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THE CENTRAL ITALY 2016 SEISMIC SEQUENCE RECORDED AT THE CERRETO DI SPOLETO STRONG-MOTION STATIONS.

Dario RINALDIS [1], Salomon HAILEMIKAEL [2], Guido MARTINI [3]

ABSTRACT

In the 80's ENEA installed a strong-motion network in the Cerreto di Spoleto village, Umbria region (Central Italy). The site was selected because it is located in the Central Apennines, where relevant seismogenic sources of Italy are mapped and the seismic hazard level is higher at the national scale. Moreover, the site is also characterized by geological and geomorphological conditions that may induce a significant increase of the expected ground-motion due to site effects. The strong-motion network is made of four stations: two are located inside a building on top of the Cerreto di Spoleto ridge (CMC at basement; CMS), one is located at the foot of the ridge (BCT) and the last one is located inside the nearby alluvial valley of the Nera river (BCC). During the Central Italy 2016 seismic sequence that affected Lazio, Abruzzo Marche and Umbria Regions several main shocks and a huge amount of aftershocks were recorded at these strong-motion stations. From these recordings, corrected accelerations, velocities and displacements waveforms have been calculated in time domain. Moreover, Fourier amplitude spectra and response spectra were also calculated. On August the 24th 2016, the network acquired 21 accelerometric records with magnitude ranging between 2.5 to 6.0. The epicentral distance span the interval 4 - 37 Km. In this paper, we focused on the 7 events with magnitude Ml > 4.0 and epicentral distance less than 30 Km recorded at CMC and BCT stations. Analysis of records obtained during events of larger magnitude are in progress and some preliminary results show peaks in the FAS of acceleration at very low frequency (~1- 2 Hz).

Keywords: Time domain and frequency domain analysis.

1. INTRODUCTION

A significant normal-faulting rupture earthquake shook central Italy the 24th of August 2016, and in particular the towns of Amatrice and Accumuli in the Latium region and Arquata del Tronto in the Marche region. The seismic event affected also the town of Cerreto di Spoleto, in the Umbria region, where was located a strong-motion array of four stations, deployed by ENEA since the early '80s, with slight damage to the structures. The CMC, BCT and BCC stations recorded several events; table 1 lists the source parameters for the events with magnitude Ml> 4.0. Records were analyzed in time and frequency domain and response and amplitude spectra were compared to the main frequency to the typical building in Cerreto di Spoleto. Then recorded RS were compared with the NTC08 building code; PGA, PGV and PGD were computed and PGA compared with the predicted by the GMPE ITA10 (Bindi et al., 2011). Accordingly, examining both the response spectra and amplitude spectra it was fair to state that, although there are some differences, the frequency content of CMC and BCT are quite similar and definitely exposes the fact that the shaking (in the free-field) is rich in frequencies (e.g. 2-10 Hz) that are typical of the 1-3 story buildings in the town.

[1]Researcher, ex ENEA, Rome, Italy, rinaldis.dario@tiscali.it
[2]ENEA, Rome, Italy, salomon.hailemikael@enea.it
[3]ENEA, Rome, Italy, guido.martini@enea.it

2. GENERAL SETTINGS

The Cerreto di Spoleto village is located in the Central Apennines, where the seismic hazard level is one of the highest in Italy (PGA between 0.22 and 0.27 g at 10 % probability of exceedance in 50 years; http://esse1-gis.mi.ingv.it). In particular, the historical center lies on a 550 m high limestone ridge elongated in the NE-SW direction (Figure 1). The municipality also extends in the nearby Nera river valley, an alluvial plain characterized by a strong heterogeneity of the sediment filling. The valley is primarily filled with coarse to sandy–silty alluvial deposits passing to slope debris at the valley edges. For this sector of the Nera river valley, the occurrence of a significant 2-D amplification effect has been documented in recent studies both by instrumental and numerical methods (Lenti et al., 2009).

The Cerreto di Spoleto ridge is mainly composed of limestone and marly limestone geologic units ascribable to the Umbria-Marche pelagic succession (Bartoccini et al., 1995). These geologic formations are intensely folded and faulted due to the Apennines orogenetic process (Cipollari et al., 1995), therefore the limestone units show intense jointing conditions at the outcroppings. In particular, a previous study devoted to the analysis of the site response at the Cerreto di Spoleto ridge, provided a zonation of the rock masses constituting the ridge on the basis of the mechanical properties inferred by geomechanical surveys (Figure 2; Martino et al., 2006).

We focused the attention on the recording obtained for the Central Italy 2016 seismic sequence acquired at the CMC and BCT strong-motion stations. These stations are both located on the Cerreto di Spoleto ridge:

- CMC at the basement of the city-hall, a 3 stories masonry building located on the top of the ridge (Figures 1 and 2);
- BCT installed in a reinforced concrete pillar nearby a medieval tower (about 10 m height) located at the base of the ridge (Figures 1 and 2).

It is worth to note that the CMC station is installed on the trace of a fault. For this station a strong frequency dependent amplification has been found by Martino et al. 2006. The authors found that this phenomenon is due to trapped wave generation inside a 50 m wide fault zone area where the CMC station is located.

In terms of Building code classification (DM 14 gennaio 2008, NTC08), both stations can be classified as Class A site, where the average shear wave velocity in the uppermost 30 m (Vs30) is higher than 800 m/s and for which no modifications of the ground-motion are expected because of the occurrence of site effects due to strong impedance contrast in the subsurface structure. However the geomorphological conditions at the two stations are very different. In fact, in terms of NTC08 topographic conditions, the CMC site can be classified as T4 while BCT as T1. This means that topographic amplification of ground-motion can be expected for CMC.

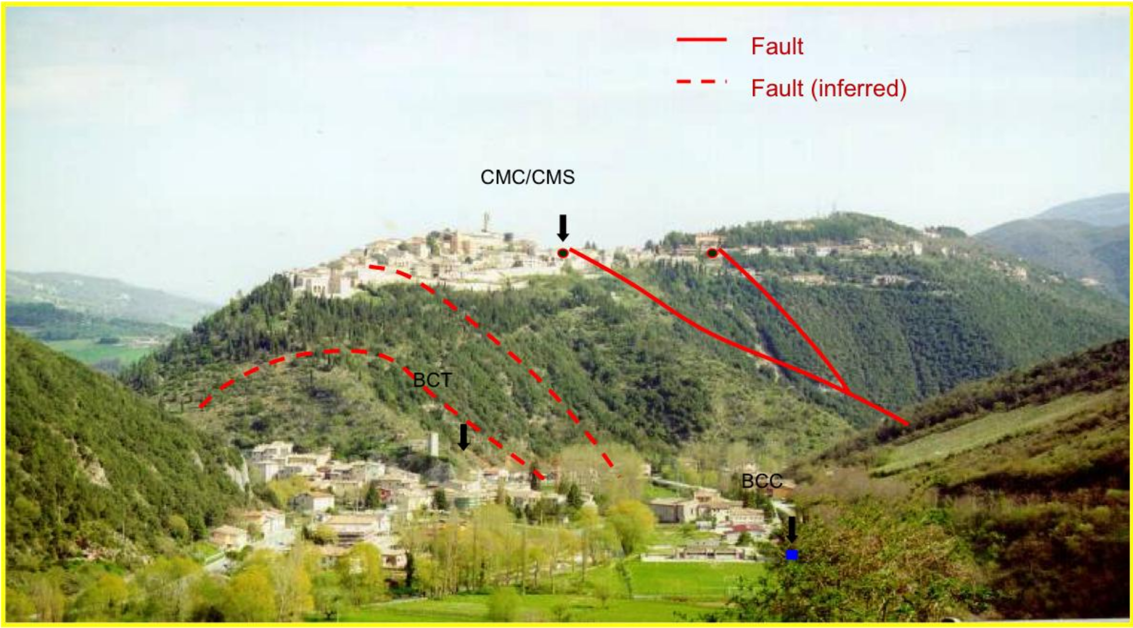

Figure 1. Picture of the Cerreto di Spoleto ridge with positions of the strong-motion network sensors. The image also shows the main faults in the area.

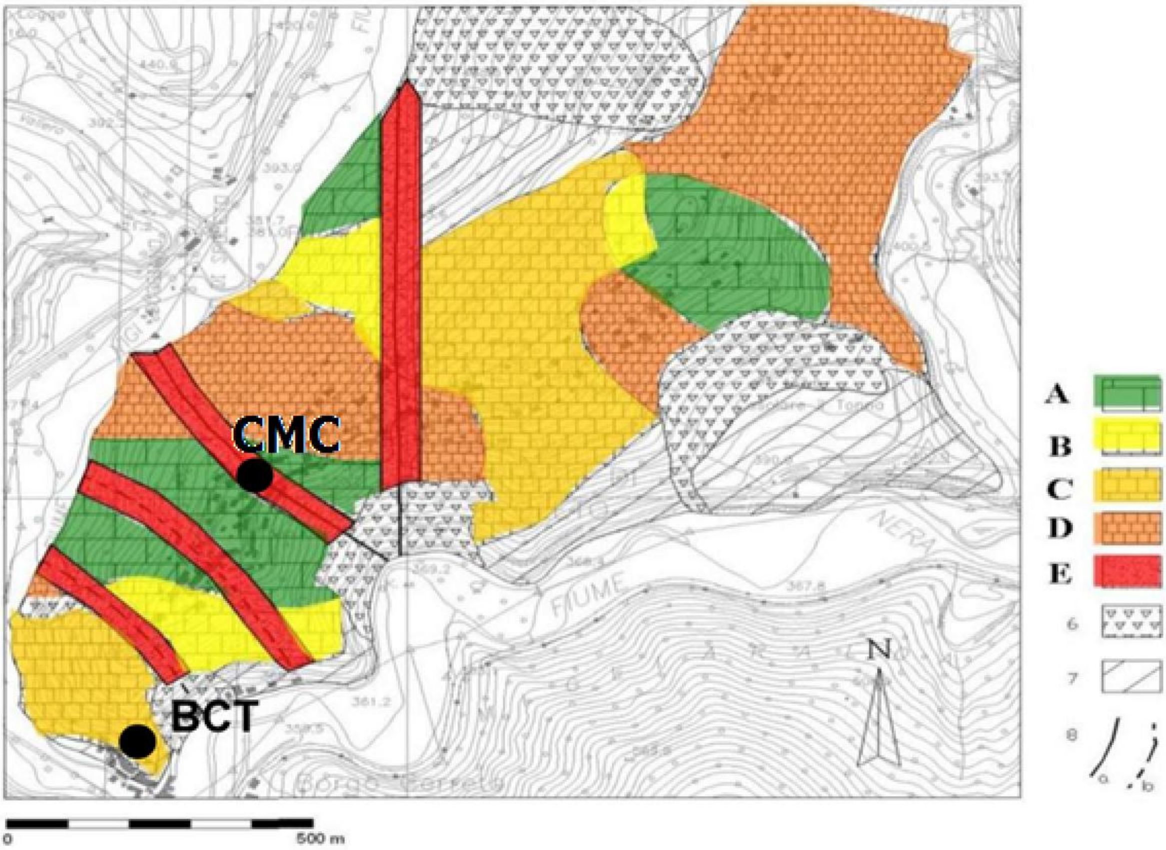

Figure 2. Map of the rock mass quality in the Cerreto di Spoleto ridge. The different colors are related to the rock masses mechanical properties estimated by geomechanical surveys. The stiffness of the rock mass decreases passing form green color to red (A to E in legend). The positions of the CMC and BCT strong-motion stations are also reported as black dots (modified after Martino et al., 2006).

3. DATA ANALYSIS

Following the August 24th 2016 main-shock a long seismic sequence struck Central Italy causing strong damage in numerous towns. In particular, it caused casualties and almost complete destruction in the municipalities of Amatrice, Accumoli and Arquata del Tronto (Tertulliani and Azzaro, 2016). In the August 24th the CMC and BCT stations recorded acquired 21 accelerometric records with magnitude ranging between 2.5 to 6.0. The epicentral distance span the interval 4 - 37 Km.
In this paper, we focused our attention on the 7 events with local magnitude larger than 4. The source parameters are reported in Table 1, extracted from the Italian seismic catalog (www.ingv.it).

Table 1. Source parameter of the analyzed events (source: http://cnt.ingv.it).

File ID CMC	File ID BCT	Date	Trigger Time	Epicentral area	Ml	Time	Lat.	Long	Depth (Km)	Distance (Km)
BU001	BV005	16-08-24	01:36:39	RIETI	6.0	01:36:32	42.70	13.23	8	29
BU011	BV012	16-08-24	02:33:34	PERUGIA	5.3	02:33:29	42.79	13.15	9	19
BU012	BV013	16-08-24	02:59:43	PERUGIA	4.1	02:59:35	42.80	13.14	9	18
BU015	BV014	16-08-24	03:40:23	RIETI	4.1	03:40:11	42.62	13.25	11	35
BU017	BV015	16-08-24	04:06:58	PERUGIA	4.4	04:06:50	42.77	13.13	8	18
BU029	BV021	16-08-24	11:50:35	PERUGIA	4.5	11:50:30	42.82	13.15	8	19
BU035	BV025	16-08-24	17:46:20	RIETI	4.2	17:46:09	42.66	13.22	10	30

To analyze our data we pre-processed the waveforms by removing the instrument response and baseline correcting the data. Successively, the waveforms were filtered by using an Ormsby band-pass filter in the frequency band 0.2-30 Hz (Ormsby, 1961). The filtered traces were integrated to obtain the velocity and displacement time histories.
The peak values of acceleration, velocity and displacements were calculated (Table 2) in order to perform comparisons between recorded values and expected values considering the recent estimates of the ITA10 GMPE (Bindi et al., 2011).
Furthermore, both Fourier Amplitude Spectra (FAS) and 5 % damped response spectra (RS) in acceleration, velocity and displacement were calculated. Fourier Amplitude data were smoothed by means of a running average Hanning windows of 0.1 Hz. An example of the results of the different processing steps is shown in Figure 3.
In particular, the RS were calculated to perform comparisons between recorded and the Italian Building Code spectral shapes (NTC08) expected for the Cerreto di Spoleto site.

Table 2. PGA, PGV and PGD of the recorded waveforms at the CMC and BCT stations.

Trigger Time	Ml	CMC PGA (cm/s2)	CMC PGV (cm/s)	CMC PGD (cm)	BCT PGA (cm/s2)	BCT PGV (cm/s)	BCT PGD (cm)
01:36:39	6.0	-203.00	12.50	1.50	-103.00	-5.25	-1.12
02:33:34	5.3	107.00	3.68	0.29	62.10	-4.81	1.72
02:59:43	4.1	10.70	0.39	-0.02	5.95	0.12	0.01
03:40:23	4.1	7.63	-0.16	-0.01	3.84	-0.08	-0.004
04:06:58	4.4	24.90	-0.85	0.06	14.00	-0.28	0.03
11:50:35	4.5	-83.40	-2.16	0.10	-82.30	1.31	-0.07
17:46:20	4.2	10.90	-0.35	-0.02	-8.52	0.13	-0.01

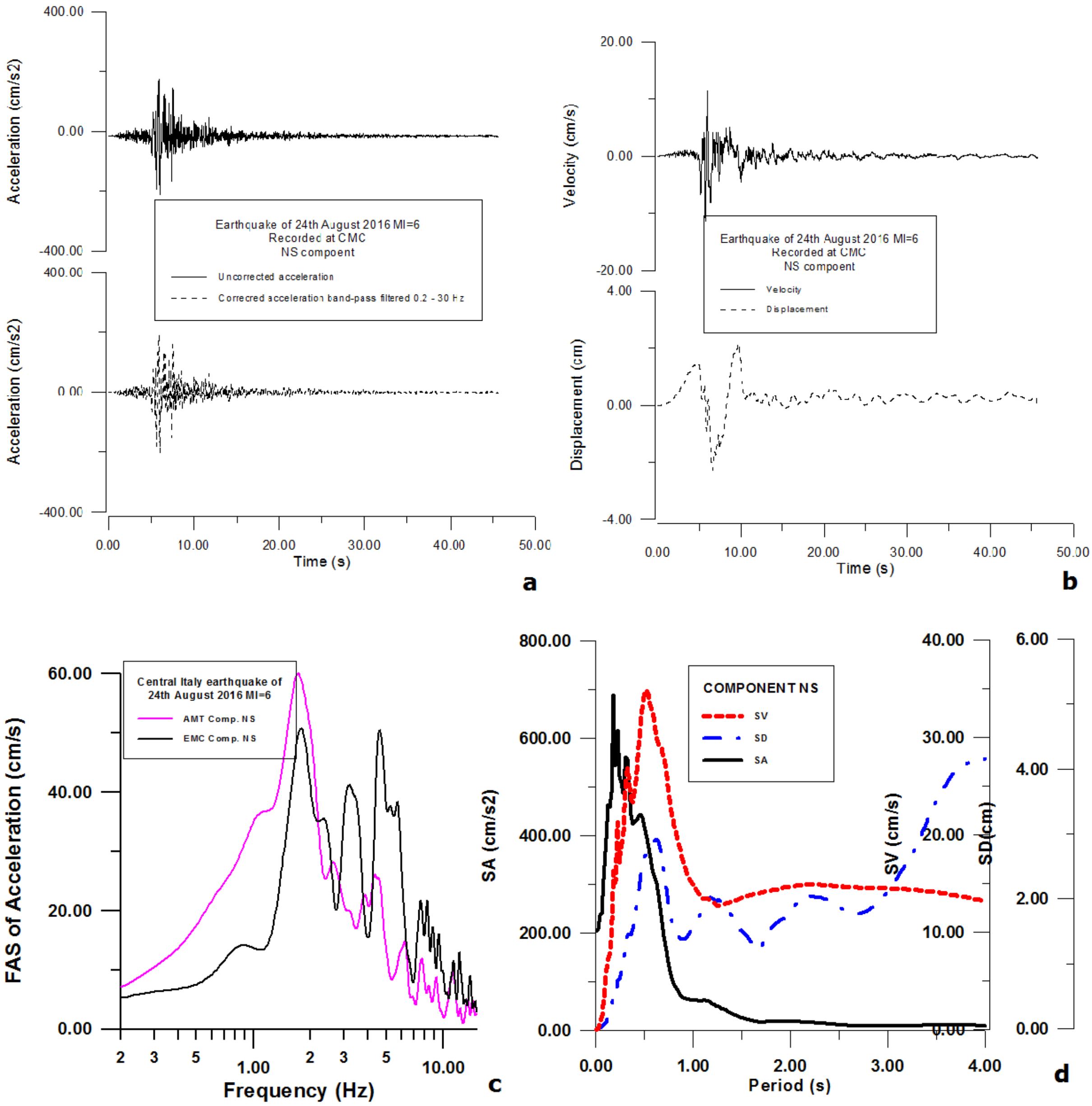

Figure 3. Central Italy earthquake of 24th August 2016, recorded at Cerreto di Spoleto cantina station (CMC), NS component: uncorrected and corrected acceleration (a), corrected velocity and displacement (b), FAS of acceleration recorded at CMC station (purple curve) and Amatrice station (AMT-black curve) in the near field (c); acceleration (SA), velocity (SV) and displacement (SD) response spectra (d).

4. RESULTS

In terms of peak values, for each earthquake the higher values were recorded at CMC station with respect to BCT. This behavior is consistent with the amplification effect observed by Martino *et al.* (2006).

We analyzed the normalized residuals between the observed PGA values and the predicted values of the ITA10 GMPE (Bindi et al, 2011). Following the approach of Scherbaum (2004), normalized residuals were calculated as $(\log y_i - log y_i')/\sigma_i$, where y_i is the observed value, y_i' is the predicted value and σ_i is the predicted standard deviation (Figure 4). With respect to the predicted values ITA10 GMPE, the measured PGA on the horizontal components are in general significantly higher. Moreover, the deviations between the observed and predicted PGA's seem to increase with magnitude. This could suggest an anomalous behavior of both recording sites.

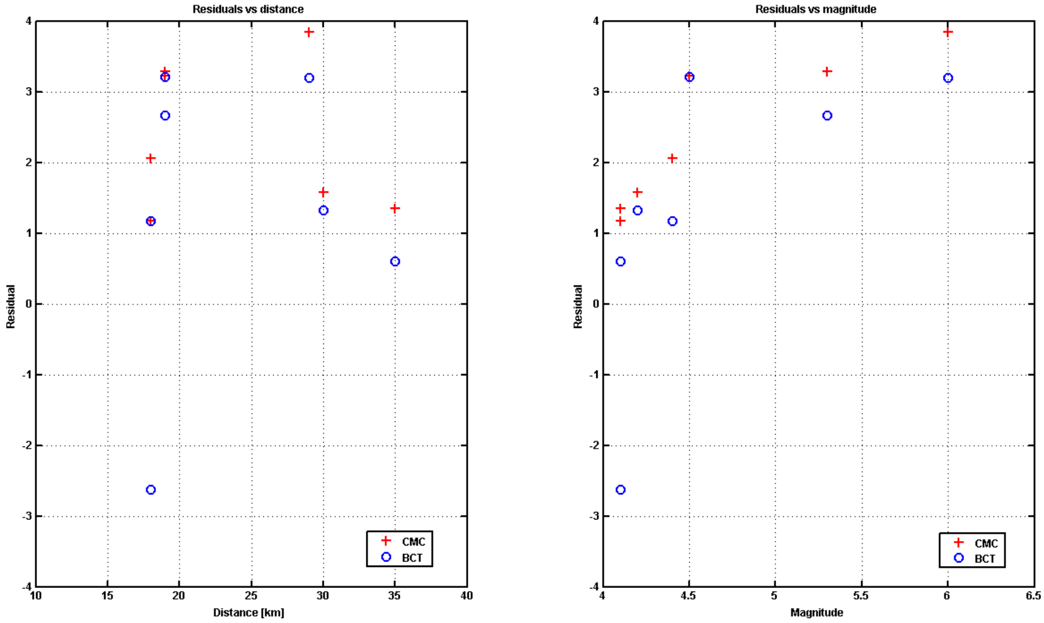

Figure 4. Normalized residuals between the recorded PGA at CMC (red cross) and BCT (blue circle) stations and horizontal PGA predicted by the GMPE ITA10 (Bindi et al., 2011) as a function of distance (left panel) and magnitude (right panel).

Fourier Amplitude Spectra (FAS) of the acceleration are shown in Figure 5. All FAS of the recorded accelerations at the CMC station clearly show a peak at 6 Hz in the NS component (see Figure 5a). The peak at 6 Hz was already observed by Martino et al. (2006). In the WE direction, the peak at 6 Hz is not present, but in some records a peak around 4 Hz was observed (Figure 5b). FAS of the accelerations recorded at BCT station showed a flat shape in the analysed frequencies (see Figure 5c and 5d). The records of the August 24th 2016 Ml 6.0 earthquake, acquired at both stations, showed peaks at about 1.5 and 3.5 Hz. This may be likely related to a source effect as the 1.5 Hz peak was also observed in the FAS the near field recordings at AMT station (Figure 3c).

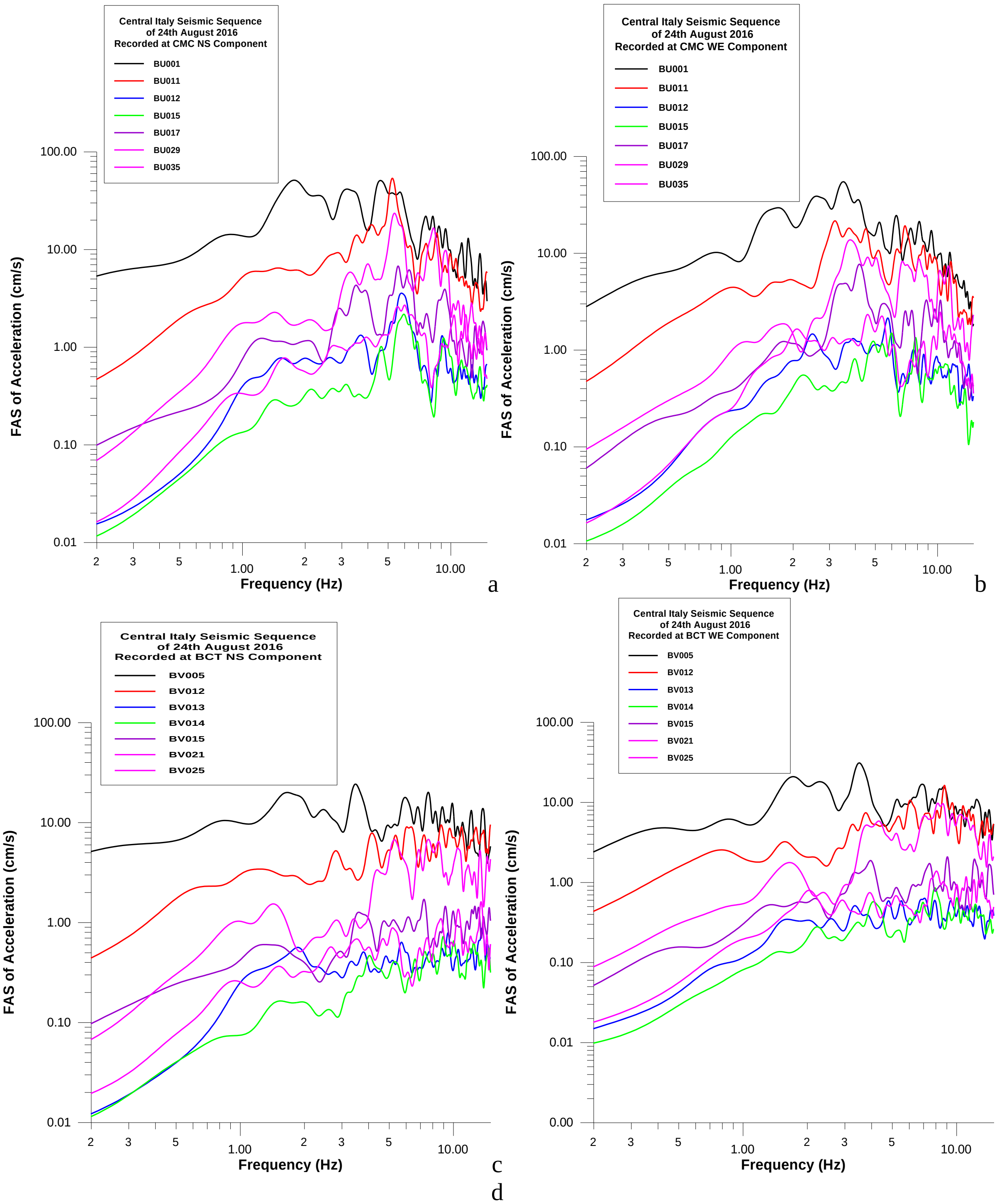

Figure 5. Horizontal component FAS of acceleration at CMC (a and b) and BCT stations (c and d).

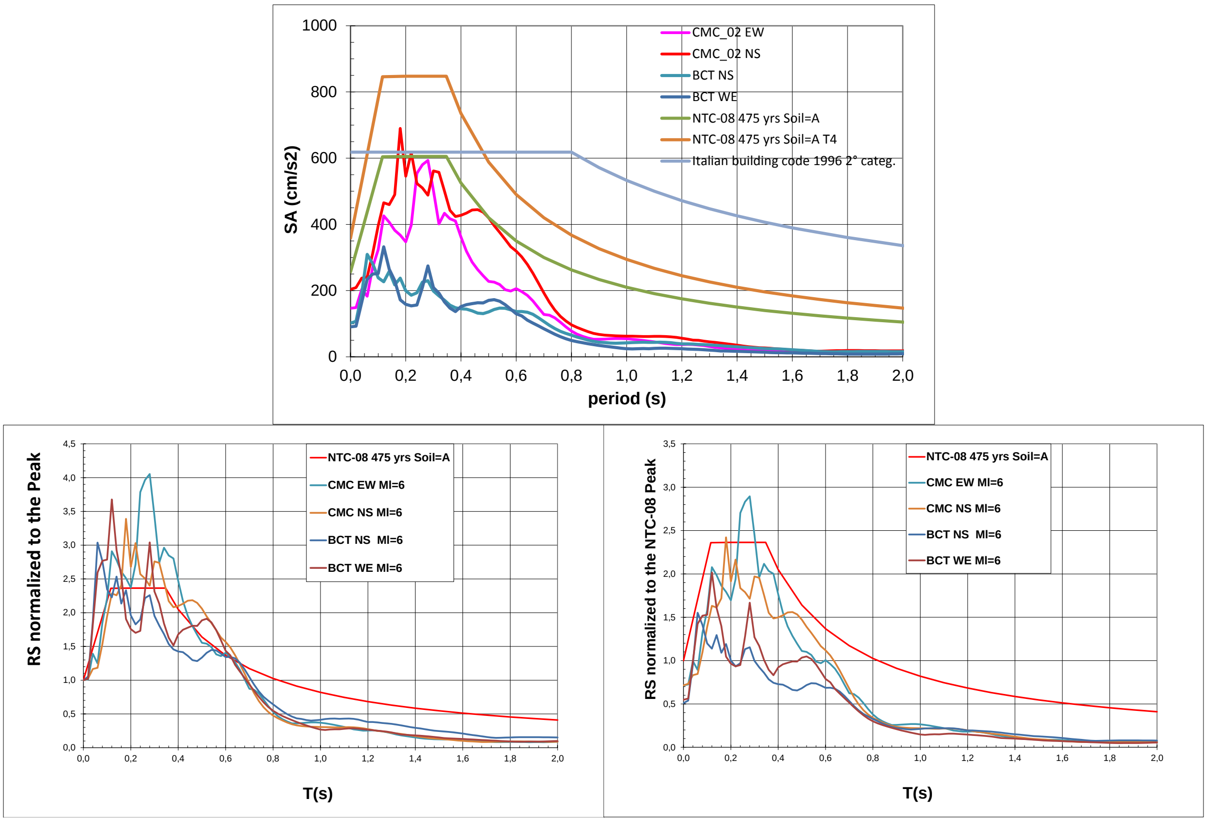

Figure 6. Comparison between recorded Acceleration Response Spectra (SA) and Italian Building Code spectral shapes (NTC08). SA absolute values (top panel). Bottom panel: normalized SA with respect to PGA (left); normalized SA with respect to the NTC-08 475 years return period for soil class=A and topography class=T4 for CMC and topography class=T1 for BCT (right).

Figure 6 shows 5 % damped response spectra (RS) and comparison with the Italian Building Code spectra (NTC08) RS. The top panel shows that the demand do not exceed the values proposed by the old and recent NTC08 Building Codes. The situation is completely different if we analyze the normalized RS. In fact, the spectral ordinates normalized with respect to the PGA (Figure 6 left, bottom panel) exceed the NTC08 spectral shapes in a wide range of periods (up to 0.6 s). This may suggest that the plateau of NTC08 spectral shape should be extended toward longer periods.
Considering that in the Cerreto di Spoleto Village old buildings, that were designed before the introduction of national Building Codes, were damaged by the Central Italy 2016 seismic sequence and the recently designed buildings, using the spectral shapes plot in Figure 6 (bottom panel, left), the seismic demand in case of a less distant earthquakes but similar to the August 24th 2016 one may likely exceed the building capacity.
If we consider the RS normalized with respect to the NTC-08 475 years return period for soil class=A and topography class=T4 for CMC and T1 for BCT, respectively, the spectral ordinates provided by the building code is conservative with respect to the recorded normalized one, suggesting that the recorded waveforms are compatible with the national hazard level for 475 years return period.

5. CONCLUSIONS

In this paper, we analyzed 7 earthquake records of the Central Italy 2016 seismic sequence, including the August 24th 2016 Ml 6.0 earthquake and some of its aftershocks recorded at CMC and BCT stations in Cerreto di Spoleto ridge (Central Italy).
The peak values of ground motion on the horizontal components, compared with the ITA10 GMPE (Bindi et al, 2011), are generally higher, except for few records, suggesting an anomalous behavior of

both recording sites.
The FAS of the recorded accelerations at both stations for August the 24th 2016 mainshock showed the source effect in terms of 1.5 Hz peak. At the CMC station, all recorded FAS clearly showed a peak at 6 Hz in the NS component, related with an amplification effect already reported in the scientific literature (Martino et al., 2006). In the WE direction this last peak is lacking and a peak around 4 Hz is observable. On the other hand, FAS of the accelerations recorded at BCT station showed a flat shape in the analyzed frequency range (0.2-30 Hz).
Finally, as an additional remark, the comparison between NTC08 Italian Building Code spectral shape and recorded RS suggests that the recorded values are compatible with the national hazard level for 475 years return period; however the seismic demand in case of a less distant earthquakes but similar to the August 24th 2016 one may likely exceed the capacity of old buildings that were designed before the introduction of national Building Codes.

6. REFERENCES

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