SITE EFFECTS ESTIMATION AND THEIR EFFECTS ON STRONG GROUND MOTION AT AMATRICE VILLAGE (CENTRAL ITALY)

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

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1 Introduction

We present a summary of seismological and geophysical investigations at the village of Amatrice (Central Italy), placed on an alluvial terrace and severely stroke by the Mw 6.0 event of August 24, 2016. The high vulnerability alone could not explain the heavy damage (X-XI MCS), whereas the vicinity of the seismic source and the peculiar site effects should be claimed to understand the ground motion variability.

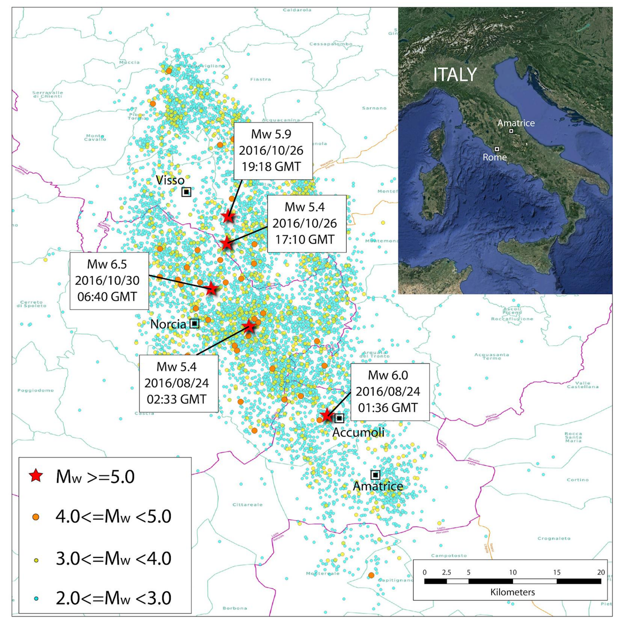


Figure 1. Central Italy seismic sequence (August 24 - November 30, 2016). The inlet shows the map of Italy with the position of Amatrice. The epicentral locations are from the INGV web service (http://terremoti.ingv.it/en/). From Cara et al., 2019.

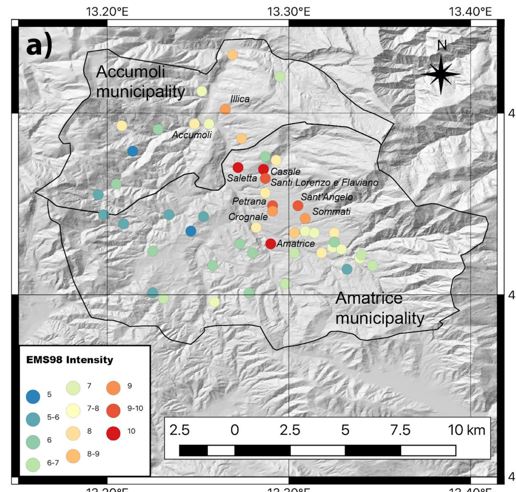


Figure 2. EMS-98 Intensity for the hamlets at Accumoli and Amatrice municipalities. Survey after the Mw 6.0 earthquake occurred on the 24th of August 2016. From Cara et al., 2019.

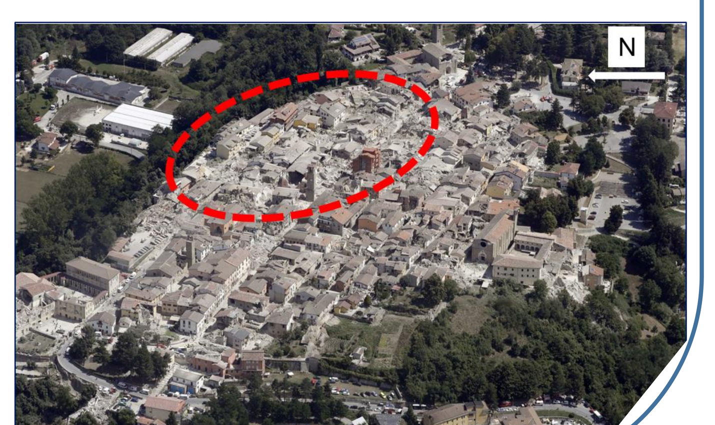


Figure 3. downtown Amatrice after the August 24th Mw 6.0 earthquake. The red line shows the area mainly interested by total collapses. From Milana et al., 2019.

2 Collected data

After the first mainshock, we investigated the Amatrice terrace for microzonation purposes together with several Italian institutions (Priolo et al., 2019).

- ✓ We installed 7 seismic stations as a part of the network 3A (Cara et al., 2019).
- ✓ We performed an extensive campaign of 60 single-station ambient noise measurements. Downtown stations recorded also few earthquakes;
- ✓ we performed several 2D passive seismic arrays aimed at obtaining Vs profiles down to a depth of few tens of meters (Milana et al., 2019).

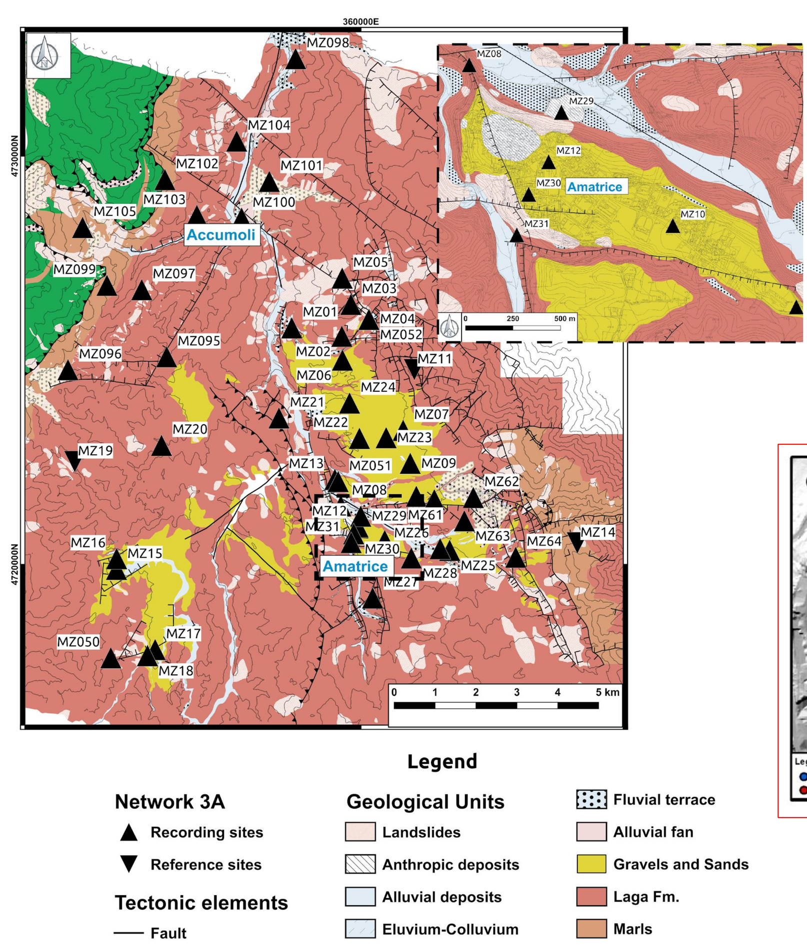


Figure 4. Simplified geological map of the Amatrice and Accumoli municipalities. Position of the seismic stations of the network 3A on a simplified geological map (scale 1:52800); the inlet shows a zoom of the Amatrice area. From Cara et al., 2019.

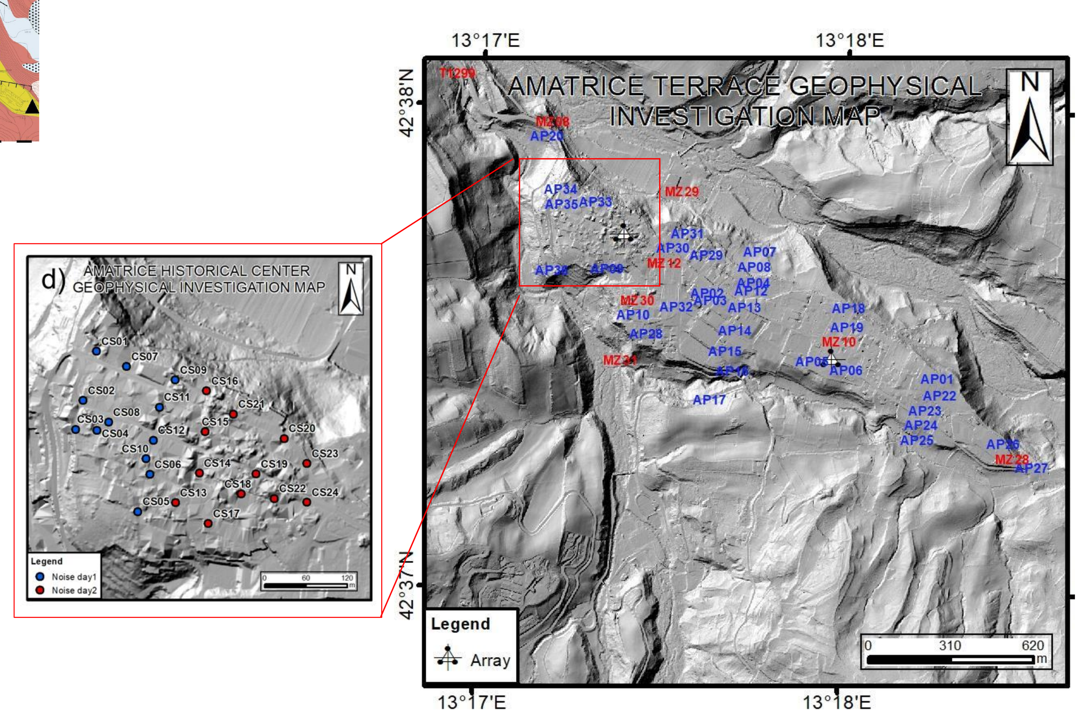
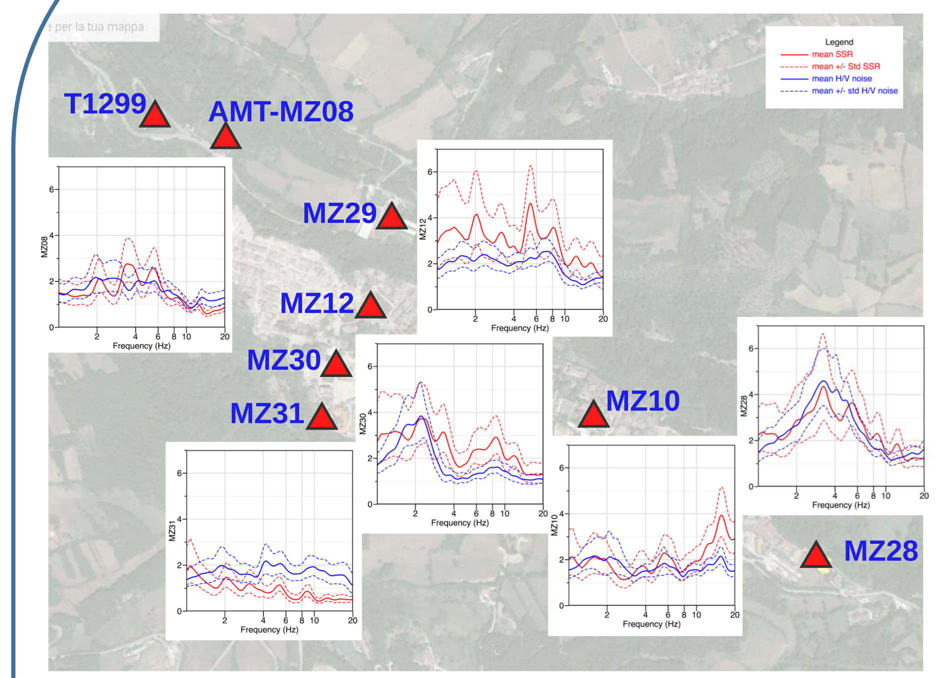


Figure 5. Map of the stations deployed on the Amatrice terrace. Red labels refer to 3A seismic stations and blue labels to stations for noise measurements; triangles indicate the center of 2D arrays. The inlet shows 12 sensors installed in Amatrice downtown (June 28th -blue dots- and June 29th - red dots-, 2017). From Milana et al. 2019

3 Data analysis



Earthquake recordings were used to empirically evaluate ground motion amplification effects through spectral ratios, and noise data were collected for defining the spatial distribution of the resonance frequencies. Data analysis reveals a diffuse amplification effect that reaches its maximum values in downtown with resonant frequency (f0) of about 2 Hz.

Figure 6. Standard Spectral Ratio on earthquakes (SSR) and Horizontal-to-Vertical on ambient noise (Hvnoise) for the Amatrice stations. Selected events (135 for MZ31 to 420 for MZ08) have ML higher than 3.0 and epicentral distance less than 55 km from Amatrice.

Seismic amplification is also site dependent and variable with the direction of the horizontal ground motion. This behavior is particularly clear at stations close to the northern edge of the Amatrice terrace, suggesting the presence of topographic effects due to the morphology of the area.
In the SW section, the presence of a secondary peak indicates a lateral variability in the geological conditions of the sedimentary layers that characterize the terraced area.

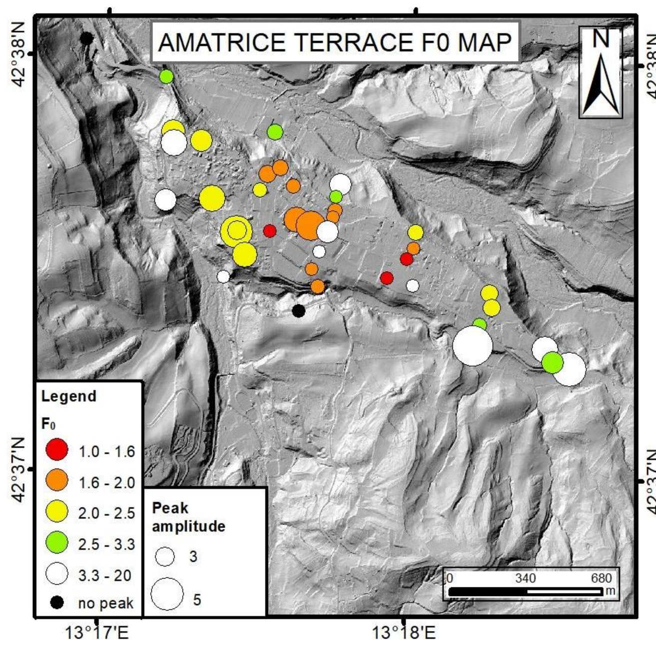


Figure 7. Map of the fundamental peak frequencies (f0) from HVnoise. The color scale refers to the frequency value, the symbol size is proportional to the amplitude of the peak associated to the f0 value. From Milana et al., 2019.

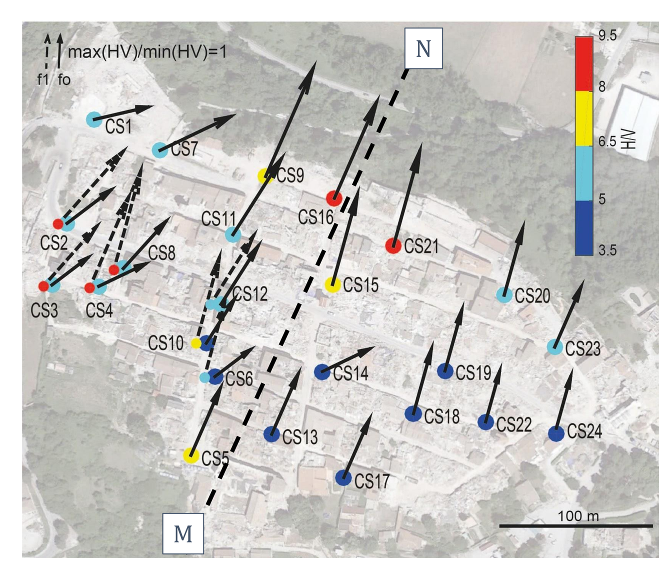
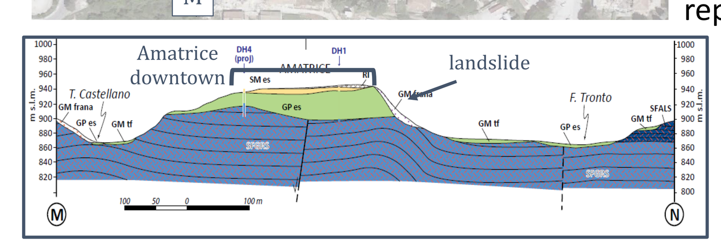


Figure 8. Polarization effects from rotated HVnoise. Arrows: direction of maximum peaks at fo=1.8-2.7 Hz (plain) and f1=2.7-3.2 Hz (dashed); their length is proportional to the amplification variation respect to the minimum amplification (i.e. the bar length increases for sites with strongly polarized effect). The circle color relates to maximum amplitude, the dashed line represents the geological cross-section trace.



Geological cross-section from Microzonation report (www.regione.lazio.it/prl_ambiente).

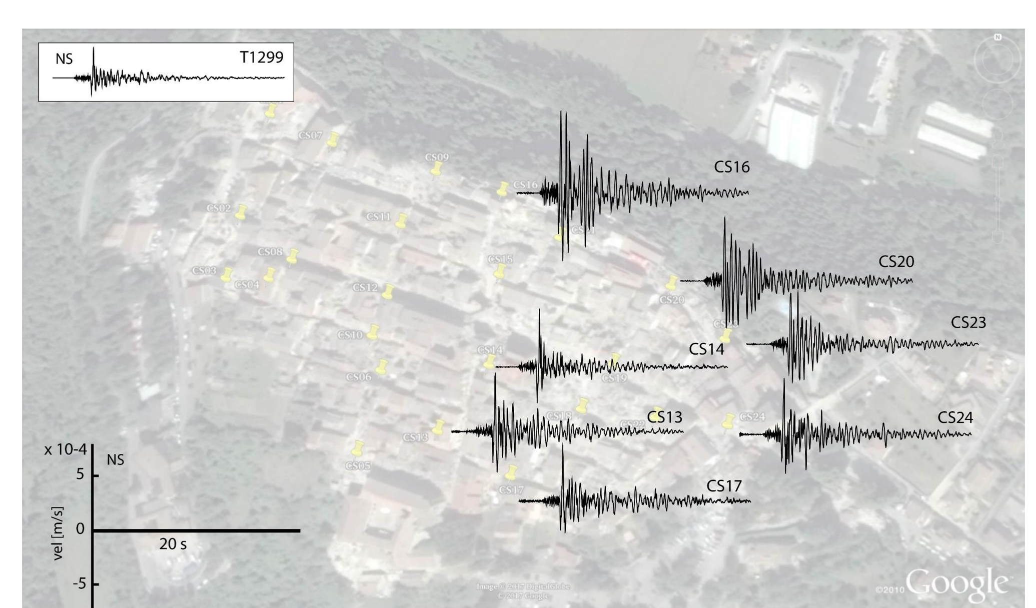


Figure 9. Time histories (NS component) recorded downtown for the June 29th, 2017, ML 3.1 seismic event

For stations (CS16-20-23) located close to the edge of the terrace slope, the amplification effects are more evident both in terms of peak ground motion and in the complexity of the waveforms. This feature, along with the clear polarization resulting from directional HVSR analysis, suggests a combination of stratigraphic and topographic amplification effects that probably played an important role in the damage produced by the August 24th event.

4 Ground motion recordings

- ✓ The network 3A operated in continuous recording mode from September 19, 2016, to the end of November 2016 (DOI: 10.13127/SD/ku7Xm12Yy9).
- ✓ Continuous data are distributed by *European Integrated Data Archive* (EIDA; https://www.orfeus-eu.org/data/eida) and by Engineering Strong Motion Database (ESM; https://esm.mi.ingv.it)
- ✓ Stations in Amatrice village were equipped with both velocimeter (Le-5s) and accelerometers (Episensor).
- ✓ They recorded hundreds of earthquakes of the seismic sequence (Fig.1), including the Mw 5.4 and 5.9 on October 26 and the Mw 6.5 on October 30, 2016, some regional earthquakes and the Mw 8.1 New Zealand event.

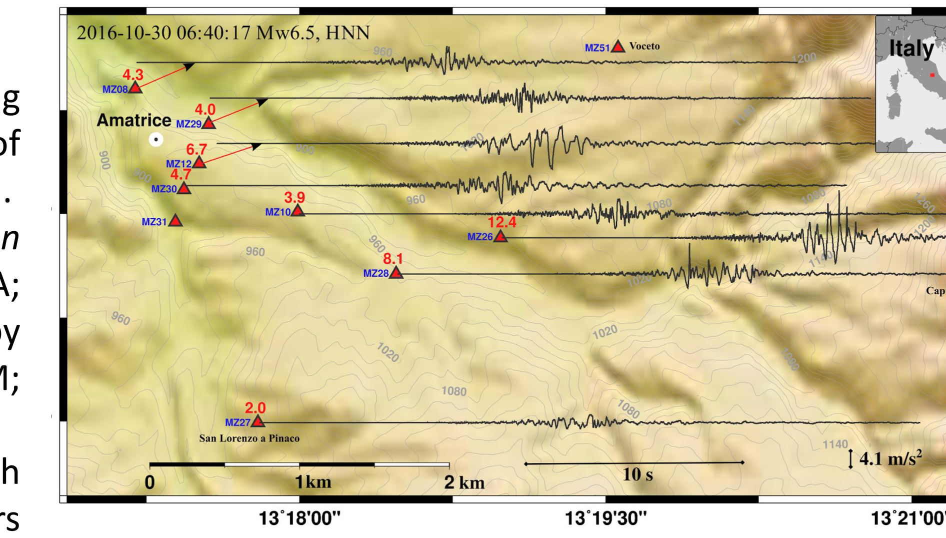


Figure 10. Mw 6.5 mainshock recorded by the network 3A. N-S components (EHN or HNN channels) recorded by stations at Amatrice during the 30th of October 2016 (Mw 6.5). Red numbers are PGA in m/s^2.

5 Reconstruction of August 24th, 2016, Mw 6.0 ground motion

Empirical transfer functions were used to recover the ground motion that could have hit the historical center of Amatrice during the August 24 mainshock, through the convolution with the only record few hundreds meters away from the historical center: IT.AMT station (belonging to the National Accelerometric Network RAN; http://ran.protezionecivile.it) that recorded a PGA of about 0.87 g.

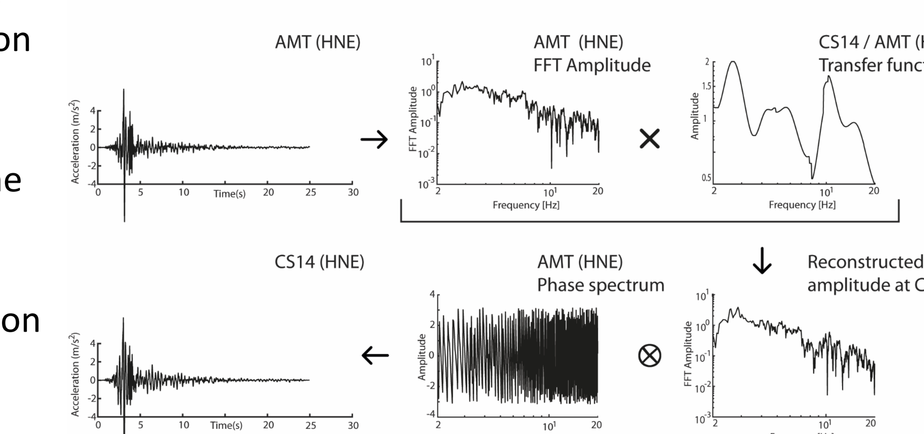


Figure 11. Method for ground motion simulation. The August 24th seismograms were reconstructed through the Inverse Fast Fourier Transform using the FFT phase of the reference station and the FFT amplitude modified by a transfer function of each station respect to a reference site. Seismograms are band-pass filtered at 2-20Hz.

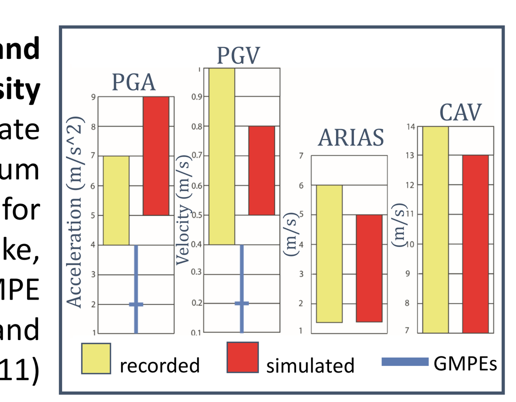
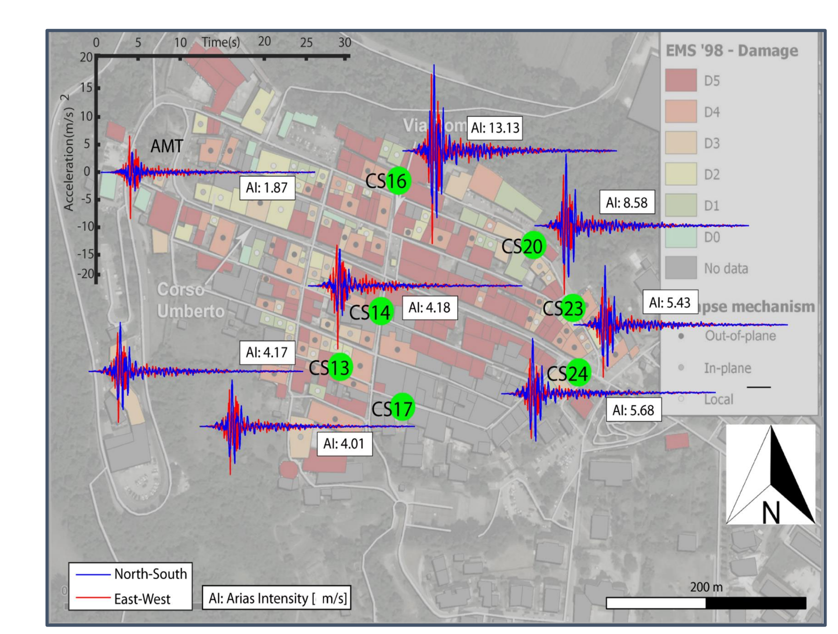


Figure 12. Recorded and simulated intensity measures. Bars indicate minimum and maximum value at the MZ stations for Mw 6.5 earthquake, compared with GMPE values for soil class B and Mw 6.5 (Bindi et al., 2011)

- ✓ Tests on the data quality reconstruction were performed, by using the recordings of the network 3A for the Mw 6.5 (October 30th, 2016).
- ✓ Recorded values exceed the GMPE prediction
- ✓ Simulated values well reproduce PGV and integral parameters (Arias Intensity, AI, and Cumulative Absolute Velocity, CAV), whereas they overestimate PGA showing larger variability.
- ✓ Failures: we don't account for the real phase content at the station, resulting in an unlikely coherence at high frequencies between the signals recorded at different sites, and we disregard the possible non-linear effects.



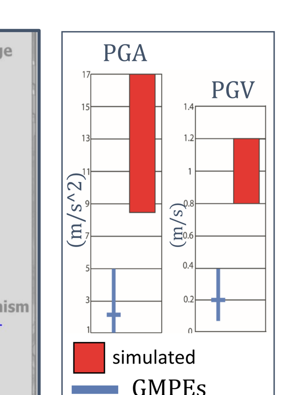


Figure 13. Mw 6.0 simulation. Reconstructed seismograms and intensity measures. Map shows EMS-98 damage distribution (Fiorentino et al., 2017).

We used the recordings of August 24th event at AMT station to simulate the ground motion in Amatrice downtown. The reconstructed peak values are much greater than expected from GMPE. This behavior could therefore justify the high intensity level and damage distribution (X-XI MCS; Galli et al., 2017). The reconstructed time series are characterized by the North-South motion larger than the transversal direction, due to polarization effects of the seismic waves.

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Priolo et al. Seismological analyses of the seismic microzonation of 138 municipalities damaged by the 2016–2017 seismic sequence in Central Italy. Bull Earthquake Eng (2019): 1-41. Doi: 10.1007/s10518-019-00652-x