Local seismic response studies in the north-western portion of the August 24^{th}, 2016 Mw 6.0 earthquake affected area. The case of Visso village (Central Apennines)

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Abstract

In this work, we investigate the possible causes of the differential damaging observed in Visso village (Central Apennines, about 28 km north from the August 24^{th}, 2016 Mw 6.0 earthquake epicenter). Following insights from the available geological cartography at 1:10.000 scale, a preliminary geophysical survey has been performed in the damaged area in order to constrain geometries and extent of the subsoil lithotypes. Then, these results have been used to retrieve a Vs profile close to the most heavily damaged buildings. This latter has been used as input for a numerical analysis aimed at deriving the motion at the ground level in the study area. In particular, a linear equivalent simulation has been performed by means of EERA code and the waveform has been obtained convolving the time history recorded during the August 24^{th}, 2016 mainshock at Spoleto Monteluco (SPM) site. Our preliminary results indicate a possible correlation of damaging to the thickness and shape of the geological units. Nevertheless, further analyses are necessary to highlight any 2D basin and / non - linear soil behaviour effects in order to compare them to the intrinsic buildings vulnerability, according to the EMS98 guidelines.

I. Introduction

On August 24^{th}, 2016 a Mw 6.0 earthquake affected a narrow NW-SE-trending portion of the Central Apennines. At October 8th, 2016 the epicentral distribution covered an area of about 35 km distributed across the mainshock. Roughly, seismic events with magnitude (ML) higher than 4.0 are localized, from north to south, near Norcia, Accumoli, and Amatrice villages, where major damage patterns and co-seismic effects are being documented. Epicenters of the earthquakes having ML < 4.0 are nevertheless distributed in a more extensive area (at least 100 km in length along NW-SE direction) partly overlapping the Colfiorito sequence (of 1997) to the north and the L'Aquila sequence (of 2009) to the south. Peripheral localities (such as Visso and Gualdo di Macerata) showed heavy damages at buildings after the August 24^{th}, 2016 Mw 6.0 earthquake (VI degree of the MCS intensity; Gruppo di Lavoro INGV 2016). This observation allowed us to investigate the case of Visso village for illustrating and discussing any evidence of site effects at the boundaries

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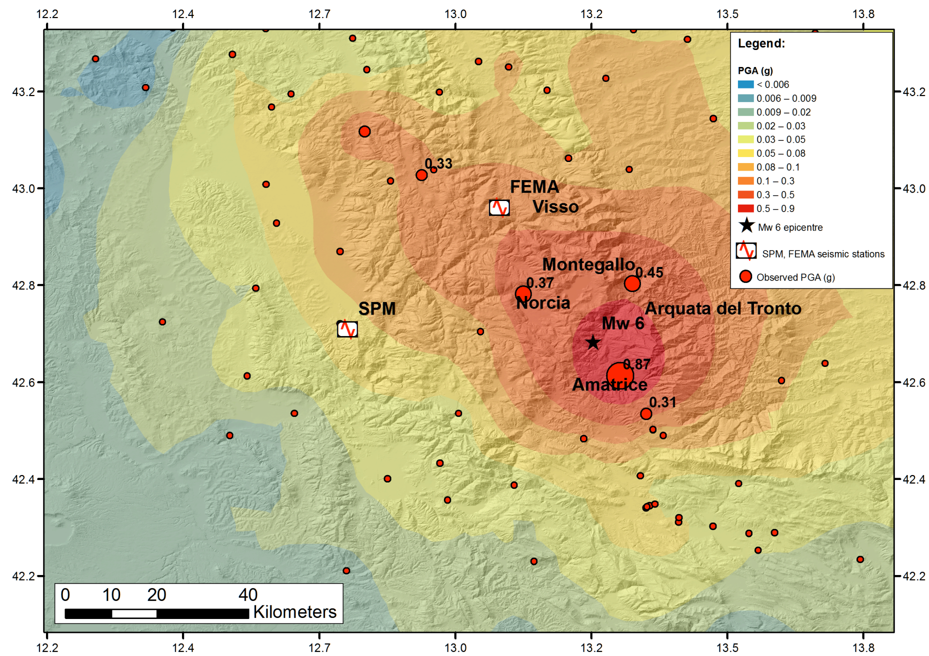

Figure 1: *Map of interpolated maximum horizontal Peak Ground Acceleration, PGA, (g) values. Red circles are proportional to the maximum horizontal PGA observed (for sake of clearness only labels greater than 0.25 g are shown). Red star represents the August 24th, 2016 (from: http://esm.mi.ingv.it) Mw 6.0 event. Localization of SPM and FEMA seismic stations are shown as well as the references to the main municipalities affected by the Mw 6.0 earthquake.*

of the epicentral zone. In this work, after a geologic overview of the investigated area, we discuss the pilot damage survey. Thus, we present preliminary results coming from a geophysical study and a numerical analysis in the damaged area of the village, aiming at discussing factors leading to the observed damages.

II. The study area

The spatial distribution of the ground motion around Visso village is given in Figure 1 . This latter is a map of the interpolated maximum horizontal Peak Ground Acceleration, PGA (g) values obtained using data recorded at the Italian Seismic Network (RAN, operated by the Civil Protection Department) and the National Seismic Network (RSN, operated by the Italian Institute of Geophysics and Volcanology) during the August 24th, 2016 Mw 6.0 earthquake. Data in Figure 1 were interpolated by an ordinary kriging algorithm (Stein, 1999). The processed records used in this analysis are available at http://esm.mi.ingv.it/DYNA-stage/ (Luzi et al., 2011), while PGA values for two stations (AQA and RQT) were integrated from the RAN download website (http://ran.protezionecivile.it/IT/index.php). A value of 0.237 g in the NW direction has been recorded at the closest station to Visso (FEMA station), whose localization is shown in Figure 1. The map displays acceleration values in the range between 0.1 and 0.3 g in the Visso area.

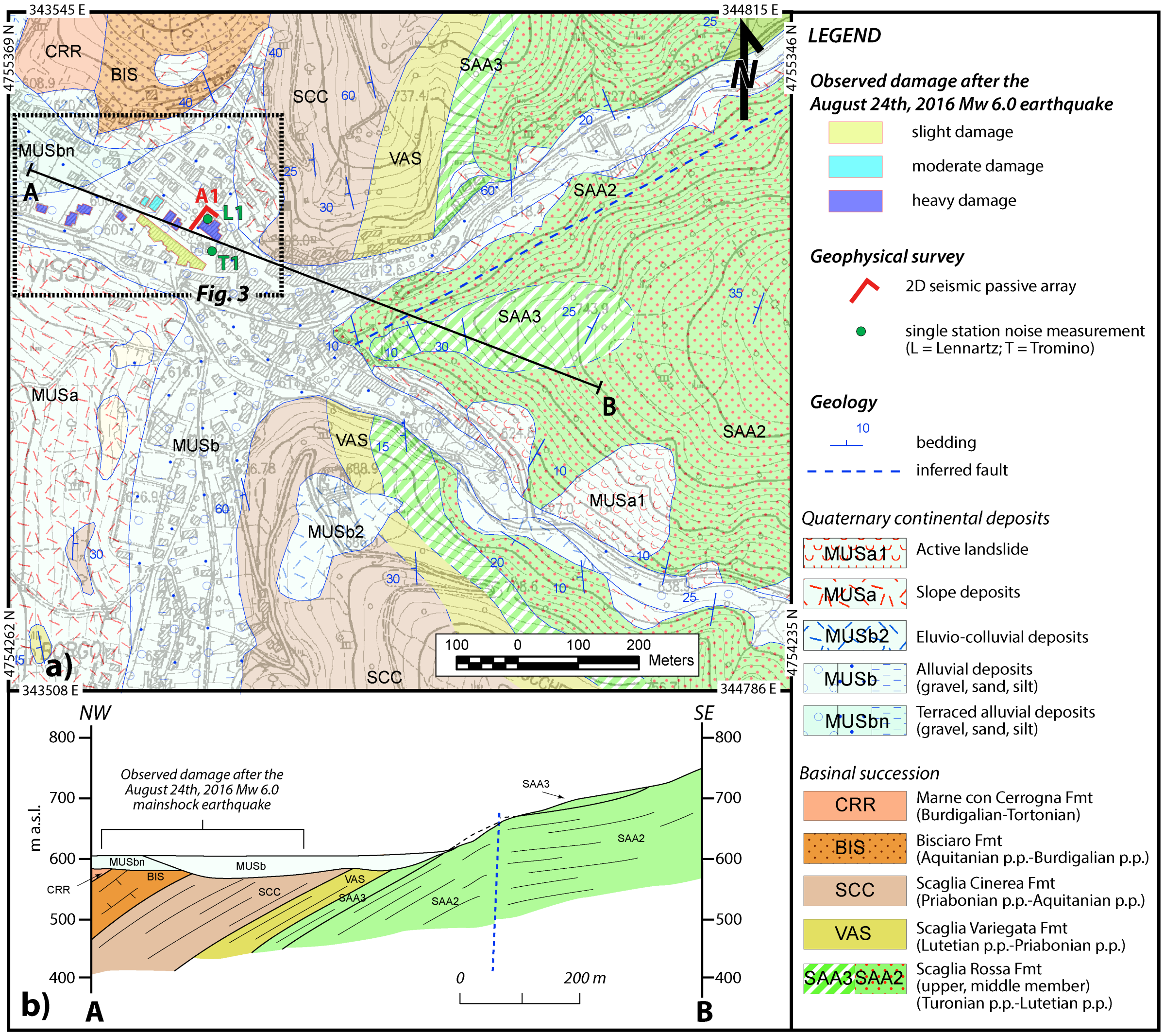

Figure 2: *a)Geological map (at 1:10.000)scale of Visso village (after regional geological cartography available at http://www.regione.marche.it/Regione−Utile/Paesaggio−Territorio−Urbanistica/Cartografia/Repertorio#326_Cartografie−tematiche). The observed damage zone and the geophysical data carried out are indicated; b) interpreted cross section showing the main stratigraphical relationships.*

From a morphological viewpoint, Visso village is located in a depressed area of the Sibillini Mountains, at the Umbria-Marche regional boundary. Here, the thrust-and-fold belt of the Central Apennines involves a Meso-Cenozoic multilayered sedimentary sequence composed of limestones, marly limestones, marls and flysches (e.g. Calamita et al., 1994). Thrust sheets are incorporated to form an east-verging tectonic wedge that was definitively uplifted at the Lower Pliocene. The compressive structures are reworked and dissected by normal fault systems, mainly striking NW-SE. Quaternary normal faults led to the formation of morphological depressed areas and the evolution of intramountain basins. In the studied area of Visso (Figure 2), the tectonostratigraphic setting includes the Cretaceous−Miocene basinal succession made of, from bottom to top, the Scaglia Fmt (Scaglia Rossa, Scaglia Variegata and Scaglia Cinerea), the Bisciaro Fmt and the Marne con Cerrogna Fmt. Following the regional geological cartography (available at http://www.ambiente.marche.it/Territorio/), these Formations are organized in a monoclinale architecture striking from NNW−SSE to N−S, and dipping to W with low−to−moderate angles (Figure 2b). The monoclinale architecture is at the footwall of a major thrust surface striking roughly N−S and passing throughout the western part of Visso village (not shown in Figure 2a,b). Quaternary continental deposits cover all the basinal succession. The latter consist of alluvial deposits (showing gradational facies of gravels, sand and silts), eluvio−colluvial deposits, and widespread slope deposits. Stratigraphical relationships allow considering about 40 m as the maximum thickness of the continental deposits occurring in the central part of Visso village. The thickness reduces when moving towards the east, where the Scaglia Rossa Fmt crops out.

The August 24^{th}, 2016 Mw 6.0 earthquake caused diffuse damage at buildings located in the central−western part of Visso village. Masonry buildings are mostly two to four storeys built in simple stone masonry style, sometimes with tie−rod connections among walls. An expeditious survey allowed classifying slight (very fine cracks in plaster), moderate (cracks in many walls or fall of fairly large pieces of plaster), and heavy (large and extensive cracks in many walls or in partitions and infill walls) damages for both masonry and reinforced concrete buildings. The photographic documentation of Figure 3 was realized after this survey, not including internal inspections of the buildings. Heavy damages were observed also in buildings partially re−built after the 1997 Umbria−Marche sequence, while the historical part of the village (which develops toward the southeastern portion) appeared mainly less affected from the August 24^{th}, 2016 Mw 6.0 mainshock.

III. THE GEOPHYSICAL SURVEY AND PRELIMINARY NUMERICAL MODELING RESULTS

Preliminarily, we performed two Horizontal to Vertical Spectral Ratio (HVSR) single station measurements and a 2D seismic passive array close to the most damaged buildings. Figure 2, a shows the localization of these latter geophysical investigations. Single station noise measurement named L1 was carried out with a Lennartz Le3D/5s (cut−off frequency at 0.2 Hz) connected to a SARA digitizer for a length of about 40 min, whereas single station noise measurement named T1 was obtained using an all−in−one instrument seismograph (Tromino). The array was arranged in a L−geometry using 22 geophones at 4.5 Hz connected to a 24−bit acquirer, covering an area of 60x30m^2. Surface−wave dispersion curve measured by this array (Capon, 1994; Asten, 2006) was inverted through a neighbourhood algorithm using the Geopsy software (www.geopsy.org), jointly with the HVSR ambient noise spectral ratio related to Rayleigh waves ellipticity recorded at L1 station, in or-

Figure 3: *Photographic documentation associated to the damage survey (Date: 2016/08/26).*

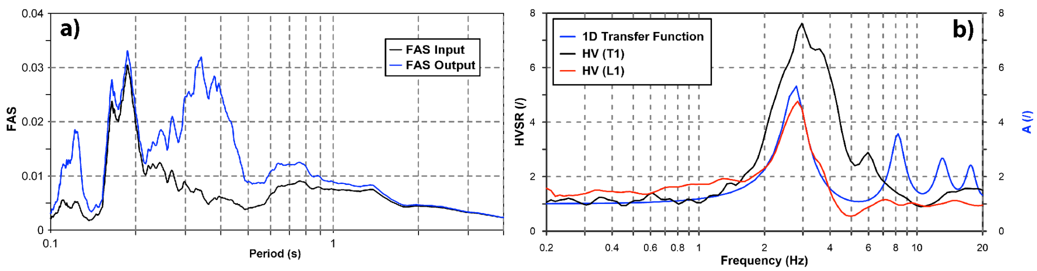

Figure 4: *a) FAS from 1D linear equivalent modeled at the ground level in the most damaged portion, compared to the Fourier spectrum in input; b) comparison between HVSR and transfer function obtained at the same vertical.*

der to obtain a shear−wave velocity (Vs) profile representative of that site. Bottom up, the first unit (Ri) is formed by anthropic layer. The second main unit (Si1) consists of sandy silt. Their dynamic soil properties were extracted from literature, since direct laboratory tests are missing. In particular, the non−linear behaviour of the silt (indicated as Si1 in Table 1) was modeled on the basis of measurements taken at Poggio Picenze, on soil with similar depositional characteristics (Lanzo et al., 2011), obtained from cyclic torsional shear tests. A linear elastic behaviour was assumed for the bedrock (the initial critical damping ratio D0 has been fixed in 0.5%). Then, a 1D analysis of seismic site response was carried out using the EERA computer code (Bardet et al., 2000), a monodimensional software able to perform linear equivalent model. Simulation was run using the recorded accelerogram obtained at SPM station, whose localization is shown in Figure 1. This station was chosen because it is the closest station of class A (according to NTC 2008) to record the mainshock. Results are shown in terms of Fourier Amplitude Spectra (FAS) for the recorded input and modeled output. More in details, Figure 4a depicts the FAS computed by 1D linear equivalent modeling (blue curve) in comparison to the FAS of the seismic input (black curve). Both spectra detected a natural amplification period at about 0.2 s, while the output FAS shows a second natural period at 0.33 s that is in good agreement with the amplification frequency highlighted in the HVSR noise measurements at L1 and T1 stations (red and black curves in Figure 4b). This latter may be interpreted as a local soil effect. Figure 4b shows a comparison among HVSRs at L1 and T1 stations and 1D modeled transfer function obtained at the same vertical (blue curve). Both HVSR curves showed a unique natural frequency at about 3 Hz, even if the T1 HVSR curve highlights a peak less sharp. Consequently, ground motion at the study site is significantly amplified in the range of periods of the engineering interest for buildings from two to four stories (typically from 0.15 to 0.5 s) due to both source and site effects.

Table 1: *Mechanical and dynamical soil parameters of each geotechnical unit.*

UG	γ	ν	**Thickness**	V_S	G/G_0 **and** D/D_0 **curves**
	KN/m^3	/	m	m/s	
Ri	17	0.2	2	200	Lanzo et al. (2011)
Si1	19	0.2	19	250	Lanzo et al. (2011)
Bedrock	21	0.2	–	1200	Linear elastic behavior $D_0 \sim 0.5$ %

IV. Discussion

Observed damage at buildings in Visso village during the Mw 6.0 earthquake was not homogeneous. Preliminary analysis seems to highlight that the local geology and dynamic parameters of uppermost geological layers may have influenced the ground motion, increasing the expected ground motion at the site at around 3 Hz. In particular, the occurrence of about 20−30 m of unconsolidated and soft alluvial deposits resting on the Scaglia Fmt defines a crucial stratigraphic factor. Further geophysical investigations (i.e. HVSR and array measurements) on a more refined grid are necessary for a twofold aim: i) to better evaluate the geological variability from the north − western to southeast portion of the village; ii) to individuate a possible correlation with the period of the most damaged buildings. This latter may be obtained using data from Seismic Observatory of Structures (http://www.protezionecivile.gov.it/) or other literature estimates. These data combined to further 2D analyses may give new insights able to quantify the amplitude−frequency−duration modifications during propagation of seismic waves in the village. Nevertheless, authors believe that the damaging survey indicated in Figure 3, even if expeditious, may be suitable for possible correlation to the heavier damages occurred after the October 30th, 2016 Mw 6.5 event, which caused the collapses of many buildings. Finally, from a methodological viewpoint, the research of factors that correlate damage distribution to surface geology may be very important for an appropriate design of seismic risk mitigation interventions and urban planning purposes.

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