5th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Crete Island, Greece, 25–27 May 2015

ANALYSIS OF GROUND MOTION ALONG A TOPOGRAPHIC RELIEF: THE CERRETO DI SPOLETO CASE-HISTORY (CENTRAL ITALY).

Dario Rinaldis[1], Salomon Hailemikael[2] , Antonella Paciello[2] and Guido Martini[3]

[1] ENEA, CR Casaccia, Roma Italy
e-mail: dario.rinaldis@enea.it

[2] ENEA, CR Casaccia, Roma Italy
{salomon.hailemikael,antonella.paciello}@enea.it

[3] ENEA, CR Frascati, Roma Italy
e-mail: guido.martini@enea.it

Keywords: temporary seismometric network, permanent accelerometric network, topographic amplification, horizontal-to-vertical spectral ratio method.

Abstract. *With the aim of evaluating the seismic hazard and vulnerability of villages with valuable historical monuments in Central Italy, since the late 80's ENEA operated an accelerometric network at the Cerreto di Spoleto village in the area of Central Apennines. The area is characterized by high level instrumental seismicity and seismic hazard. The accelerometric network, consisting of one station located at a rock site close to the hill base and of two accelerometers located inside a building at the relief top, recorded the Umbria-Marche aftershocks of 1997 as well as more recent earthquake sequences. In 2001 a temporary seismometric network was deployed at Cerreto di Spoleto village in order to better characterize the ground motion spatial variability along the ridge. The accelerometric network, consisting of one station located at a rock site close to the hill base and of two accelerometers located inside a building at the relief top, recorded the Umbria-Marche aftershocks of 1997 as well as more recent earthquake sequences. Analysis of the accelerometric records pointed out broadband seismic amplification above 1 Hz at the relief top. In 2001 a temporary seismometric network was deployed at Cerreto di Spoleto village in order to better characterize the ground motion spatial variability along the ridge. The seismic station were deployed at the ridge base and along the crest. To this aim we analyzed waveform in the frequency domain through the Horizontal-to-vertical spectral ratio method. Except for the trapped waves effect, the results showed no clear evidence of ground motion amplification for the stations located on the crest. This evidence suggests that the seismic amplification observed on the accelerometric records is not related to topographic amplification.*

1 INTRODUCTION

In reports of destructive earthquakes is often described more severe damage in relief areas with respect to foothills [1] and amplifications of ground motion on top of topographic features have been widely highlighted in the scientific literature [5,6].

In general the experimental observations obtained by either time domain or spectral methods demonstrated that: (i) the seismic motion amplification occurs at mountain tops and it is larger in the horizontal component normal to the ridge trending axis; (ii) amplification is usually moderate, reaching maximum values of about 10 fold in few particular case studies [10]; (iii) the frequency at which amplification occurs is related to the fundamental mode of vibration of the topographic feature and corresponds to wavelengths comparable to ridge half width.

The present work is devoted to the analysis of occurrence of topographic amplification at the Cerreto di Spoleto hill which is an elongated ridge located in an area of the Italian territory characterized by moderate seismicity and selected in 2001 as a test site for site effects evaluation.

2 GENERAL SETTINGS

The Cerreto di Spoleto ridge is located in the Central Apennines, which is a mountain range crossing almost the entire Italian peninsula from N to S and is characterized by a thrust belt structure [2]. The study area is in the Umbria-Marche section of the Apennines, close to the Nera river valley (Valnerina) (Fig. 1a).

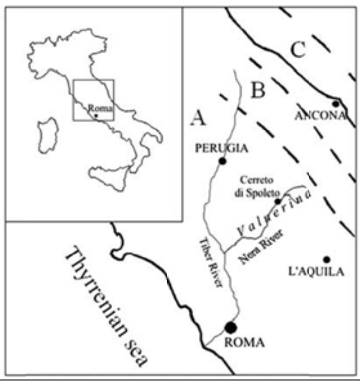

Figure 1a. Study area location, after [9].

The region is characterized by an important seismic activity both instrumental and historical. In fact, the Valnerina area was struck by several earthquake swarms during the centuries, such as the 1703 (estimated epicentral intensity XI MCS) sequence and the recent 1997 sequence (average intensity, VIII MCS). The Cerreto di Spoleto hill is a NW-SE trending ridge with height ranging between 200 to 250 m with respect to the adjacent Nera river valley and steep flanks. The hill is mainly made of limestone rock. The ridge is characterized by the presence of several faults belonging to two major systems: one trending about NS and one with strike about N30°W (Fig. 1b).

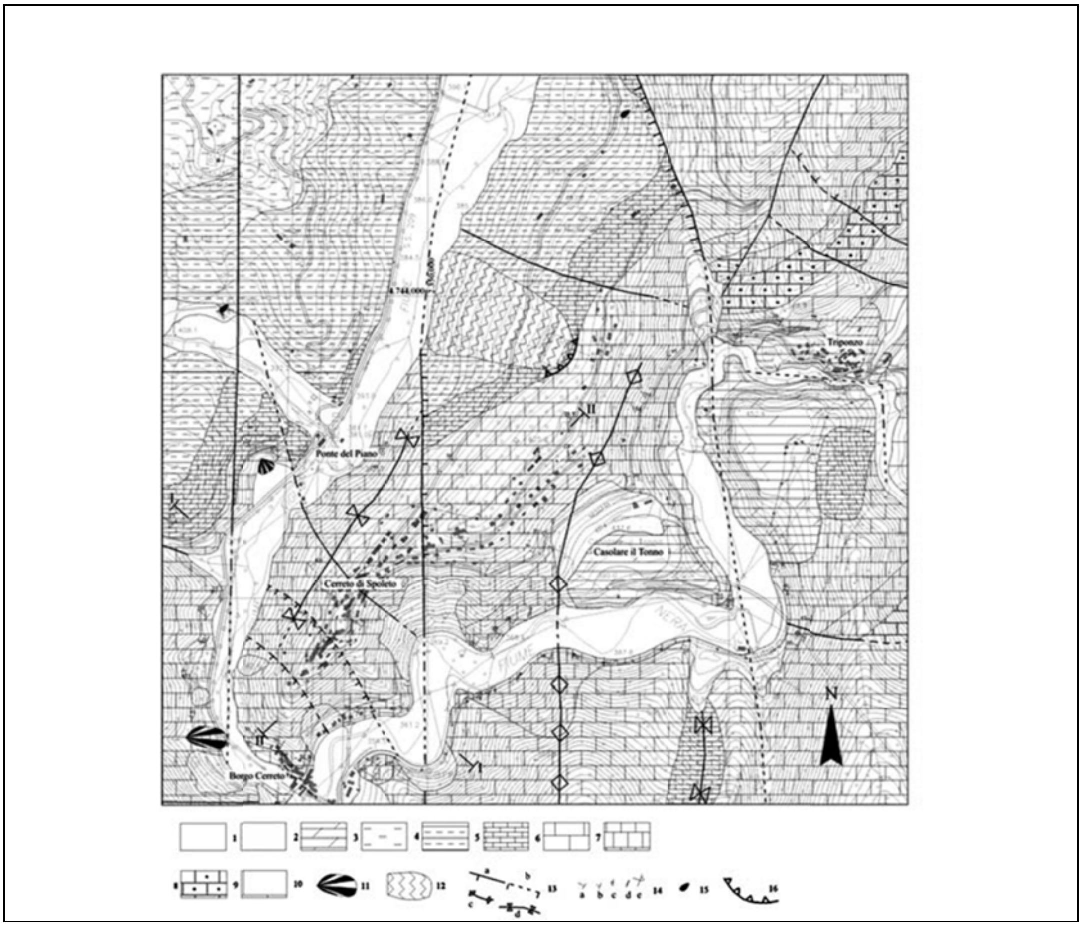

Figure 1b. Geologic map of the Cerreto di Spoleto area. (1) alluvial deposits; (2) slope debris; (3) travertine deposits; (4) Bisciaro Formation (lower Miocene–middle Miocene); (5) Scaglia Cinerea Formation (upper Eocene–lower Miocene); (6) Scaglia Variegata Formation (middle–upper Eocene); (7) Scaglia Rossa Formation (upper Cretaceous–middle Eocene); (8) Scaglia Bianca Formation (lower Cretaceous–middle Cretaceous); (9) Marne a Fucoidi Formation (lower Cretaceous); (10) Maiolica Formation (upper Jurassic); (11) alluvial fan; (12) landslide debris; (13) certain fault (a), uncertain fault (b), anticlinal axis (c), synclinal axis (d); (14) attitude of beds: <30 (a), 30-50 (b), >50 (c), vertical (d), reverse (e); (15) spring; (16) landslide scarp, after [9].

3 SEISMOMETRIC DATA ANALYSIS

In order to evaluate the occurrence of topographic effects at the top of the Cerreto di Spoleto hill, we performed spectral analysis of a previously acquired waveform dataset. The weak motion data were recorded during a seismic monitoring experiment performed in 2001 and aimed at site effect estimation along the Nera river valley and across the Cerreto di Spoleto hill. The temporary network was made by 7 stations, deployed as depicted in Figure 2, equipped with K2 Kinemetrics acquisition system coupled with 3-1 component Ranger SS1-1Hz seismometers aligned with the NS, EW and Vertical directions. The stations were equipped with GPS for absolute timing and the sampling frequency was set to 200 Hz. The network recorded about 20 small magnitude local events which were analyzed by means of standard spectral ratio (SSR) [3, 4] as well as Horizontal-to-vertical spectral ratio (H/V) [7, 8] techniques in a previous paper [9] was observed site amplification at one of the stations located at ridge top as a consequence of trapped wave propagation inside a fault zone, i.e. a very local effect not related with topography.

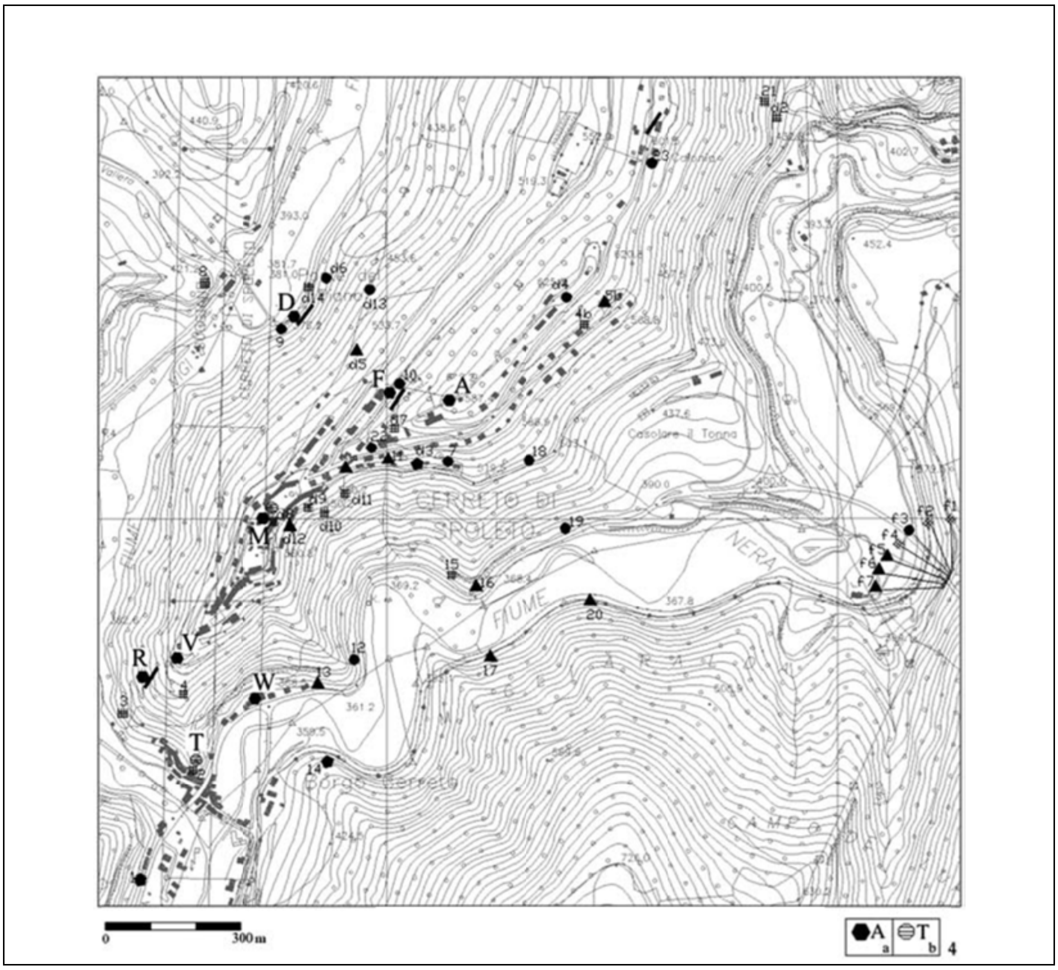

Figure 2. Velocimetric (a) and accelerometric (b) station locations, after [9].

With respect to previous analysis we decided to analyze this dataset with the same techniques, but windowing the waveform around the S phase. In particular, we selected 6 events with SNR>3 among the dataset and decided to use signals recorded only at stations M, F and A located along the ridge crest and at station R considered as reference. After correcting for the instrument response, the records of each event and component were windowed around the S phase. To window the data we used a 5% cosine-taper window which started about 1 second prior the S phase onset and ended 10 s later. The resulting signals were de-trended and converted to the frequency domain. The calculated spectra were smoothed using a 0.35-Hz running frequency window. Finally we used the smoothed spectra of the north-south (NS), west-east (WE) and vertical (V) components to calculate the SSR and the NS/V and WE/V spectral ratios. We derived the H/V curve, for each event and station, as the geometric average of the NS/V and WE/V ratios and the SSR curve as the geometric average of the NS and WE smoothed spectra divided by the geometric average of the same components recorded at the reference station. The results are depicted in Figure 3a and Figure 3b, in terms of average SSR and H/V functions respectively, in the frequency band 0.5-10 Hz.

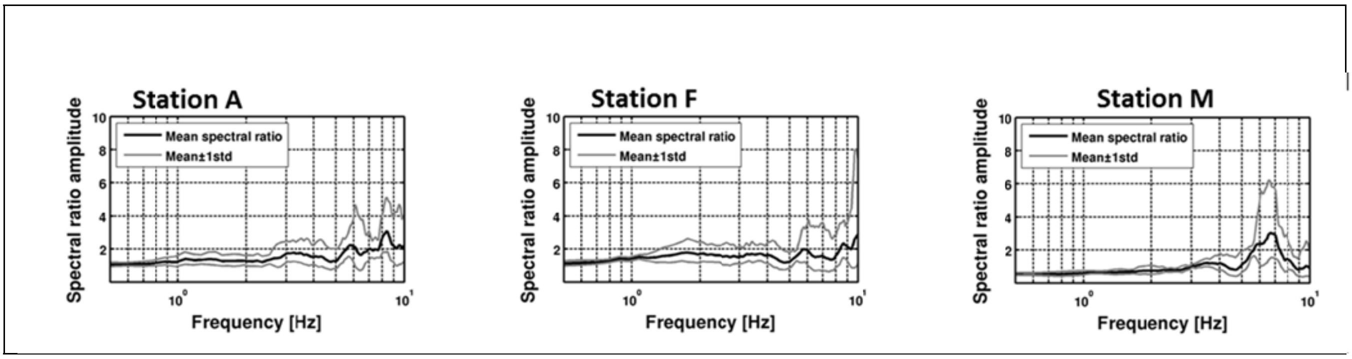

Figure 3a. SSR functions calculated at the considered stations

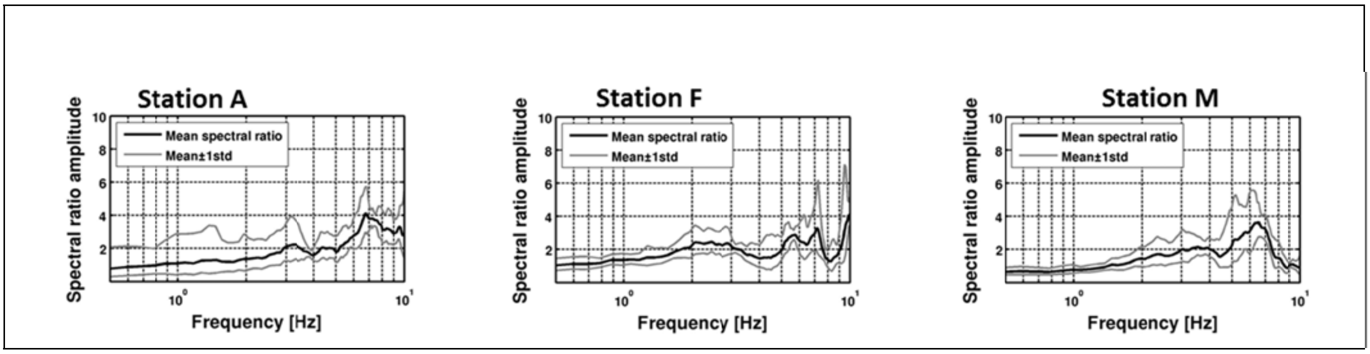

Figure 3b. H/V functions calculated at the considered stations

The results confirmed the occurrence of ground motion amplification both in terms of SSR and H/V functions at the M station. The average amplification level is between 3 and 4 in the narrow frequency band between 6-7 Hz. At station F, the average SSR function shows flat shape with amplitude value between 1 and 2, while the H/V function shows amplitude just above level 2 in the frequency band 2-3 Hz and 5-7 Hz and about 10 Hz. At station A, the average amplitude of SSR function is about 1 almost in the whole considered frequency band, while the H/V function shows maximum amplitude level between 6 and 8 Hz. While the results obtained at station M are in agreement with those obtained by [9] and related with trapped wave propagation, the results obtained at the F and A station suggest to exclude the occurrence of topographic site effects. In fact, given the high frequency range of the SSR and H/V maxima at the two stations, as the dimension of the hill is in the order of hundreds of meters, the slight amplification is likely related to the presence of a weathered rock layer below the stations, rather than to the hill fundamental mode.

4 ACCELEROMETRIC RECORDS

The accelerometric array of Cerreto di Spoleto [11], since the deployment, recorded several seismic events. Here records obtained during the period 2005-2010 at all the accelerometric stations are analyzed. Frequency domain analysis, by means of acceleration Fourier Amplitude Spectrum (FAS) of records, were performed. In figure 2 the position of the stations of the accelerometric array is shown. In particular, on the ridge, M is the station of Municipio (the building where the City Hall is located), where two digital accelerometers were deployed (the first one at the basement of the building, CMC station; the other at roof, CMS station). Then T is the station near a bell-tower named BCT. Events recorded at all stations (BCT, CMC and CMS) are listed in Table 1 with date, time origin, epicentral coordinates and magnitude. The maximum PGA between the two horizontal components of the analyzed records are also listed. As shown, event magnitudes were small, and ground-motion PGA was ranging between few gals to 0.1 g (at CMS station). The first 5 records listed in table 1 were originated in Val Topino (see figure 4a) when the others were originated in Val Nerina (see figure 4b). Figure 5a and 5b shows the FAS of acceleration (NS and WE components) for the records obtained at the BCT station and figures 5c and 5d the same for the CMC station.

Figure 4. a) Recorded Events in Val Topino; b) Recorded events in Val Nerina.

EVENT DATA				RECORD DATA		
Date	Time	Epic. Coord.	Magnitude	PGA CMC (cm/s^2)	PGA CMS (cm/s^2)	PGA BCT (cm/s^2)
15.12.2005	06:00:30	42.748 12.773	Ml=3.3	8.40	31.40	11.75
15.12.2005	13:28:37	42.738 12.760	Ml=4.2	27.95	71.03	27.81
16.12.2005	20:12:36	42.735 12.735	Ml=3.4	7.64	29.77	10.76
18.12.2005	08:06:46	42.738 12.753	Ml=3.5	8.82	20.82	12.87
05.01.2006	17:30:39	42.744 12.756	Ml=3.6	11.86	35.70	20.18
08.02.2007	01:32:55	42.820 13.217	Ml=3.8	19.25	43.68	11.47
06:08.2009	10:23:41	42.793 13.176	Ml=2.3	8.02	27.07	8.60
10.01.2010	08:33:38	43.119 13.445	Ml=4.0	6.77	20.63	6.86
12.01.2010	08:25:14	43.119 13.451	Ml=4.1	7.81	21.58	8.83
12.01.2010	13:35:48	43.135 13.433	Ml=4.2	5.92	14.23	6.74
28.08.2010	07:07:56	42.834 12.654	Ml=4.1	6.54	17.01	6.58
06.12.2010	10:32:04	42.793 13.011	Ml=3.4	19.24	96.10	27.29

Table 1. Records from Cerreto di Spoleto strong-motion array (ETNA).

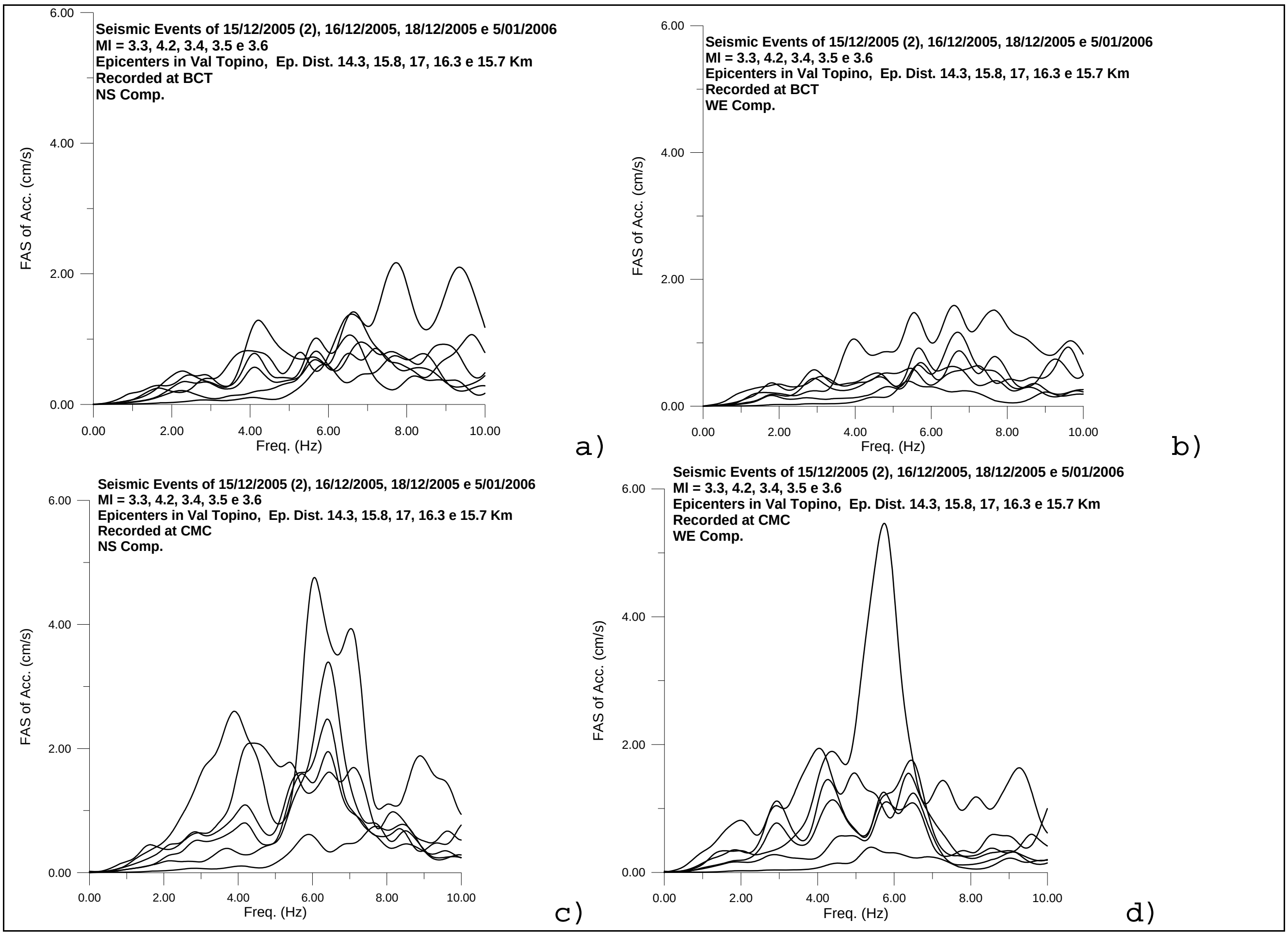

Figure 5. FAS of acceleration (NS and WE components) for the records obtained at the BCT (a and b) and CMC (c and d) stations.

In previous papers [11, 12] was stated, as preliminary result, that for all the analyzed events the FAS of acceleration at the CMC station is larger than the one obtained at BCT station in the frequency interval between 2-8 Hz.

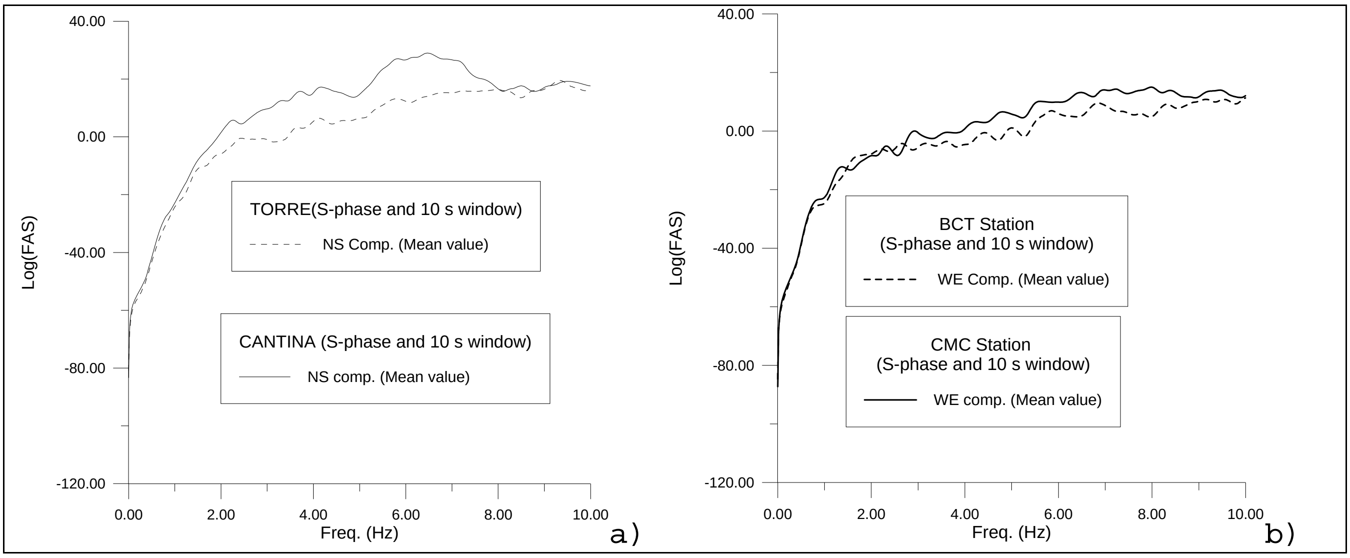

Figure 6. Cerreto di Spoleto accelerometric array: mean values of FAS of recorded accelerations at BCT and CMC stations (a) NS component; (b) WE component.

To confirm this behaviour a mean of the spectra was computed at both BCT and CMC stations. Figure 6a shows the averaged spectra for the NS components and figure 6b the WE ones: the FAS of acceleration in the frequency interval of 2-8 Hz is larger at the CMC.
Then a spectral ratio between the two horizontal component of acceleration, recorded at CMC and BCT, was computed to have a better evidence of the spectral amplification. Figure 7a and 7b show a clear amplification in the interval of interest. The averaged records were from the last six events listed in table 1. The results should be interpreted carefully since the standard deviation is large.

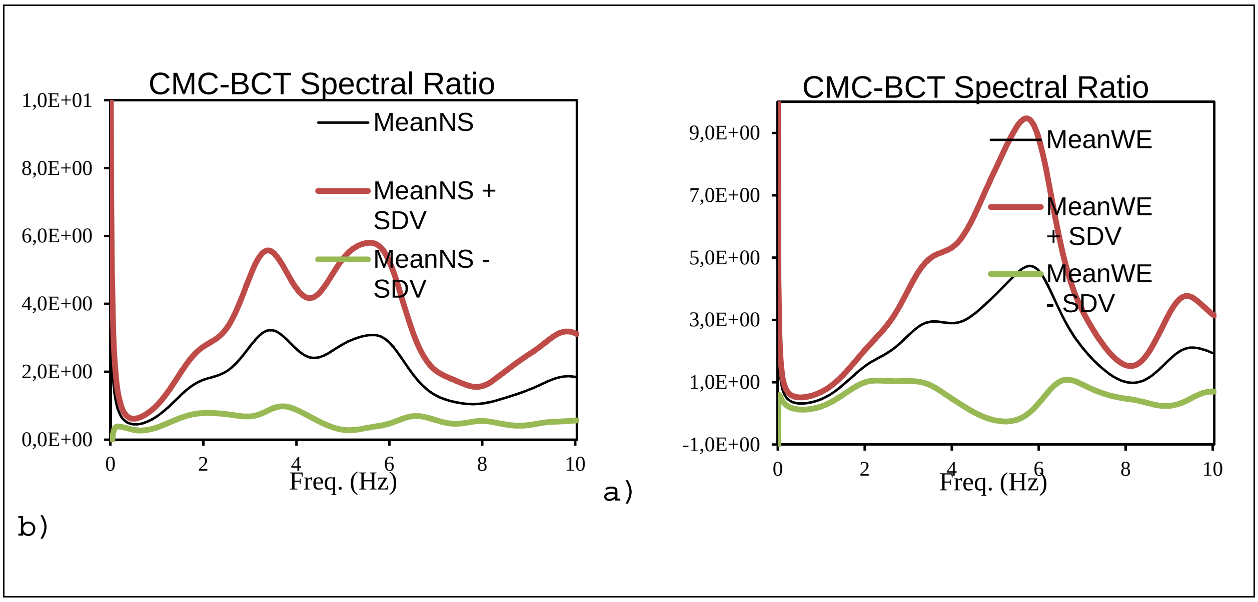

Figure 1. Mean Ratio between the FAS of acceleration of six events recorded at the BCT and CMC stations of the Cerreto di Spoleto accelerometric array: NS component (a), WE component (b).

5 CONCLUSIONS

As already highlighted by [9], the analysis of waveform recorded at the Cerreto di Spoleto hill, showed the occurrence of ground motion amplification in the frequency band 6-7 Hz at the ridge top in a specific location and related to trapped wave propagation. At other two stations located at the ridge top, we did not observed the occurrence of ground motion amplification at frequencies consistent with the hill dimension. We observed slight amplification at one station in terms of H/V function, above 6 Hz, likely related to the presence of a shallow weathered rock layer. The analysis of accelerometric waveforms recorded at the ridge top and base, showed ground motion amplification in a broad frequency band between 2 and 8 Hz. While the amplification above 6 Hz at ridge top is consistent with that obtained by the analysis of velocimetric records, the 2- 6 Hz amplification was not observed by the 2001 seismic experiment. These results, seems to indicate a particular behavior of the Cerreto Torre accelerometric station, which may de-amplify the seismic ground motion in the 2-6 Hz frequency band.

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