SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

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SEISMIC SOURCE PARAMETERS AND RADIATION EFFICIENCY OF MICROEARTHQUAKES ALONG THE IRPINIA FAULT ZONE IN SOUTHERN APENNINES, ITALY

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We have analyzed the P- and S-wave displacement spectra of 717 microearthquakes in the moment range 4×10^{9} - 2×10^{14} Nm recorded at the dense, wide-dynamic range, Irpinia Seismic Network (ISNet), operating in southern Apennines (Italy) since 2007, and the national seismic network. ISNet is deployed along the 1980 Ms 6.9 Irpinia fault zone (Figure 1a), which is the last destructive seismic event occurred in the area, causing about 3,000 deaths and widespread damage.

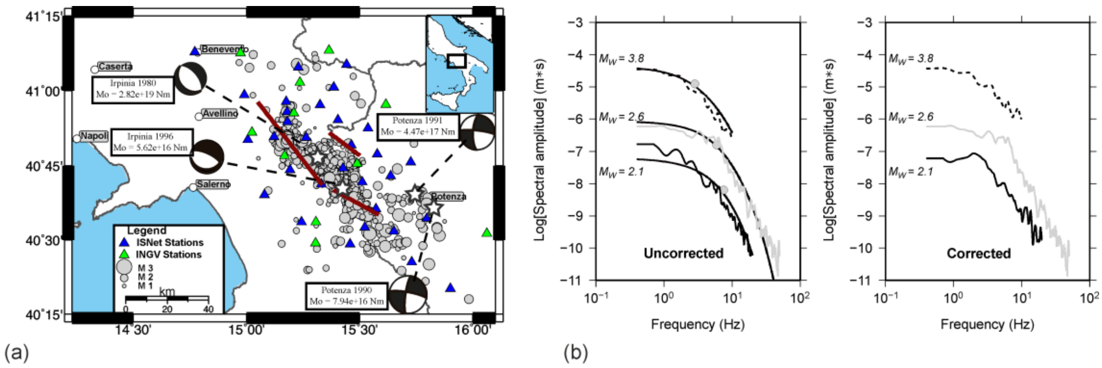

Figure 1. Panel a: Epicentral distribution of the microearthquakes analyzed in this study. The three main rupture fault segments of the 23 November 1980, MS 6.9, Irpinia earthquake are also drawn as from Bernard and Zollo (1989). Panel b: Example of S-wave displacement spectra for three different magnitude uncorrected (left panel) and corrected (right panel) for path attenuation and site amplification factors/terms.

Source, attenuation and site parameters are estimated by using a parametric modeling approach, which is combined with a multi-step, non-linear inversion strategy. The multi-step approach allows to jointly invert source and attenuation functions, together with site/station correction (Zollo et al., 2014).

In the present study, we used the following formulation for the far-field displacement spectrum and anelastic attenuation (modified after Brune, 1970):

$$S_o(\omega) = \frac{\Omega_o}{1+\left(\frac{\omega}{\omega_c}\right)^{\gamma}} \; e^{-\pi f t^*} \qquad (1)$$

where Ω_0 is the low-frequency spectral level ($\omega \ll \omega_c$) (related to seismic Moment *Mo*), ω_c is the angular corner frequency and γ controls the high-frequency spectral fall-off.

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As for the anelastic attenuation function, the most general formulation considers a frequency-dependent t^* through a frequency-dependent quality factor $Q(\omega)$ (e.g. Morozov, 2008):

$$t_c^* = \frac{T_c}{Q_o \omega^n} \qquad (2)$$

where n is a positive real number and Q_o is the quality factor evaluated at the reference frequency of 1 Hz.

To obtain seismic moment *Mo*, we estimated the geometrical spreading for a linear variation of velocity with depth (Ben-Menahem and Singh, 1981), while we considered an average constant radiation pattern and a constant free surface surface coefficient.

The source radius is obtained as $r = k_c\, c/f_c$ where c is the S-wave velocity and f_c is the corner frequency. The coefficient k_c depends on the adopted circular rupture model and wave type. Assuming the Madariaga (1976)' model, k_P =0.32for P-waves and k_S =0.21 for S-waves, while according to the Brune (1970)' model the same constant (k_S=0.37) could be used and the velocity becomes the P- or S-wave velocity, depending on the analyzed seismic phase spectrum. Seismic moment and radius of a circular fault rupture are then used to estimate the static stress drop (Keilis-Borok, 1959):

$$\Delta\sigma = \mu \frac{7\pi}{16}\frac{\bar{u}}{r} = \frac{7}{16}\frac{M_o}{r^3} \qquad (3)$$

where μ is the rigidity and $\bar{u}$ is the average earthquake slip along the fault surface.
Preliminary tests using synthetic and observed data proved that the proposed inversion strategy is able to retrieve robust, unbiased and uncorrelated estimates of the source and anelastic attenuation parameters in the frequency band 0.4-50Hz (Figure 1b).

The results of the analysis have shown that, an attenuation model with constant-*Q* has to be preferred to frequency dependent *Q*-models. Consistent estimates of the median P and S quality factors Q_P = 167 (90; 296) and Q_S = 226 (114; 417) (with the 68.8% confidence limits given in parenthesis) are obtained from two different techniques based on the modeling of the low-frequency spectral decay of the smaller earthquakes, and on the full bandwidth inversion of displacement spectra of larger magnitude events.
Relatively high values of Q_S/Q_P (median value 1.3, (0.8, 2.1)) are found in the same depth range where high V_P/V_S and a peak in seismicity distribution are observed (Amoroso et al. 2012), indicating a highly fractured, partially or completely fluid-saturated medium embedding the Irpinia fault zone, down to crustal depths of 15-20 km.

As for the seismic source, we found that the mean values of γ for P- and S- wave are different from 2 and comparable within the errors (γ_P =2.2±0.9 and γ_S =2.4±0.8). This observation may be attributed to source directivity effects, which can be pronounced even at a small magnitude scale (e.g., Boatwright 2007; Convertito and Emolo, 2012).

A nearly constant stress drop ($\Delta\sigma$=1.4MPa (0.5; 5.0)) (Figure 2) and apparent stress (τ_a = 0.1MPa, (0.03, 0.4)) scaling of P- and S-corner frequencies and seismic energies is observed above a seismic moment value of about 10^{11} Nm. Below this value, corner frequencies and seismic energy are not measurable, due to the instrument band-limitation and dominant noise effect at high frequencies.
The median values and distribution of S-to-P corner frequency (1.5, (0.9, 2.4)) and seismic energy ratios (15, (3,75)) are consistent with kinematic and dynamic models of an expanding circular rupture at a constant stress drop scaling.
The distribution of the measured radiation efficiency (η_{SW}= 0.06, (0.03, 0.13)), indicates a rather small radiation efficiency (Figure 3). The radiated energy is thus only a small fraction of the whole energy spent by friction. We conclude that fracture development and the rupture process implying a large positive dynamic overshoot is the dominant mechanism controlling the microearthquake fractures along the Irpinia fault zone.

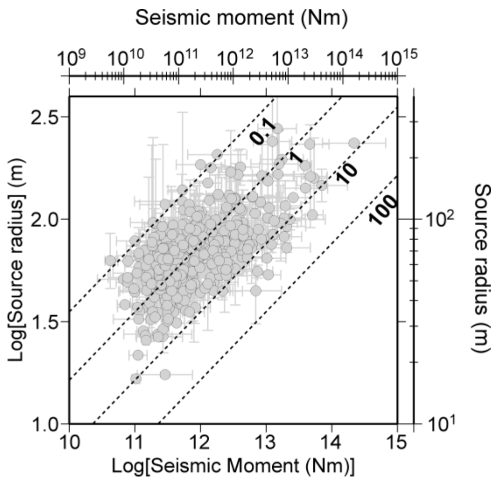

Figure 2. Log of the measured Madariaga (1976 983)’ source radius model *vs* the log of the seismic moment and relative uncertainties. Dashed lines refer to the theoretical constant stress-drop values expressed in MPa.

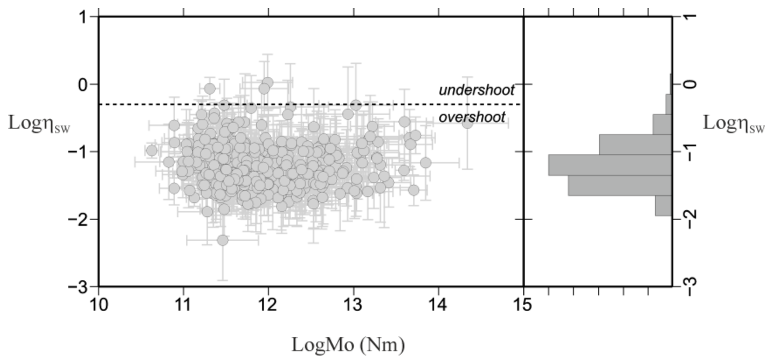

Figure 1. The Savage–Wood seismic efficiency *vs* seismic moment (in log-log representation) and histogram of the observed values. The dashed line corresponds to the threshold limiting the undershoot from overshoot dynamic weakening mechanisms.

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