MONITORING OF A HILL IN CENTRAL ITALY TO STUDY POSSIBLE TOPOGRAPHICAL EFFECTS: THE CASE OF NARNI (TR) RIDGE

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ABSTRACT

In the framework of the S4 Project – Task4- a monitoring activity was planned with the aim to investigate possible site amplification due to topographic irregularity affecting strong-motion stations. After geological and seismological surveys, the Narni hill (TR), in the Umbria region (Central Italy) was selected. Here, the analog RAN station, installed on the top of the hill, recorded only the 16 December 2000, Ml 4.1 earthquake, occurred at hypocentral distance of 5.5 Km.
Narni is a little village built on an elongated rocky ridge with NW-SE orientation, characterized by a vertical West side and by a moderate slope in the East one. In order to find suitable sites for installation, in February 2009 a microtremor survey was performed both at the top and at the bottom of the hill. On the basis of the results, obtained by Nakamura method (1989), 7 velocimetric stations (belonging both to INGV-MI-PV and INGV-CNT Department) were installed in 10 different sites from March 25 to September 7, 2009 .
As reference stations, three sites (NRN2, NRN3, NRN5) installed at the base of the ridge were selected. To complete the network, one site was installed at the mid of the East side (NRN1), while the other stations (NRN4, NRN6, NRN7, NRN8, NRN9 and NR10) were located on the top of the ridge, some of these nearly the vertical slope of the West side. The velocimetric network recorded 702 earthquakes in the magnitude range from 1.5 to 5.8 and epicentral distances up to 100 km. Most of the recorded events belong to the 6th April 2009 L'Aquila sequence. Preliminary results based on horizontal to vertical spectral ratios (HVSR; Lermo and Chavez-Garcia, 1993) and standard spectral ratios (SSR; Borcherdt, 1970) analyses show amplification peaks up to 6 in frequency band between 2 and 4 Hz, at stations installed on the top of the ridge. In particular, directional amplification in the transverse direction respect to the orientation of the ridge can be observed through the computation of rotated HVSR. Similar results were already found on noise measurements, showing larger amplification peak at frequencies around 3 Hz, when the HVSR is computed respect to EW component.

Site: ENEL Box
Municipality: **Narni** (TR)
Coordinates: 42.515 N – 12.519 E
Elevation: 290 m s.l.m
Date of installation: 10/12/1974

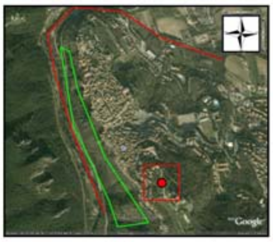


Fig. 1 The municipality of Narni (TR), is expanded on the top of a ridge, 1.35 Km long, with NNW-SSE orientation and characterized by an asymmetry in the steepness, with a vertical slope in the West side. Three transverse sections, respectively of 400 m, 550 m and 800 m are also indicated.

NTC (2008) : New Italian technical rule for building

Category	Features of topography	Location of buildings	St
T1	plane surface, slope or isolated relief with gradient i ≤ 15°	/	1
T2	slope with gradient i > 15°	at the top of the relief	1.2
T3	reliefs with crest width less than the base and 15°≤ i ≤ 30°	at the crest of the relief	1.2
T4	reliefs with crest width less than the base and i >30°	at the crest of the relief	1.4

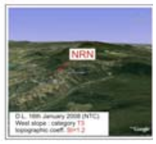


Fig. 2 According to the rules of *New Italian technical rules for building (NTC, 2008)*, Narni ridge could be classified as *T3*, having a width at the top smaller than the same one at the base and having an average slope (considering both sides) between 15° and 30°.

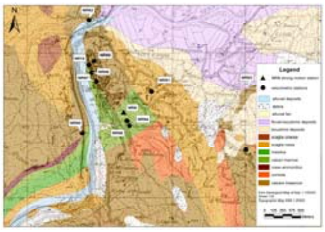


Fig. 3 1:100000 geologial map of Narni (TR). The dark dots indicate the temporary velocimetric seismic network. Massive limestone, cherty and marly limestone form the lithology of Narni ridge. At the base, alluvial deposits outcrop along the Nera river (West side), while lacustrine and fluvial deposits outcrop on East side locally overlapping the massive limestone. Isolated debris flows are present on SW and SE sides. The level of fracturation of the massive limestone is moderate, so that the geomechanical features do not modify the massive rock.

1 SEISMICITY OF NARNI (TR)

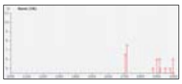


Fig. 4 **The historical seismicity of Narni** from 1700. (http://emidius.mi.ingv.it/DBMI04).The stronger earthquake occurred in 1714, with Is 7-8 and Mw=5.37.

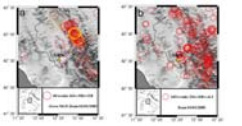


Fig. 5 **The instrumental seismicity of Narni**. a: events with Ml ranging from 4.0 to 5.8 (Repi up to 50 Km) occurred from 01 January 1983 (in yellow the events with Ml > 5.0); b: events with 3.0<Ml<4.3 occurred from 01 January 2000 (http://bollettinosismico.rm.ingv.it/).

2 16/12/2000 NARNI EARTHQUAKE (Ml 4.1)

On 16th December 2000, a Ml 4.1 earthquake occurred at hypocentral distance of 5.5 Km from Narni, located at NE respect to the municipality.

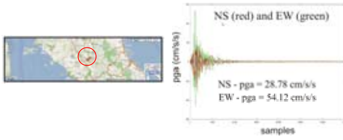
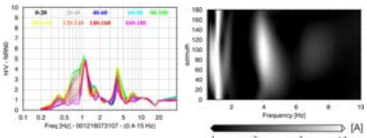


Fig. 6 NS (red) and EW (green) components of 16 December 2000, Ml 4.1, Narni earthquake recorded by the NRN strong motion station. The larger PGA values (54 cm/s/s) was recorded on the EW component. Since the azimuth of the event with respect to the ridge elongation was 90°, the difference in the observed PGAs could be due to directional propagation effects.

Fig. 7 Left: HVSRs (Lermo and Chavez-Garcia, 1993) computed considering the ratio between the radial component and the vertical one. The amplification functions represent subsequent rotation of the radial component between 0° and 180° with step of 5°. The highest amplifications have been detected for frequencies of about 1 Hz (with amplification up to 5) and around 4 Hz (with amplification up to 4). In both case the maximum was detected for direction transverse with respect to the ridge under study (between 80° and 100°).
Right: the same results obtained in the left panel but showed by the Frequency-Azimuth plot.



3 NOISE MEASUREMENTS

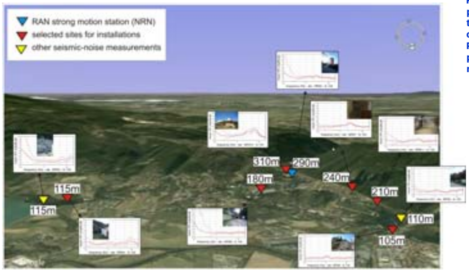


Fig. 8 East side view of Narni: noise HVSRs between horizontal components over the vertical one.

In order to select the most suitable sites for housing the stations of the temporary velocimetric network, on February 2009, several noise measurements were performed, some of these at the base of the ridge, and the others both at the top of the ridge and in the middle of the slope (East side).
PROCESSING: Noise-HVSRs (Nakamura, 1989) were performed considering at least 30 minutes of ambient noise signal, recorded with sampling rate of 100 Hz.

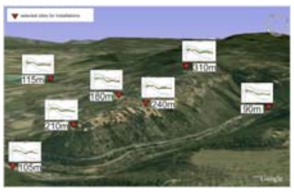


Fig. 9 East side view of Narni: Power Spectrum Density (Peterson, 1993).

Fig. 10 West side view of Narni: noise HVSRs between horizontal components over the vertical one.

The mean and linear trend were removed, Butterworth 4 poles filter between 0.2 Hz and 25 Hz was applied. Signals were windowed in time series of 60 s (%5 cosine taper). For each time window the FFT was calculated, and then smoothed by using a Konno Ohmachi window (b=20). For each window, spectral ratio was calculated between the root mean square average spectrum of the horizontal components over the vertical one. The average HVSR and the standard deviation were finally computed.

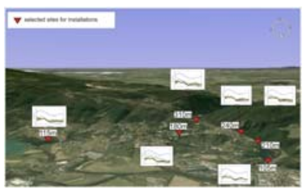
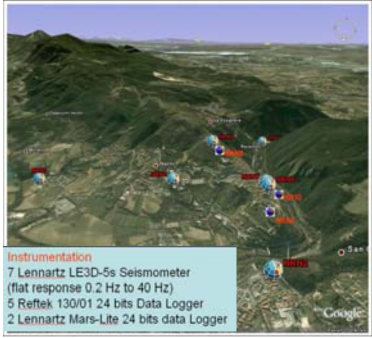


Fig. 11 West side view of Narni: Power Spectrum Density (Peterson, 1993).

4 THE TEMPORARY VELOCIMETRIC NETWORK

The temporary velocimetric network finally included 10 stations. All stations were installed directly on rock.
The stations used as reference sites were installed at the base of Narni ridge, in the basement of Madonna del Ponte Shrine (NRN2), at ex Miriano aqueduct (NRN3), in free field, and in the court of "Palmira" Restaurant (NRN5). The station at half slope is set on east side in S.Girolamo storehouse theatre and named NRN1. The stations at the top of Narni ridge are NRN4 and NRN8 installed in the basement of Albornaz stronghold, NRN6 in the basement of Narni Civil Protection building and NRN7 in the basement of Eroli Palace in correspondence of the break of the ridge on west side, NRN9 in the basement of a car parking and NR10 in the undergrounds of Narni. All stations are provided of Lennartz LE3D-5sec seismometers equipped with a Reftek 130/01-24 bit data logger and MarsLite digital recorders. The sampling ratio is 125 Hz.



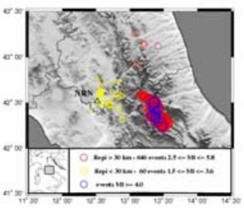


Fig. 12 Left: The temporary velocimetric network; Right: dataset recorded by the velocimetric network in the period 25 march 2009 - 7 September 2009. The dataset includes 706 earthquakes with Ml ranging from 1.5 to 5.8 and epicentral distances up to 100 km.

NRN4-NRN8 (top)

NRN7 (top)

NRN2 (base)

NRN5 (base)

Fig. 13 Some example of installation. NRN4/8 and NRN7 represent one of the two stations installed at the top of the ridge. NRN2 and NRN5 represent two of the three reference stations.

5 HVSRs

Most of the records included in the dataset (about 600 events), belong to the 6th April 2009 L'Aquila sequence. Preliminary results based on horizontal to vertical spectral ratios show, in agreement to the noise-results, constant amplifications, detected for the stations located at the top of the ridge, between 3 and 4 Hz (with amplification factor up to 6). In many cases it is possible to observe the higher amplification for transverse directions respect to the orientation of the ridge.

The example for the 6th April 2009, Mw 6.3, L'Aquila earthquake. The epicentral distance is 68 km and the azimuth is 107°

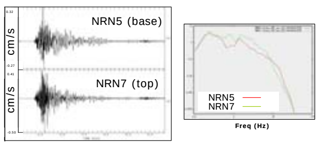


Fig. 14 Left: Waveforms for WE components recorded at NRN5 (base) and NRN7 (top). Right: FFT computed on the S–phase for the same records.

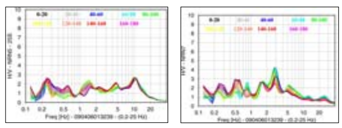


Fig. 15 HVSRs computed for rotating the radial component between 0° and 180° (step of 5°). The results are reported for stations NRN5 (left) and NRN7 (right).

Other examples

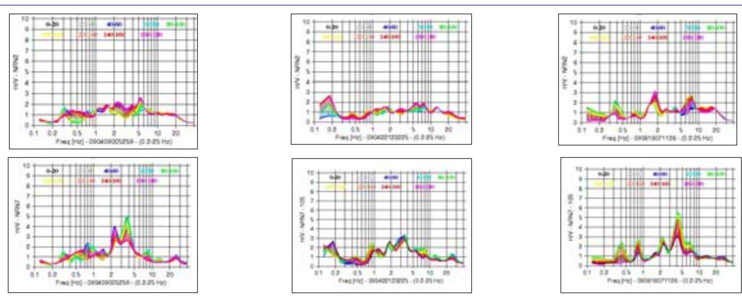


Fig. 16 HVSRs for the 09th April 2009, Mw 5.1, L'aquila aftershock. R-epi 68 km km and azimuth 94°.

Fig. 17 HVSRs for the 22th April 2009, Ml 3.6, earthquake. R-epi 26 km and azimuth 89°.

Fig. 18 HVSRs for the 16th August 2009, Ml 3.1, earthquake. R-epi 16 km and azimuth 108°.

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