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Site effect studies following the 2016 Mw 6.0 Amatrice Earthquake (Italy): the Emersito Task Force activities

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Abstract

On August 24, 2016, at 01:36 UTC a M_W *6.0 earthquake struck an extensive area of the Central Apennines (Italy) between the towns of Norcia and Amatrice. Due to the mainshock magnitude and the widespread damaging level of buildings in the epicentral area, the Emersito task force has been mobilized by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The aim of Emersito is to carry out and coordinate the monitoring of local site effects, caused by geological and geomorphological settings. During the first days of the seismic emergency, Emersito installed a temporary seismic network for site effect studies at 4 municipalities close to the epicentral area (Amandola, Civitella del Tronto, Montereale and Capitignano), using 22 stations equipped with both velocimetric and accelerometric sensors. The selection of the sites where stations have been installed was mainly driven by the proximity to the epicentral area (without interfere with the rescue operations) and by peculiar geologic and geomorphologic settings (topographic irregularities, fault zones, alluvial plains). Preliminary analyses performed on ambient noise and aftershocks signals show that directional amplification effects may have occurred at stations installed on the top of topographic irregularities. We also observed the lengthening and amplification of the seismograms and a variability of the peaked frequency across the sedimentary basin between Montereale and Capitignano, probably related to a different thickness of the deposits. Further analyses are necessary to assess the correlation with surface geology.*

I. INTRODUCTION

The earthquake ground-motion depends on the source process, on the propagation of the incoming wave-field through the crustal medium, and on the transmission of the seismic waves from bedrock to the Earth surface (free-field motion). The last contribution is known as *site effect*, and substantially modifies the amplitude, the frequency content and duration of the seismic waveforms.

Three main types of site effects can be identified: impedance contrast between bedrock and softer soil, the lateral heterogeneities in the elastic and/or geometrical properties of the soil and the topographic settings that can produce 2D or 3D effects.

Site effects due to soft soil layers (e.g. alluvial or sedimentary cover) overlapping hard rock produce seismic wave amplification whose extent depends on the impedance contrast between different layers. These effects are usually modeled by 1D wave propagation through the soil column.

When lateral heterogeneities of the subsoil mechanical properties are not negligible (e.g. sediment filled valleys), 2D or 3D geometries are more appropriate to describe the complexity of the ground motion (Kawase, 1996; Bindi et al., 2009; Chaljub et al., 2010; Di Giulio et al., 2016). In the last decade particular attention has been devoted to the ground motion directional amplification in fault damage zones, related to fracture networks and the resulting stiffness anisotropy of the rock mass (Pischiutta et al., 2012).

Concerning the topographic effects, a correlation between pattern of damage and topographic elevation has been recently investigated (Paolucci, 2002; Massa et al., 2014), although there are fewer evidences compared to the previous two types of site effects.

Usually, these studies use seismic noise and background seismicity because stronger events are available for a target area during a seismic sequence only.

Emersito is a task force of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) that involves several headquarters (Milano, Roma, L'Aquila, Grottaminarda; Italy). Its aim is to coordinate and carry out seismic monitoring to investigate possible site effects caused by seismic events of moderate–to-large magnitude (M≥5) in the Italian territory. In case of relevant seismic sequences, a rapid installation of temporary seismic stations is fundamental to seismic monitoring, to the research in the field of seismic hazard and, in some cases, to support post-emergency activities (e.g. microzonation studies). Emersito operated for the first time during the Emilia 2012 sequence (Bordoni et al, 2012), and it was officially established in 2015 (DDG, 2015); mobilization procedures have been test during the INGV Emergency simulation performed on 2015 (Pondrelli et al, 2016).

On August 24, 2016 (01:36 UTC) a M_W6.0 earthquake struck an extensive area in the Central Apennines (Italy) between the municipalities of Norcia and Amatrice. The epicenter was located by the INGV close to the Accumoli village. A large aftershock (M_W 5.3, August 24 02:33 UTC) and over 9000 aftershocks have been located up to September 16, 2016, in an extended area of about 50 km in the Appennine direction (from the town of Ussita to the North, to the lake of Campotosto in the South), and about 15 km width (INGV working group, 2016). In the first days of the seismic emergency (August 24th-25th, 2016), we have chosen several urban areas located at the margin of the epicentral area and characterized by geological and structural features able to produce local site effects (Figure 1). Several issues were considered for the selection of the areas: availability of geological maps and first level microzonation studies, location of recording stations of temporary and/or permanent seismic networks (Italian National Seismic Network operated by INGV and Italian Strong Motion Network operated by the Italian Department of Civil Protection), rescue activities in the epicentral area. The available information was centralized in a web Geographic Information System (Arcgis on-line) to facilitate the data sharing to all Emersito members (Figure 1). During August 26th-31st, 22 temporary seismic stations were installed in four municipalities: Amandola (FM), Civitella del Tronto (TE), Montereale (AQ), and Capitignano (AQ). Additional 5 recording stations were set in Acquasanta Terme (AP) by the INGV National Earthquake Centre in cooperation with the Emersito task force.

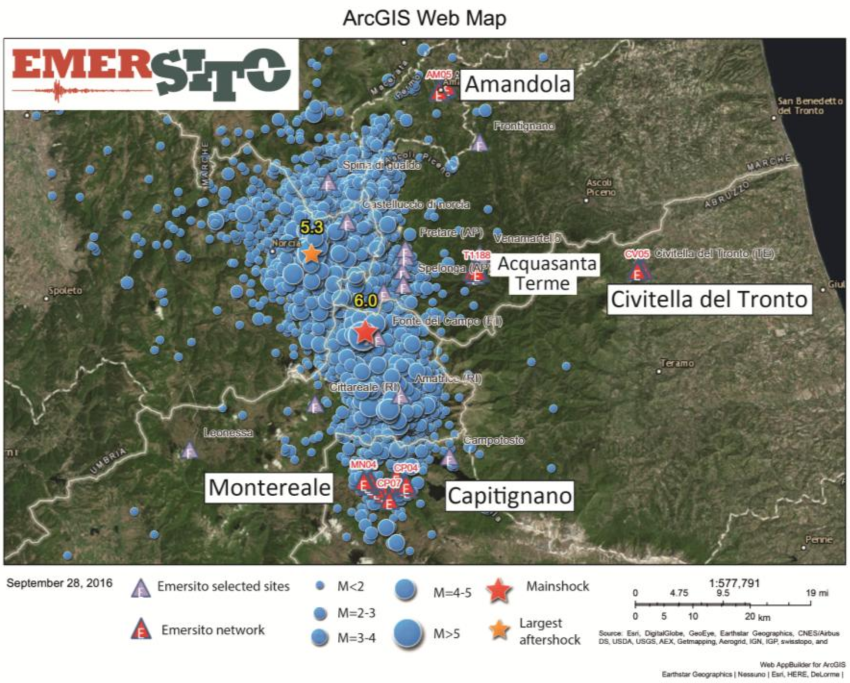

Figure 1. *Thematic levels of Emersito ArcGis on-line with the 2016 Amatrice seismic sequence (from August 24th to September 28th) together with the selected sites and the temporary network.*

II. INSTRUMENTAL SETTING

The instrumental setting was composed of 22 digitizers (Reftek 130 and Quanterra), equipped with both Lennartz-5s velocimeter and Episensor accelerometer (Emersito report, 2016). All the stations recorded in continuous mode: five of them transferred data to a remote server in real-time, while the remaining stations were in a stand-alone configuration. Data will be distributed through the European Integrated Data Archive (EIDA, http://eida.rm.ingv.it/), by using the international XO code assigned on August, 29th to the temporary Emersito network by the Federation of Digital Seismograph Networks (www.fdsn.org/networks/detail/XO_2016).
The XO network was named "Seismic Network for Site Effect Studies in Amatrice Area (Central Italy)" and the station codes were registered at the International Seismological Centre (ISC) on September 6th. Table 1 reports network and station code, municipality, site coordinate, digitizer, sensor, type of seismic data acquisition (real-time vs local), and installation period.

III. DESCRIPTION OF THE SELECTED SITES AND PRELIMINARY RESULTS

Amandola

The village of Amandola is located 30 km Northeast from the epicentral area (Figure 1). It extends along a relief, with SW-NE trend, constituted by clayey sandstones. Several buildings of the historical center, and also the hospital, suffered some damage after the mainshock. Figure 2 shows the location of the 5 stations (Table 1), which were installed along the ridge and at the base of the relief, with the aim of investigating possible topographic effects. In particular, the hospital area was monitored by AM03 station.

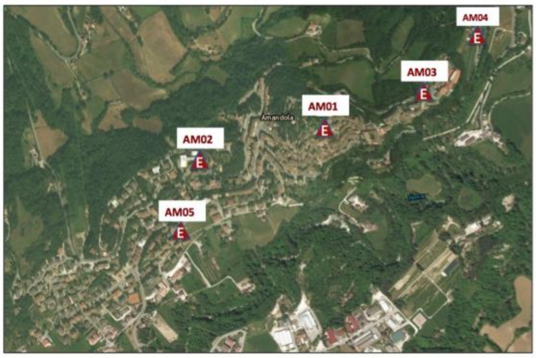

Figure 2. *Stations installed at Amandola.*

All stations installed at Amandola sent data in real time to the remote INGV acquisition center and were soon available (i.e. in average 2 hours later each event origin time) and downloadable from the real time INGV Strong Motion Database (ISMD; http://ismd.mi.ingv.it).
Due to the broadening of the sequence towards North (Gruppo di Lavoro INGV, 2016), AM05 was integrated to the Italian Seismic Network with the aim to improve the location operated by the INGV National Earthquake Centre.
A preliminary analysis of the Horizontal to Vertical Spectral Ratio (HVSR) was performed considering at all stations 1 hour of ambient noise (running window length of 120 seconds, 4th order Butterworth filter in the frequency band 0.1-15 Hz, tapering 5%, Konno-Ohmachi logarithmic smoothing with b=20). Possible transient signals were deleted by visual inspection. In general, all stations installed at the top of the ridge show HVSR with amplification ranging from 3 to 4 in the frequency range 3-4

Hz. The maximum amplification was observed in the N-NW direction (Figure 2); AM05, installed at the base of the ridge, can be considered the reference site in the range of interest for topographic effect, showing amplification at frequency > 8 Hz due to a very thin layer of landfill. Further investigations are needed to ascribe the recordings behavior to a topographical effect.

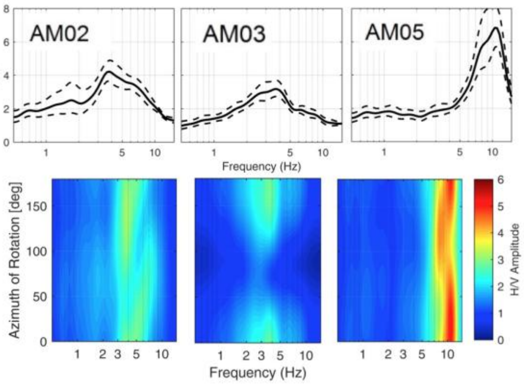

Figure 3. *HVSR on noise recorded at AM02, AM03 and AM05: (top) quadratic mean of the two horizontal components ± 1 standard deviation; (bottom) rotated spectral ratio at different azimuths.*

Montereale and Capitignano

The villages of Montereale and Capitignano are located 20 km South of the mainshock and in correspondence with the southernmost epicentres of the sequence (Figure 1). Both municipalities suffered slight damage after the mainshock and the larger events. Figure 4 shows the 12 stand-alone stations installed to study topographic and basin effects, as well as to investigate possible fault effects close to CP04, CP05 and CP06 (Table 1).

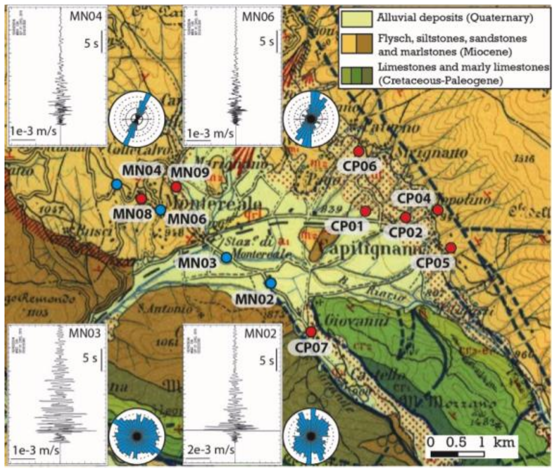

Figure 4. *Stations installed at Montereale and Capitignano, superimposed to the Geological map of Italy at 1:100,000 scale. Displayed seismograms refer to the recorded NS component of the Ml 3.6 earthquake (01/09/2016 03:53, hypocentral distance R=16km); rose diagrams indicate the horizontal polarization averaged on 19 earthquakes with Ml≥ 3 recorded in the period 30/08-1/09/2016.*

MN04, MN08 and MN06 are located on the top of a topographic irregularity, characterized by a maximum height of 140 m from the nearby level ground and maximum slope of 18°. They are on Miocene flysch units (Figure 4) and, as a first approximation, they can be considered stiff rock sites. Signal polarization analysis performed in the time domain (Jurkevics, 1988) indicates a predominant N-NE/S-SW direction of the horizontal motion at these sites (Figure 4). The directional amplification effect is confirmed by the HVSR performed on noise and on earthquakes (MN04 in Figure 5).

The stations on Quaternary alluvial deposits are affected by the lengthening and amplification of the seismograms (MN02 and MN03 in Figure 4). At those stations, signal polarization analysis shows an isotropic distribution of polarization azimuths, i.e. the site tends to produce a similar amplitude level on the two horizontal components. Moreover, the HVSR on noise recorded at MN02 and CP07 show an amplification peak at 1.5 Hz and 6 Hz, respectively, that it is probably related to a different thickness of the basin deposits (Figure 5). Further investigations are needed to verify the persistence of the behavior and the correlation with the topography.

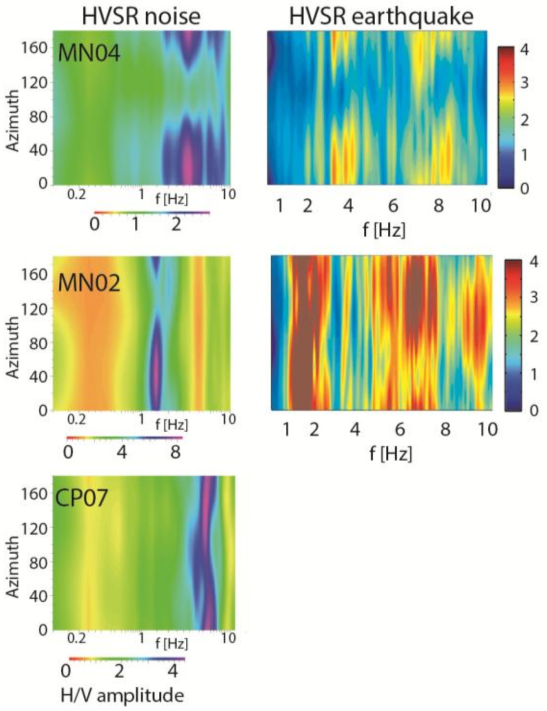

Figure 5. *Rotated HVSR on noise (left) and on earthquakes (right) recorded at MN04, MN02 and CPT07 of Figure 4. The HVSR on earthquakes is averaged on 19 events with Ml=3.0÷3.9 recorded in the period 30/08-1/09/2016; CP07 data were not available in this period.*

Civitella del Tronto

Civitella del Tronto, a village located at about 30-40 km East of the epicentral area (Figure 1), did not suffer significant structural damages for the August 24th mainshock. The municipality is located on a topographic relief, with a SW-NE trend, consisting of travertine overlaying sandstones. Five stand-alone stations were installed along the top and at the base of the relief to detect possible topographic effects (Figure 6). Data were not available at the time of this study because the stations were dismounted at the end of September 2016.

Figure 6. *Location of the stations installed at Civitella del Tronto.*

IV. CONCLUSIVE REMARKS

The Emersito efforts during the 2016 Amatrice seismic emergency consisted in the deployment of 22 stations equipped with both velocimeter and accelerometer within few days after the mainshock of August 24th 2016, with the aim of studying site effects for selected areas. Usually, these studies use background seismicity while during a seismic sequence stronger events are available and they can be recorded with a rapid installation of a temporary seismic network.

Due to the morphology of the settlements stroke by the earthquake, we focused in the investigation of the site effects of topography, small intra-mountain basin and fault zone to seismic motion. Preliminary results suggest the presence of such effects, requiring further analyses to assess the correlation with surface geology. The collected dataset will be available in EIDA node and could support other seismological studies (e.g. source and directivity effects, role of fluids, earthquake location).

The remarks in this paper refer to the first phase of the Central Italy seismic sequence, up to the end of September 2016; at the time of publication, several large magnitude earthquakes that contributed to modify the damaging level of the studied villages have hit the area.

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Table 1. *Emersito seismic stations installed at the beginning of the 2016 Amatrice seismic emergency (network code XO)*

Station code	Municipality	Lat. [°]	Lon. [°]	Elev. [m]	Digitizer	Vel. Sensor	Acc. Sensor	Acquisition	Installation period
AM01	Amandola	42.980556	13.358708	549	REFTEK130	LE3D-5S	EPISENSOR	Real-time	29/08-10/10/2016
AM02	Amandola	42.979597	13.353573	516	REFTEK130	LE3D-5S	EPISENSOR	Real-time	30/08-10/10/2016
AM03	Amandola	42.981622	13.362768	511	REFTEK130	LE3D-5S	EPISENSOR	Real-time	29/08-10/10/2016
AM04	Amandola	42.983345	13.365007	455	REFTEK130	LE3D-5S	EPISENSOR	Real-time	30/08-10/10/2016
AM05	Amandola	42.977404	13.352786	464	REFTEK130	LE3D-5S	EPISENSOR	Real-time	from 30/08/2016
CV01	Civitella del Tronto	42.772736	13.666229	642	Q330	LE3D-5S	EPISENSOR	Stand-alone	31/08-26/09/2016
CV02	Civitella del Tronto	42.773104	13.669496	600	Q330	LE3D-5S	EPISENSOR	Stand-alone	30/08-26/09/2016
CV03	Civitella del Tronto	42.772644	13.672969	540	Q330	LE3D-5S	EPISENSOR	Stand-alone	30/08-26/09/2016
CV04	Civitella del Tronto	42.772273	13.666690	585	Q330	LE3D-5S	EPISENSOR	Stand-alone	31/08-26/09/2016
CV05	Civitella del Tronto	42.771551	13.663721	605	Q330	LE3D-5S	EPISENSOR	Stand-alone	31/08-26/09/2016
CP01	Capitignano	42.52458	13.28758	885	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	29/08-17/09/2016
CP02	Capitignano	42.52389	13.29596	898	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	29/08-19/09/2016
CP04	Capitignano	42.52529	13.30163	957	REFTEK130	LE3D-5S	---	Stand-alone	30/08-16/09/2016
CP05	Capitignano	42.52052	13.30267	925	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	29/08-16/09/2016
CP06	Capitignano	42.53498	13.28591	900	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	29/08-17/09/2016
CP07	Capitignano	42.50748	13.27508	842	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	30/08-16/09/2016
MN02	Montereale	42.51393	13.26704	827	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	26/08-16/09/2016
MN03	Montereale	42.51916	13.25532	823	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	26/08-17/09/2016
MN04	Montereale	42.52906	13.23519	977	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	27/08-16/09/2016
MN06	Montereale	42.52400	13.24480	923	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	26/08-16/09/2016
MN08	Montereale	42.52624	13.24125	916	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	27/08-16/09/2016
MN09	Montereale	42.52987	13.24546	827	REFTEK130	LE3D-5S	EPISENSOR	Stand-alone	27/08-16/09/2016