THE 1997 UMBRIA-MARCHE EARTHQUAKE: ANALYSIS OF THE RECORDS OBTAINED AT THE ENEA ARRAY STATIONS

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SUMMARY

The analyses of the accelerometric records obtained during the Umbria-Marche seismic crisis of September-October 1997 at the ENEA local arrays, and temporary stations, close to the epicentral area, are presented. The first array in Cerreto di Spoleto Town, designed to study the effects of surface geology is composed of four digital stations. The second array in Norcia is composed of two analog stations. Two temporary stations were installed in Preci and Foligno.

Records of the principal shocks, (I) September 26, 1997 0.33, M_L=5.5, (II) September 26, 1997 09.40 ,M_L 5.8 and (III) October 14, 15.23, M_L=5.4, are analyzed in time domain, frequency domain and in terms of energy to evaluate consistency among the different approach with respect to the most common parameters used to predict strong ground motion. More than 40 aftershocks of M_D ranging from 2.9 to 4.5 were recorded at all the stations until October 14, and some of them are also analyzed.

The main result is that one parameter approaches, PGA or spectral amplitude and shape, even related to one parameter description of soil condition, are misleading in describing ground motion generated by earthquakes. More and more data are needed to look for a more realistic description of the expected seismic ground motion. These can be obtained only with an adequate dense instrumentation of the seismically active areas

INTRODUCTION

Since many years ENEA has recognized the importance of installing strong motion instrumentation in areas prone to seismic risk. The Umbria-Marche portion of the Apennine chain has a long history of seismic crisis characterized by small to moderate events, lasting several months [Boschi and Cocco, 1997].

During the ‘80-s ENEA installed several instruments in the Umbria portion of the Apennine around the Nerina valley. At Cerreto di Spoleto, the array originally composed of 8 instruments, installed at 5 recording stations, was modified in such a way that only 4 instruments were surviving when the 26 September events struck the Umbria-Marche region. The instruments were CODISMA (Contraves Digital Strong Motion Accelerographs) with 12 bits acquisition system and PCB triaxial accelerometers. The 4 accelerographs were installed at 3 different sites: 1) Cerreto tower, CTO, rock site; 2) Cerreto football field, CCA, narrow alluvial valley, 200 *m* from CTO; 3) Cerreto City Hall basement, CMB, rock site, top hill, about 300 *m* from CTO; 4) Cerreto City Hall top floor, CMT.

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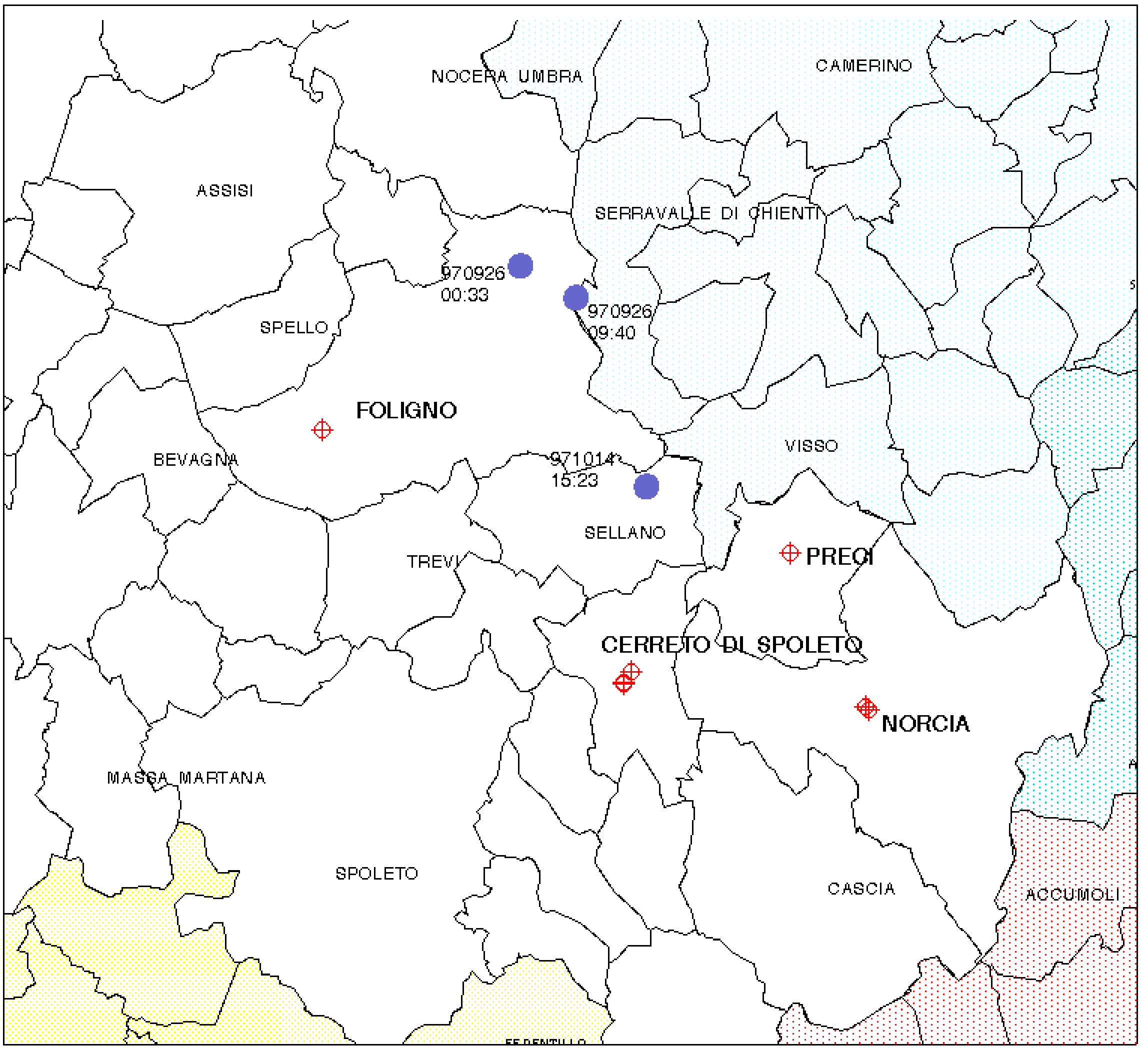

Figure 1: ENEA array stations (⊕) and earthquake epicenters (●)

Unfortunately, during the seismic sequence, instruments showed many malfunctions and only few events were recorded at the CCA (none at CMB).

The second array in Norcia, about 20 km far from Cerreto, is composed of two analog stations, with triaxial accelerograph Kinematics SMA-1: 1) Norcia Altavilla, NAL, firm soil site at the border of a debris plane; 2) Norcia industrial area, NZI, debris site, about 2 *Km* from NAL.

During the days following the main shock the permanent arrays were extended installing a CODISMA accelerometer in Preci, PRE, a rock hill top site north-west of Cerreto di Spoleto, and an accelerometric station in Foligno, FOL, center of an alluvial basin, at the basement of the bell tower of the "Santa Maria Infraportas" basilica. The station FOL was composed of a FBA-23 Kinematics triaxial force-balance accelerometer connected to a MARS-88/fd Lennartz acquisition system. In table 1 the records analyzed are listed.

Table 1: Umbria-Marche Earthquake: events recorded at ENEA stations

Date		26 Sept	26 Sept	06 Oct	12 Oct	12 Oct	13 Oct	14 Oct.	15 Oct.	16 Oct.	16 Oct.	08 Nov	09 Nov
time		00.33	09.40	23.24	11.08	20:12	13:05	15.23	22:53	04:53	12.00	15.32	19.07
magnitude (M_L or M_D^*)		5.5	5.8	5.3	4.5^*	3.7^*	3.9^*	5.4	4.0^*	4.1^*	4.1^*	3.9^*	4.4^*
PRECI	PRE											7095	7098
NORCIA ZONA INDUSTRIALE	NZI	7035	7036	7039				7038					
BORGO CERRETO TORRE	CTO	7042	7043		7044	7045	7046	7047					
BORGO CERRETO CAMPO SPORTIVO	CCA								7062	7063	7064		
NORCIA ALTAVILLA	NAL	7034						7040					
FOLIGNO	FOL				7204	7209	7215	7217					

TIME DOMAIN ANALYSIS

For the three principal shocks, records at rock sites show evidence of high frequency content (Figure 2 - records 7042, 7043, 7047 at CTO) while records obtained from instruments installed in soft soil (Figure 2, records 7035, 7036, 7038 at NZI) show evidence of low frequency content due to the reflections of the seismic waves in the layers of the alluvial basin of Santa Scolastica plane.

The records obtained at NAL, which is at the border of the same plane, show low frequency content that looks different from the previous ones (Figure 2, records 7034 and 7040): records in NZI shows greater energy in the T-waves.

The record obtained at CTO during the shock of September 26, 00:33 (I), show a larger PGA, but shorter duration, if compared with the record obtained at same station during the shock of September 26, 09:40 (II). Since the fault is the same and hypocentral distances are equivalent, the noticed features can be attributed to the different propagation of the fault rupture.

With reference to the shock of October 14, 15:23 (III) it is interesting to note that records 7047 obtained at CTO and 7217 obtained at FOL have comparable *s-p* arrival time difference, but PGA values are much smaller in the second one. This occurrence is related to the propagation path and the local soil conditions.

Finally the analysis of records obtained in the remaining two stations, PRE and CCA, is very interesting, even though these stations did not record the principal events.

Records obtained at PRE were important because this station is close to the seismic source (Figure 2, records 7095 and 7098). In fact, *s-p* is equal to 0.8 and 1.2 *s*, PGA equal to 116 and 229 cm/s^2 and M_D equal to 3.9 and 4.4, respectively.

These events were not recorded by the Cerreto di Spoleto array and the Norcia SMA-1s as well as by the nearby instruments of the ENEL permanent network. The records obtained at CCA give an experimental evidence of the seismic waves amplification due to of the narrow, geometrically complex, alluvial valley where the instruments were installed.

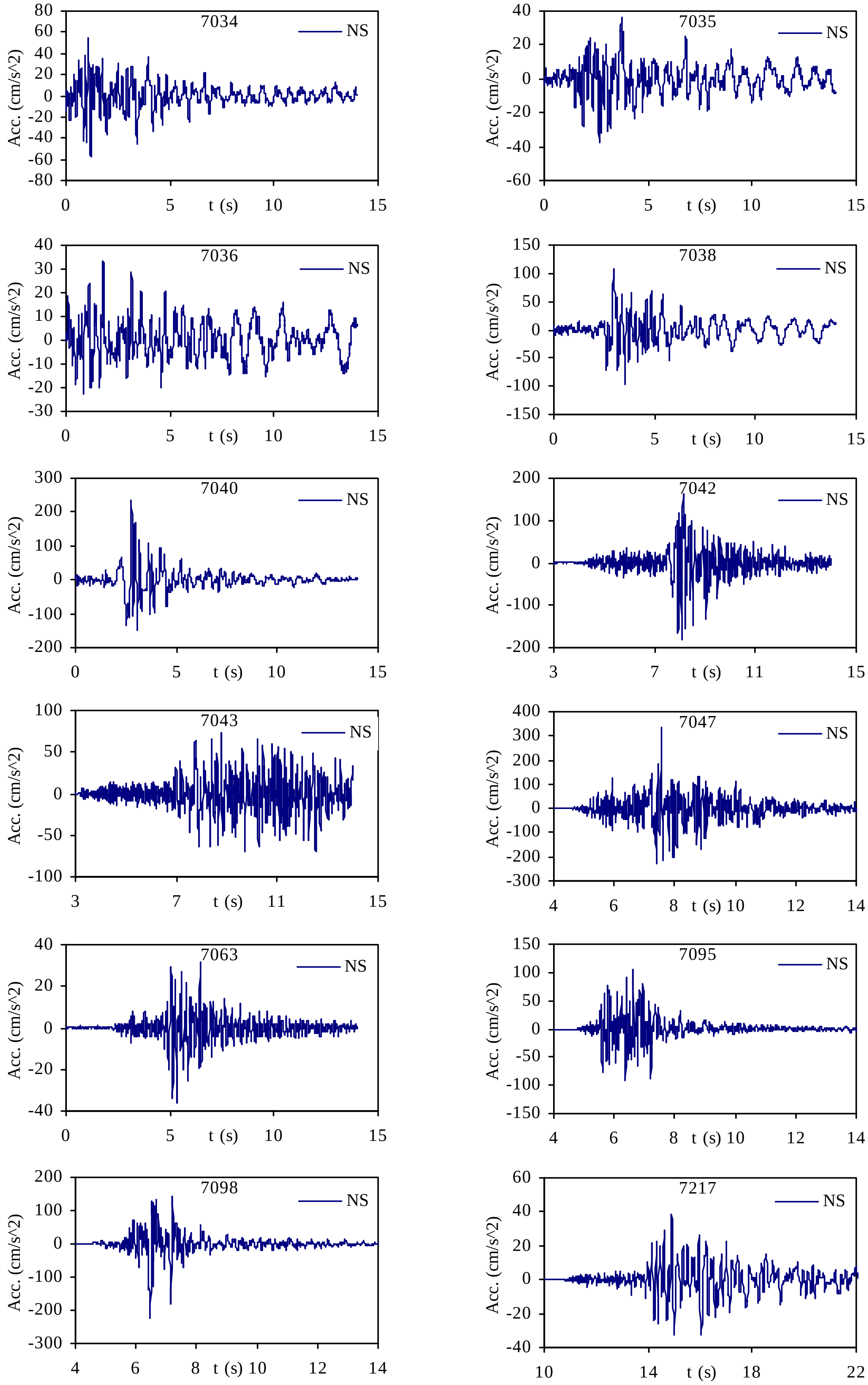

Figure 2: Time histories

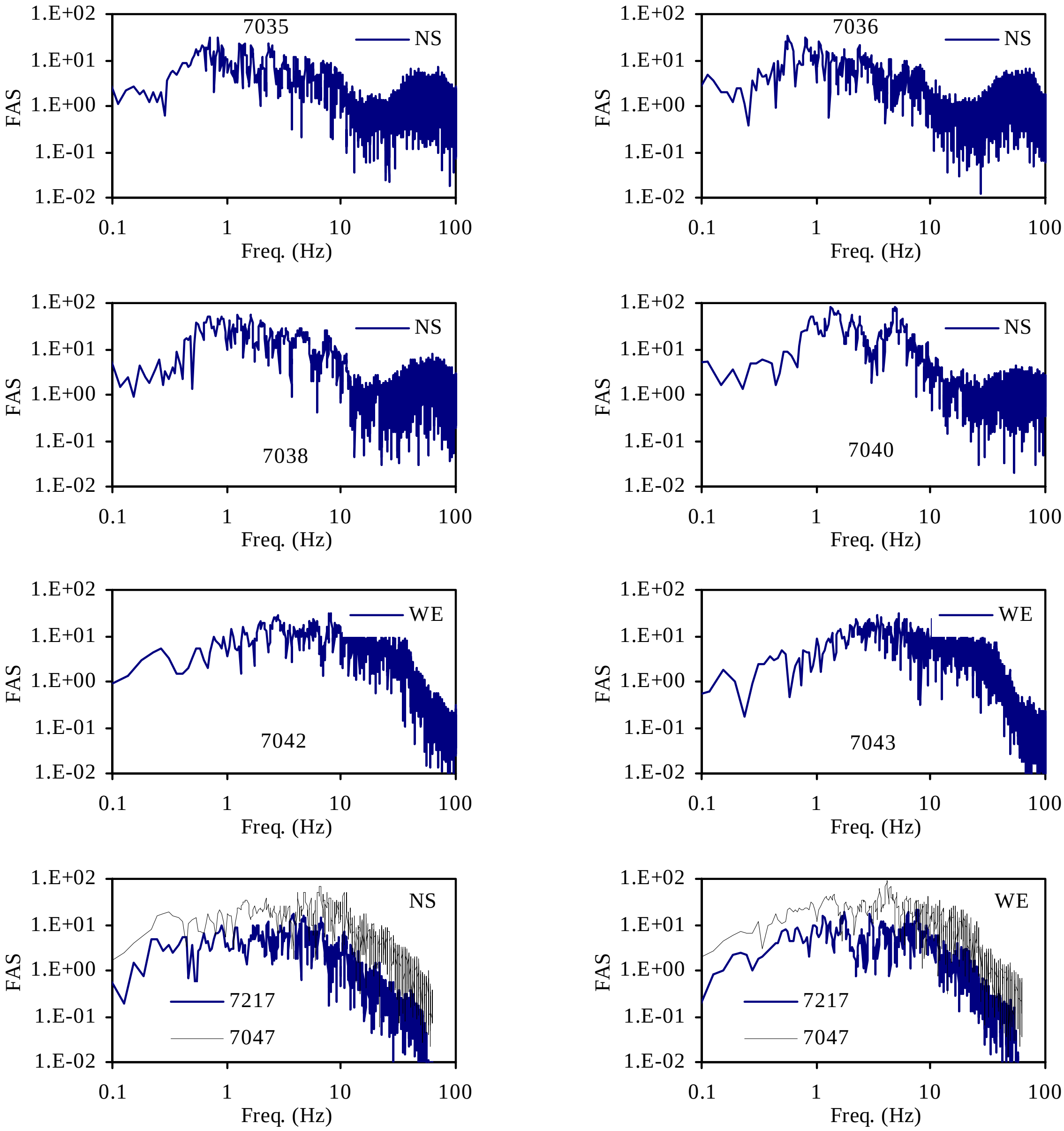

Figure 3: Fourier spectra

FREQUENCY DOMAIN ANALYSIS

The analysis of the FAS of acceleration at CTO confirms the very high spectral content of records obtained at this station (Figure 3, NS components of records 7042, 7043 and 7047). Spectral values are still important at frequencies larger then 30 *Hz*, while the low frequency content extends to values lower than 1.0 *Hz*.

The site amplification is clearly represented in the FAS of the acceleration obtained at NZI (Figure 3, records 7035, 7036 and 7038), where spectral peaks at frequency values lower than 1.0 *Hz* are dominant. Records at NAL (Figure 3, 7040) show evidence of spectral amplification in the frequency interval [1-3] *Hz*.

The FAS of records obtained at the CTO and FOL, during the seismic event of October 14 (III), have similar shapes scaled by a factor that associated to the differences on PGAs could suggest directivity of the seismic wave propagation pattern, that is different attenuation of the same source spectrum in different directions (Figure 3, records 7047 and 7217). In this hypothesis the effects of local geology were not apparent at FOL.

Records at PRE show relevant frequency content around 1.0 *Hz*, that could reflect the fault rupture. These shocks didn't produce any additional damage to the nearby structures.

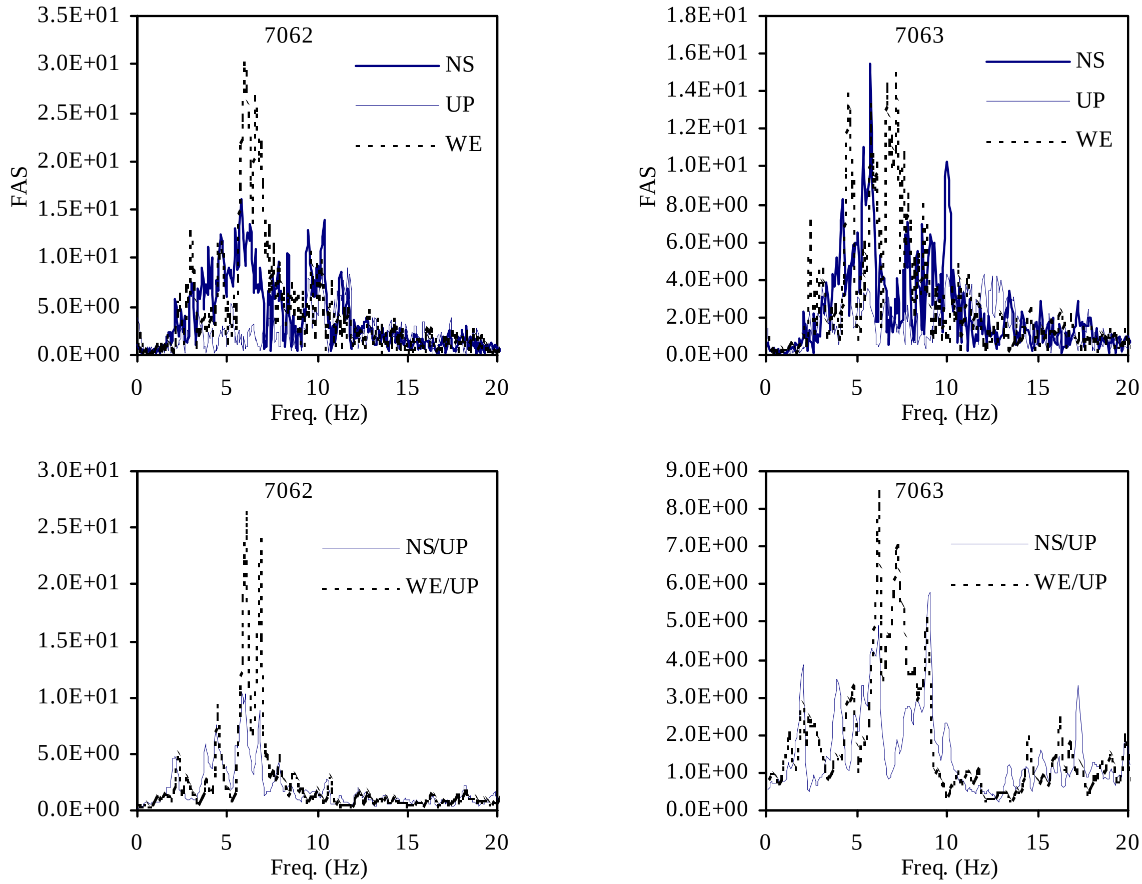

Figure 4: FAS and spectral ratios of records at CCA

The calculation of spectral ratios has been the most applied technique used to estimate site response [Borcherdt, 1970; Rogers et al., 1984; Borcherdt, 1994]. In this approach, the spectrum of the ground motion recorded at a site of interest is divided by the spectrum recorded for the same source at a nearby hard-rock site. This method assumes that hard-rock site has no amplification effect on seismic waves. Recently [Nakamura, 1989] has been shown that, if no records at nearby rock site is available, the spectral ratios between the horizontal components and the vertical component of the acceleration at the site of interest well represent the site amplification. In the following analysis we used the spectral ratios in the Nakamura sense.

At NZI all the spectral ratios show several peaks in the range [0-8] *Hz*, but none is prevailing, all of them being lower than 6. Something similar happen for the record at FOL. In addition the spectral ratio of record 7217 has two very important peaks at 14.7 *Hz* (ratio 4 and 7.5 for NS and WE, respectively) and 15.2 *Hz* (ratio 7 and 9.5 for NS and WE, respectively). The same phenomenon is apparent for all the other records of smaller events at frequencies close to the previous ones. This occurrence could depend on the supposed presence of a buried structure below the Basilica where the station was installed.

At the station CCA the spectral ratios show the complexity of the site response to seismic waves excitation. All the records show several peaks both on the FAS of acceleration and on the spectral ratios. Spectral ratios of records 7062, 7063 and 7064 show common peaks in the frequency interval [4-8] *Hz*; particular evident the peak at 6.0 *Hz*. Comparison between the FAS of horizontal components of the acceleration and the FAS of the vertical component confirms that the spectrum in the vertical direction at this frequencies is flat and very low in amplitude. This is particularly true for record 7062 (Figure 4). Several other peaks on the spectra (as well on the spectral ratios) are evidenced on the above mentioned records (i.e., 2.0, 2.2 , 4.6 and 7.0 *Hz* on record 7062; 2.0, 4.0, and 9.0 *Hz* on record 7063) but is clearly cumbersome try to model the site response. Moreover the spectral ratios ant the FAS of record 7061 show evidence of peaks at frequencies somewhat not similar with the others (even if the peak at 6.0 *Hz* seems to be confirmed as well as the trend of the spectrum on the vertical direction).

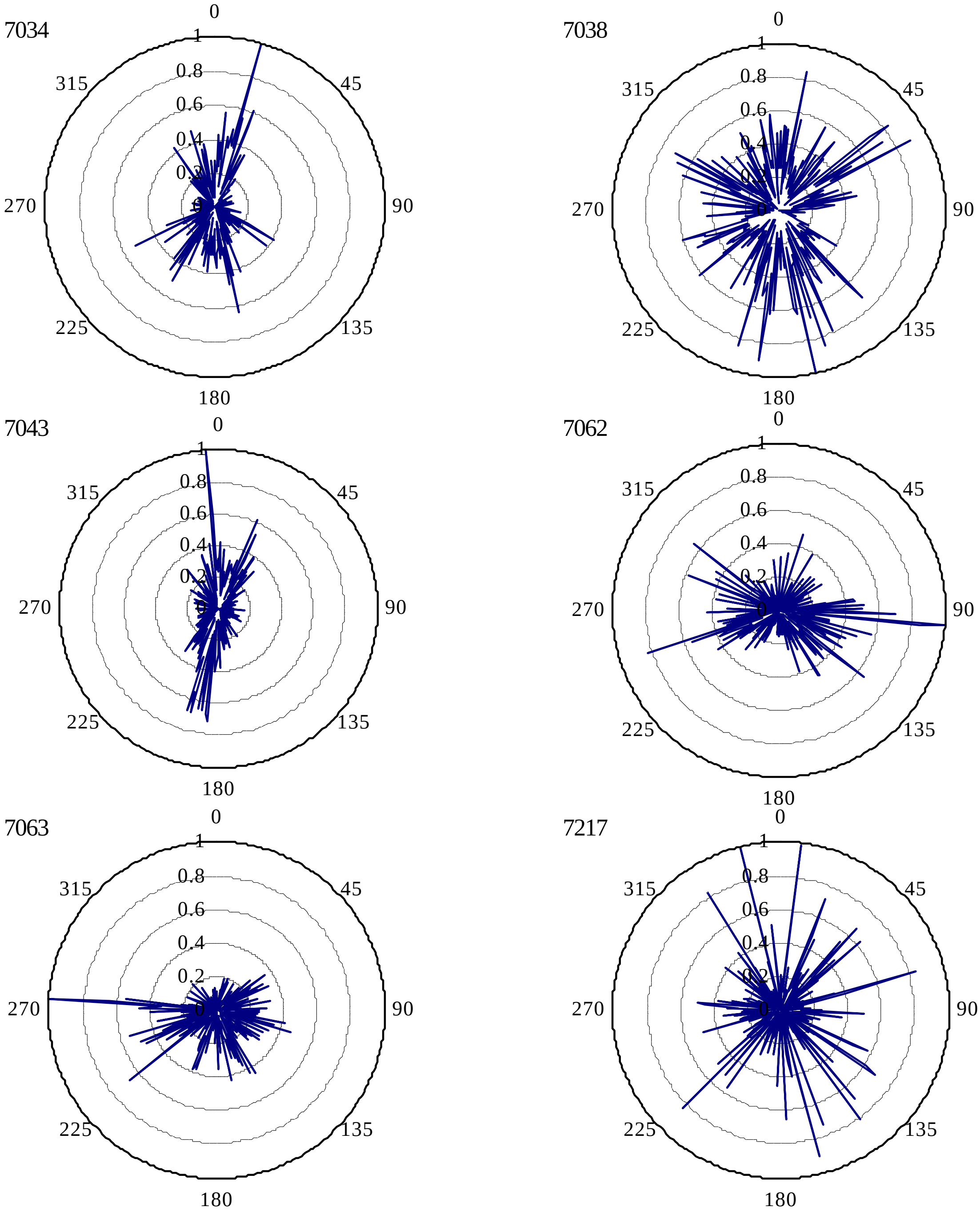

Figure 5: Azimuthal distribution of energy

3. ENERGY AZIMUTHAL DISTRIBUTION

In this paragraph we examine the records by means of the graphic representation of the azimuthal distribution of the energy at the recording point. The energy is intended in the sense given by Arias [Arias 1970]

$$I_A = \frac{\pi}{2g}\int \left(a_x^2 + a_y^2 + a_z^2\right) dt$$

Records of the principal shocks at rock site CTO have most of the energy concentrated within 15° around direction consistent with the fault rupture process along the direction NW-SE (Figure 5, record 7043).

For the opposite geological condition of the site, NZI, the energy is very dispersed in azimuthal direction (Figure 5, record 7038) according to some expected mechanical and geometrical effects of the soil condition on the seismic field. At site NAL (Figure 5, record 7034) there is relevant energy concentration in direction consistent with the rupture process and the rest along a sharp direction. This direction could be related to some border effect. The azimuthal energy distribution of the record at FOL (Figure 5, record 7217) is spread over 360° denoting the absolute prevalence of the local effects, geometrical and mechanical, with respect to the source and path effects.

The energy distribution for records at CCA of aftershocks individuates angles where there is almost absence of energy (Figure 5, record 7063). Since the events have very low magnitude, we attribute this behavior mainly to geometrical effects on the seismic field inside the valley.

CONCLUSIONS

The observations for record 7217 from time and frequency domain analysis are apparently contardictory with those from energy domain analysis. This is caused by the combination of two effects: the vicinity of the source increasing the importance of the near-field term in the computation of ground displacement (i.e. acceleration) at the site and the site amplification contributing expecially on the spreading of the energy-azimuth distribution because of the reflection of waves. Most of records obtained during the Umbria-Marche seismic events and analyzed in this paper show a high frequency content due to the importance of the near-field effect. The feature is also of interest because of the connection between the high frequency content of the strong ground motions and their PGA. Recorded PGA, seems to be sistematically higher then any prediction and this trend should be, in a future research activity, verified with the most popular attenuation laws. Then simple spectral ratios (NS and WE components divided by the Vertical component of the acceleration), for the CCA site, seems to indicate a complexity in the site response. As stated for the 7217 record at the FOL station, near field and site amplification effects are mixed and this indicates that is not always fruitful to decompose the recorded acceleration into its P-wave and S-wave components: in other words, since the vicinity of the ruptured fault, the procedure of rotating components at different stations (to follow P and S waves radiation patterns), valid for a point source is misleading for near field stations where is almost impossible to separate the SH waves contributions. A more sofisticated analysis, e.g. combining the two horizontal components as the real and imaginary parts of the complex time-series (treating the horizontal time-histories as a two-dimensional signal) can avoid dependence on components direction.

The observation that azimuthal energy distribution is very spreaded for records at soft soil NZI and FOL in conjunction with spectral ratios having several small peaks, while records at soft soil CCA have relevant amplification at single frequencies, although for small energy event, underline the relative importance of geometrical and mechanical effects.

The characteristics of near field records at PRE pose the attention on the role of the seismic field close to the source in damaging capability.

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