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# HVNSR survey in historical downtown L'Aquila (central Italy): Site resonance properties vs. subsoil model

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ABSTRACT

This paper presents and discusses the results of a detailed seismic noise survey carried out in historical downtown L'Aquila after the earthquake of 6 Apr. 2009 ($M_w$ = 6.3). Seismic noise data were interpreted through numerical simulations, with the support of a subsoil model, characterised by four main units, from the top to the bottom: (i) soft soils (anthropogenic filling material and terra rossa); (ii) L'Aquila breccia; (iii) L'Aquila pelite and sand; and (iv) the Meso-Cenozoic carbonate bedrock.

The HVNSR analysis permitted the identification of two peaks (f0 and f1) nearly everywhere. f0 (0.4–0.7 Hz) is due to the superposition of L'Aquila pelite and sand on the carbonate bedrock at 200–300 m below ground level. f1 (3–15 Hz) is caused by shallower impedance contrasts due to 3–20 m thick soft sediments overlying L'Aquila breccia and by the weathering profile of L'Aquila breccia.

A numerical simulation was carried out for three different models characterised by: (i) lithology lateral variation in the first 100 m of thickness due to the substitution, from north to south, of L'Aquila breccia with L'Aquila pelite and sand; (ii) the thickness variation of soft top soil onto L'Aquila breccia; and (iii) the presence of a weathered layer in the upper part of the L'Aquila breccia. The numerical simulation results fit the experimental seismic noise data.

A spatial correlation between areal distributions of severe damages with that of f1 resonance frequency is found. So it follows that the severe damage during the L'Aquila earthquake of 6 Apr. 2009 could have been caused by the seismic local effect of the soft top soil and the weathering profile of L'Aquila breccia.



## 1. Introduction

After the L'Aquila (central Italy) earthquake of 6 Apr. 2009 ($M_w$ = 6.3, Ameri et al., 2009; Amoruso and Crescentini, 2009; Chiarabba et al., 2009), activities of rebuilding and new urban planning for mitigating the seismic risk were started in L'Aquila's medieval historical centre. Therefore, projects funded by several institutions, including the L'Aquila University, were implemented with a view to more thoroughly characterising local seismic effects.

The paper presents and discusses the results of a detailed seismic noise survey conducted in downtown L'Aquila.

Seismic noise monitoring, carried out before (De Luca et al., 2005) and after (Çelebi et al., 2010; Bergamaschi et al., 2011; Milana et al., 2011; Martelli et al., 2012) the earthquake, showed a typical resonance frequency f0 of 0.5–0.6 Hz in the entire historical centre. As reported in previous studies (De Luca et al., 2005; Bordoni et al., 2011), the f0 was caused by the sharp seismic impedance due to the superposition of the Quaternary 300 m-thick detrital succession of the L'Aquila basin on the seismic Meso-Cenozoic carbonate bedrock.

As higher frequencies in ranges of engineering interest (i.e. 1–20 Hz), have not been studied in detail so far, a high density seismic noise monitoring survey was conducted in the L'Aquila centre. Seismic noise data were also integrated with geological field mapping, borehole data and in situ seismic investigations in order to improve the accuracy of the subsoil model. The results permitted the correlation of high resonance frequencies with building damage distribution.

## 2. Geological and geophysical setting

The centre of L'Aquila rests on a nearly triangular hill with a 700 m-high (above sea level, asl) flat terraced top. It is located in the Aterno River basin, which was struck by the $M_w$ = 6.3 earthquake of 6 April 2009 (Galli et al., 2010). The Aterno River basin is a typical WNW–ESE-trending Plio-Quaternary intramontane basin of central Italy which is located in the lower Pliocene–upper Miocene thrust and fold belt of central Apennines (Doglioni, 1991; Cosentino et al., 2010). Afterwards, from the upper Pliocene through the Quaternary, the area experienced extensional tectonics, with mainly S-dipping and NW–SE- or W–E-trending normal faults, many of which are of a seismogenic

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nature (Boncio et al., 2004). These faults controlled the evolution of intramontane basins and their fill deposits (Cavinato and De Celles, 1999).

Fine-scale detailed geological mapping of downtown L'Aquila (Figure 1) and reinterpretation of the stratigraphic well logs previously drilled therein, during and after seismic microzoning (GE.MI.NA., 1963; Amoroso et al., 2010; Gruppo di Lavoro MS–AQ, 2010; Tallini et al., 2012) (Figure 2), provided data to impose constraints on the geological subsoil model.

The continental detrital deposits filling the Aterno River basin mainly originate from lacustrine, fluvial and slope environments (Lanzo et al., 2011). The hill of downtown L'Aquila mainly consists of the L'Aquila breccia (Br in Figures 1, 2 and 3; Brs in Figure 2), made up of middle Pleistocene variably-cemented calcareous breccias and dense calcareous gravels (Br) and of calcareous breccias with sand levels (Brs); the latter breccias are not exposed but found in boreholes only. The thickness of the L'Aquila breccia, as shown by boreholes (Amoroso et al., 2010), decreases by 100 m or more in the northern part of L'Aquila's centre and by 0–10 m in its southern part, because it is laterally replaced by sand and pelite from lacustrine/fluvial sedimentation, alternating with sand-supported calcareous gravels and breccia levels (Ps in Figures 1, 2 and 3.4) (Agostini et al., 2012; Tallini et al., 2012). The L'Aquila breccia became sedimented in the above-mentioned lacustrine/fluvial palaeoenvironments via debris

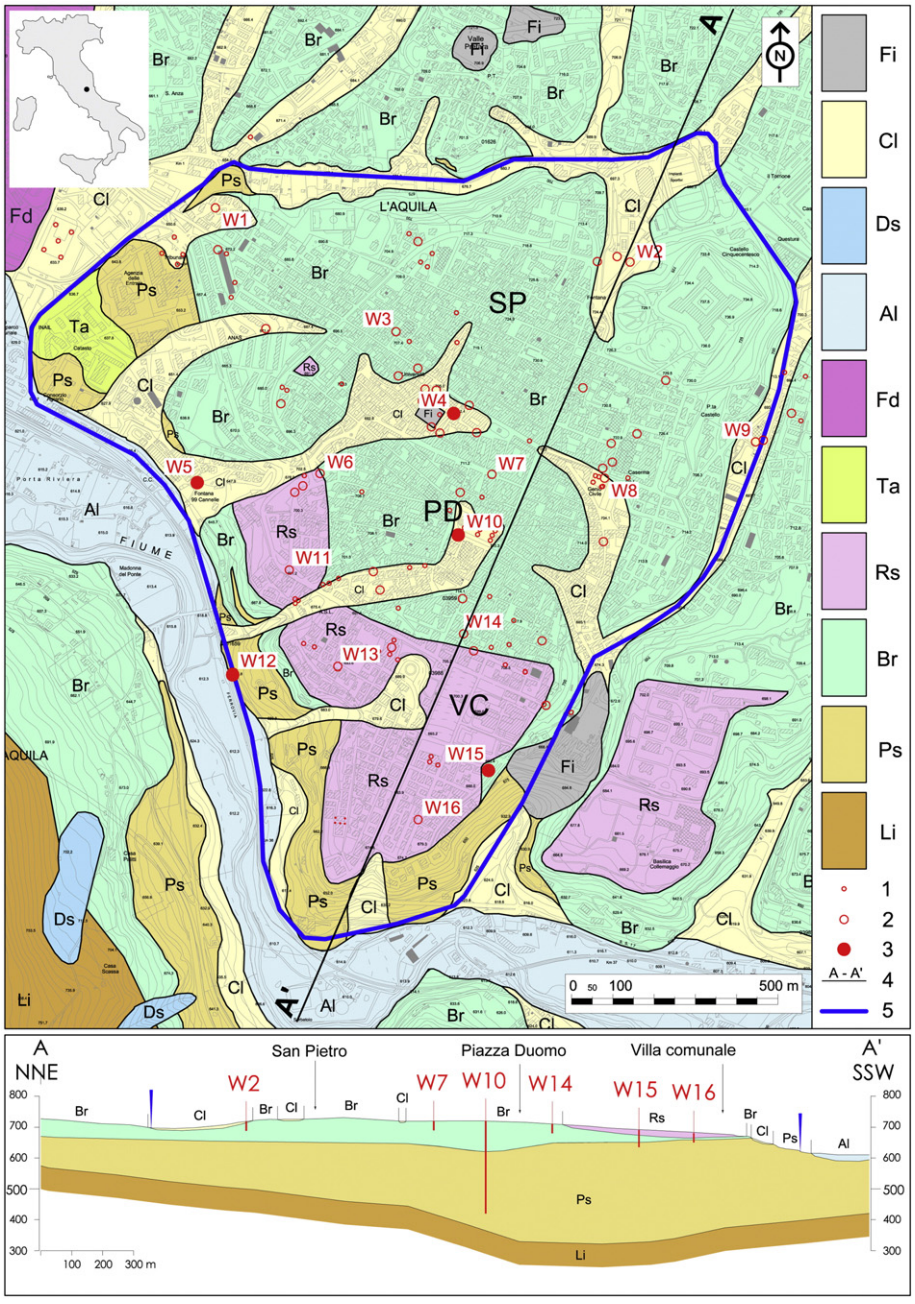


**Fig. 1.** Geologic map and cross-section of the studied area. Geological units. Quaternary units: Fi — filling anthropogenic material (Holocene); Cl — colluvium: fine-grained deposit (Holocene); Ds — debris slope deposit (Holocene); Al — Aterno River alluvial deposit (Holocene); Fd — Pettino M. pediment alluvial-debris deposit (upper Pleistocene); Ta — terraced Vetoio Stream. alluvium: gravels, sand and sandy-clayey silt with tephra horizons (upper Pleistocene); Rs — terra rossa: reddish fine-grained deposit; Br — L'Aquila breccia: dense and poor to well-cemented calcareous gravels (middle Pleistocene); Ps — L'Aquila pelite and sand (lower Pleistocene—upper Pliocene); Meso-Cenozoic carbonate bedrock: Li — Limestone with bryozoa and lithotamnia formation (middle Miocene); 1 — shallow borehole (depth < 30 m); 2 — borehole (depth 30–50 m.); 3 — borehole (depth > 50 m); 4 — cross-section trace; 5 — studied area outline; W1,..., W16 — borehole quoted in the text. SP: San Pietro church; PD: Piazza Duomo (market square); VC: Villa comunale (municipal garden).