “Chaotic complex”.

By the comparison of all the measures made on outcrop bedrock sites it was clear that measure made on Monte Cassio limestones were proper of a “real” bedrock (Figure 3 b); on the contrary measure made on “Chaotic complex” displayed a bedrock-like behaviour, but with a characteristic “disturbance” of the signal from the flat, between 2 and 10 Hz, in nearly all the measures (Figure 3 a).

This hypothesis was also confirmed by several surveys made on the same geological formations, some kilometres far from the studied area. Measures made on the “Chaotic complex” outcrops always displayed similar disturbances.

Stated this, it was possible to proceed to a much clearer interpretation of the measures done in the rest of the area characterized by quaternary covers.

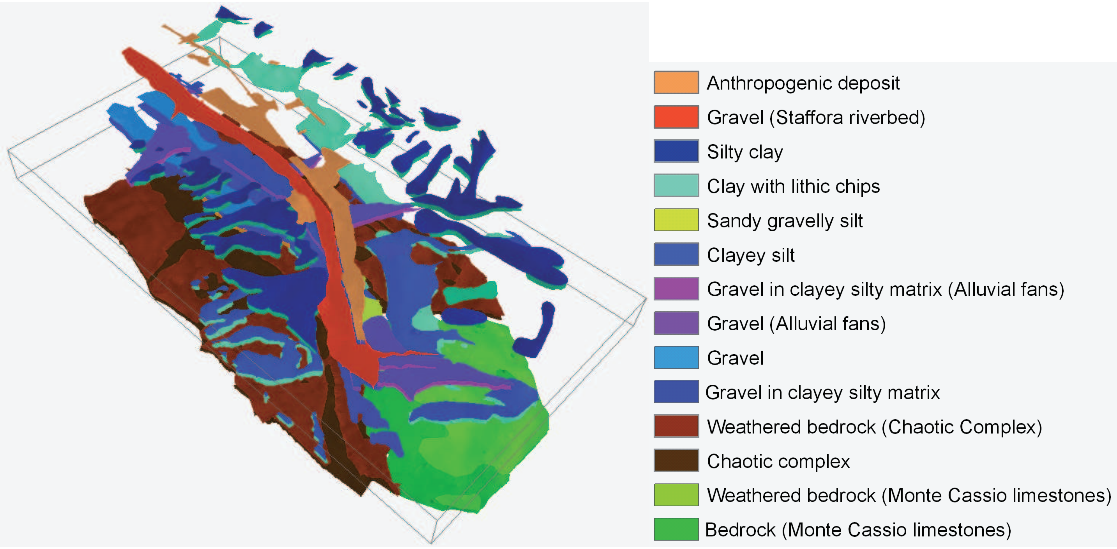

Fig. 2: 3D subsurface model of Varzi downtown.

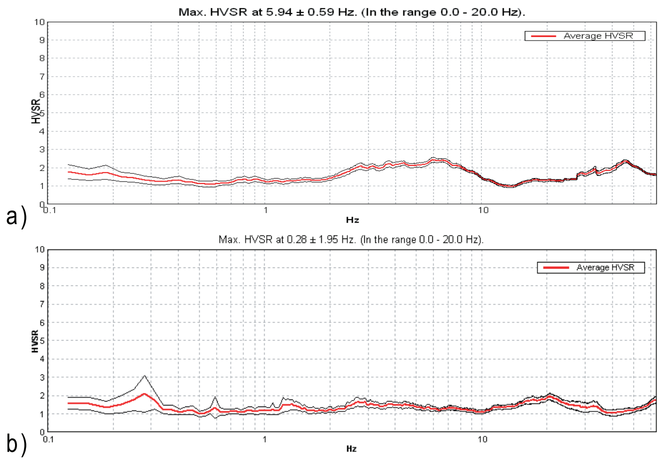

Fig. 3: HVSR trend of one of the most representative measures made on a "Chaotic complex" outcrop (a) and on a "Monte Cassio" limestones outcrop (b)

From this survey it was possible to identify three main zones belonging to three frequency ranges below 20 Hz: 3-5 Hz, 5-8 Hz and 8-20 Hz, and flat spectrum.

Interesting is also the fact that big part of the centre of Varzi is in correspondence of 4 Hz frequency, a dangerous value regarding the double resonance phenomena for relatively low buildings such as the most of the structures characterising the downtown.

Having in mind that is possible to assume that resonance frequency values can give a qualitative idea of cover thickness, the trend obtained with microtremors measurements is qualitatively good matching with the trend of cover thickness directly obtained with geotechnical probes.

5 Conclusion

We stated that the trialled technique is a powerful tool for a first and fast estimation of site conditions especially when is necessary to establish where and how much is important to improve subsoil characterization in a relatively short time and economic way.

However, it is clear from what exposed how, particularly in such kind of analyses, is important to have a good *a-priori* knowledge about local geology and that for particular conditions there is a need of more and aimed measures before coming to a final and accurate conclusion.

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