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Ambient noise HVSR measurements in the Avellino historical centre and surrounding area (southern Italy). Correlation with surface geology and damage caused by the 1980 Irpinia-Basilicata earthquake

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ABSTRACT

The article deals with the results of extensive surveys conducted in the town of Avellino, in southern Italy, with the aim of studying the site seismic response. Avellino is a town located in the Apennine Chain in Irpinia, which is a region characterized by a high seismic hazard. Several strong earthquakes hit the town in the past, the last of which occurred on 23 November 1980 (M_w = 6.8). In the last decades since that event, background low magnitude seismicity persists, including few moderate earthquakes. In order to analyse the site seismic response, our data set was made up by borehole and downhole records, ambient noise measurements both in free-field and inside buildings, and macroseismic data related to the 1980 Irpinia-Basilicata earthquake. With the intention of ascertaining the occurrence of resonance effects influencing the distribution of the earthquake damage, we performed a correlated analysis of all the data acquired.

HVSR free-field peak frequencies, joined with the data obtained from previous surveys [22], agree with the computed 1D resonance frequencies and are in the range between 1.6 and 13.0 Hz. The resonance frequencies for fifteen typical buildings in Avellino, which were partly estimated from ambient noise measurements and partly by applying the Italian regulation code, are in the range between 1.2 and 4.6 Hz, so showing that soil-structure resonance effects can be generated in a wide area of the town. Finally, we drew up a detailed damage map, related to the 1980 earthquake, which affected Avellino seriously. From our research two aspects come to light. The first regards the fact that soil-structure resonance effects can be generated in the town and were possibly associated to some buildings damaged by the 1980 earthquake. The second concerns the circumstance that the amplitudes of HVSR peaks correlate well with the rock/soil velocity contrast at depth, but do not show a relationship with the earthquake damage pattern.

The results of this study will be useful in view of putting into the field suitable risk mitigation countermeasures.

1. Introduction

As it is well known, Italy is rich in places having significant historical and artistic heritage. However, many sites are located in areas affected by natural hazards such as earthquakes, landslides, and floods. The southern portion of the Apennine chain is among the main geographical-geological domain where these phenomena are recurrent. Considering the earthquakes, if we look at the seismic hazard map of Italy, we can see how the highest expected values of ground motion acceleration are just along the Apennines and Calabrian Arc belt (http://esse1.mi.ingv.it/d2.html, last access 29 July 2018). The Avellino town is located in this seismic hazard background, in the southern Apennines. The town, where 55,000 inhabitants live, is in the Campania region, about 50 km east of Naples, and it is sited in a plain surrounded by the Apennine reliefs.

The first settlement of Avellino was built in the early Middle Age on a tuff outcropping over the middle of the plane. The town has undergone many rebuildings in consequence of the earthquakes that have hit it over the centuries. Several monuments are in the town, as the remains of a Lombard castle, the monumental churches,

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and the civil architecture, such as the Clock Tower, which is the symbol of Avellino from the Baroque period, the Dogana Palace (Custom House), and other monumental palaces.

With this in mind, the aim of this work is to apply a non-invasive survey methodology based on ambient noise measurements and macroseismic data. The aim is to supply useful tools to the stakeholders for the seismic risk mitigation.

We estimated the seismic site response produced by the local geology on seismic ground motion. The site response expresses two main concepts: the magnitude of the ground motion amplification, which is caused by the local geology and morphology, and the frequencies of the ground motion oscillations corresponding to such amplification. The estimation of the site amplification requires the availability of strong motion data, and a detailed knowledge of the local geology and morphology, as well as of the physical parameters of soils. Such information is unlikely to be recovered, especially in areas characterized by low current seismicity. The knowledge of both site and building resonance frequencies is essential in the territorial planning. This is to avoid soil-structure resonance effects, which might cause an increase in the amplitude of the seismic motion at those frequencies.

The ambient noise is a low amplitude seismic signal, generated by natural sources, such as wind, sea wave energy and pressure variations, at low frequency (<1 Hz), or anthropic sources, like industries and vehicle traffic, at higher frequency (>1 Hz). In this work, we applied the horizontal-to-vertical spectral ratio (HVSR) method to the ambient noise to estimate the resonance effects caused by the seismic motion. These are due to the local geology, and can be highlighted by soil/structure coupling. The HVSR approach is a widespread tool for estimating the site resonance frequencies. In areas having potentially high seismic risk, but characterized by low levels of current seismicity, as in the Irpinia region where Avellino is located, this method is appropriate. Moreover, as it is a passive survey technique, it is particularly useful in urban environment. Lastly, it is a low cost approach and it does not require high time-consuming numerical computation.

In a previous survey campaign carried out in Avellino through ambient noise and borehole data, some of the authors of this paper [22] found a good match between the HVSR peak frequencies measured at 16 sites and the computed resonance frequencies. These authors verified the correlation between the amplitude of sharp HVSR peaks and the basement/soil velocity contrast, even if over a limited data set. That being stated, this study continues the previous research: we expanded the HVSR measures over a grid of 58 points and also performed HVSR measures inside buildings. Furthermore, in order to evaluate the response of structures to the seismic ground motion, macroseismic data related to the November 23, 1980 (Mw = 6.8, [36] Irpinia-Basilicata earthquake were taken into account. Ambient noise measurements were supported with geological data deriving from geological mapping and geognostic surveys within the first 30 m of depth. The comparison between the sediment resonance frequencies as derived from the HVSR free-field measurements with the building resonance frequencies allowed us to identifying the areas of possible soil-structure resonance. Finally, we verified whether the entity of damage produced by the 1980 Irpinia-Basilicata earthquake (Mw = 6.8) in Avellino could be correlated to soil-structure resonance phenomena, and/or to the amplitude of the HVSR peaks.

2. Geological and seismological framework

Avellino is located near the Apennine Chain, in the Irpinia region. The town, whose altitude varies between 330 and 420 m above the seal level, lies at the external border of the calcareous Apenninic nappes, in a structural depression filled with terrigenous deposits, overlain by Quaternary formations, both terrigenous and volcanic [22]. The geological map of the area is shown in Fig. 1. The seismic bedrock changes in the urban area: it is formed by: 1) flysch deposits (thick *meso*-cenozoic basinal successions, named CPA in Fig. 1, which outcrop to the north, west and south of the city; 2) clay, sand-gravel, and pebble cemented, which outcrop to the north and east of the study area (these Miocene-lower Pliocene rocks form a high buried morphological structure below the ancient settlement of Avellino); 3) Pliocene – Pleistocene conglomerates (RVM in Fig. 1, which build up the hills in the eastern part of Avellino. Tuffs belonging to the *Ignimbrite Campana* formation (39,000 y.a., TGC in Fig. 1 follow in the succession. These tuffs

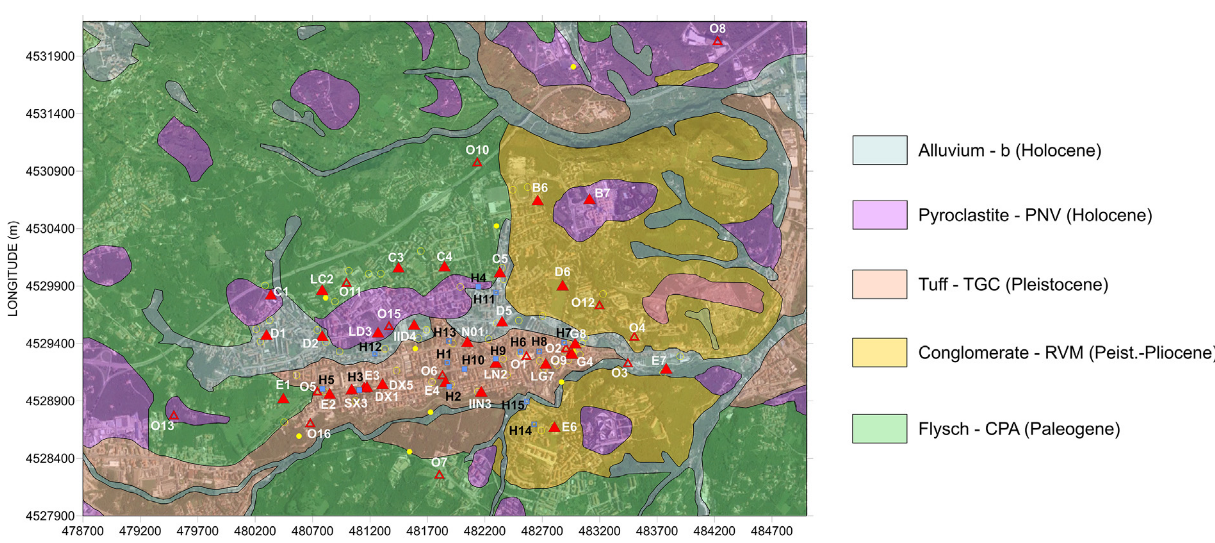

Fig. 1. Geological sketch map of the study area derived from the Geological Map of Italy, 1:50,000/Sheet No. 449 [19] (http://www.isprambiente.gov.it/Media/carg/449_AVELLINO/Foglio.html). The legend was simplified. Coordinates are UTM (meters). Close triangles indicate the noise stations operating in the town during the 2014 experiment. Open triangles indicate the noise stations operating during the 2012 experiment. Open circles indicate the position of boreholes; close circles indicate the location of downhole profiles. Open squares indicate the location of examined buildings; close squares indicate the location of examined building, also with noise measurement inside.