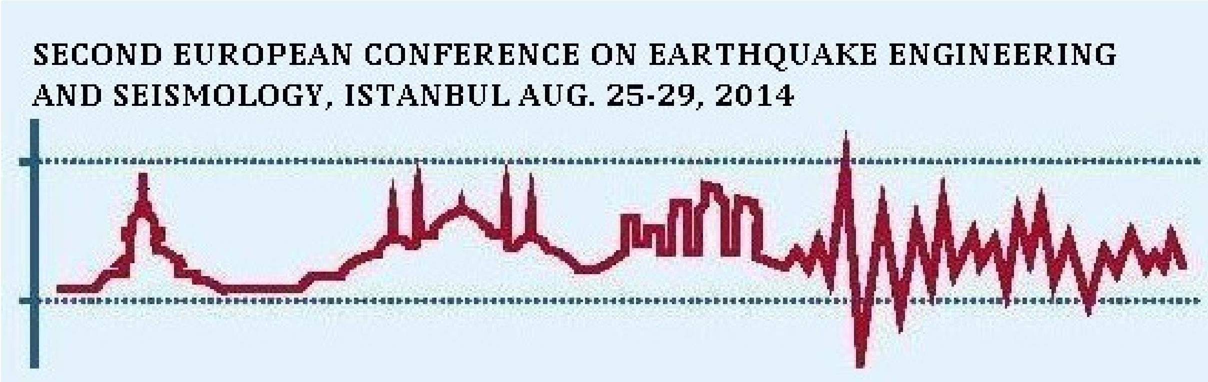

BROADBAND GROUND MOTION SIMULATIONS WITH EMPIRICAL GREEN FUNCTIONS: THE 2009 L'AQUILA EARTHQUAKE

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In near fault conditions unexpected large ground motion amplitudes associated with a rapid space gradient can be observed, owing to the coupling of source effects (focal mechanism, directivity, up-dip propagation) and local scale wave reverberations related to topography, basins and/or regional scale structures. This may result in intermediate to high frequency pulses within the source region. Moreover, high frequency peak acceleration is often observed on the vertical component of the seismic data in the presence of normal or reverse fault mechanisms. This was the case of the April 6, 2009, M 6.3, L'Aquila earthquake, where the complex ground motion pattern has produced the variability of the damage at the urban scale of L'Aquila city. Up to now, near fault effects on the ground motion are relatively poorly understood because of the limited amount of records in the fault vicinity. We aimed with this study to contribute to the investigation of the role of the source and the wave propagation at regional scale in the generation of the ground motion and its variability in the case test of the L'Aquila earthquake, for which we have a huge amount of records for both the mainshock and the aftershocks. These latter can be used as empirical Green's functions, improving the description of the elastic propagation at regional scale.

For the aim we provided broadband "blind" simulations for the L'Aquila earthquake to be compared with real records. We fixed the rupture geometry, the focal mechanism, the hypocentral position and station distribution and we generated a large amount of strong motion records for several scenarios, obtained by changing the slip roughness, the rise time and the rupture velocity on the fault plane. We used coupled numerical-empirical Green's functions as a propagator. High-frequencies beyond the corner frequency of the Empirical Green's functions (EGFs) are stocastically introduced into the model.

To be consistent with the low frequency part of the signal, we used a kinematic source model of the L'Aquila earthquake. This was obtained by inversion of local strong motion data up to 0.3 Hz. This kinematic model, however, poorly describes the waveform amplitude and shape even at low frequencies for the L'Aquila stations, where larger amplitudes seem to indicate a strong unravelled coupling of source effects with wave propagation and site. With the specific goal of better representing the strong motion data recorded at L'Aquila stations in a broader frequency range, we also used an inversion scheme, with a separated parametrization for the slip and the rupture velocity (Lucca et al., 2012) which is mainly aimed at fitting L'Aquila data at low-frequencies (up to 0.5 Hz) by the use of EGFs. The retrieved model is represented in Figure 1. We found a major slip patch between 5 and 10 km southwards of the hypocenter, which is responsible for the directivity effect observed south of the fault. We also found a smaller asperity in the upper part of the fault with slip as large as 50 cm and a third one nearby the surface, lower slip value (30 cm), which is responsible of the up-dip directivity observed at L'Aquila and GSA stations. Rupture times indicate a faster rupture in the upper part of the

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fault, in the initial stage of the rupture. The features of this model are consistent with the ones provided by the other groups (Cirella et al., 2009; Gallovic and Zahradnik 2012).

We then coupled this model with high frequency k^{-2} slip distributions obtained with a stochastic technique (Causse et al., 2009). Retrieved models were tested up to high frequencies (5-10 Hz) to provide the ground motion amplitude and its variability.

For the broad band ground motion simulations, we needed to couple the source model with a reliable Green function up to high-frequency, in a complex medium like L'Aquila region. We then used Empirical Green's functions as high frequency propagators of the waves emitted by the rupture on the fault. Starting from a dataset of more than 400 aftershocks and foreshocks recorded between March 30, 2009 and April 30, 2009 by DPC-RAN and INGV networks, with a magnitude ranging between 2.5 and 4.8, we selected about 15 events as candidates to be used as EGFs. Selection of the functions was based on location, stress drop, magnitude and signal to noise ratio. For the hypocentral position we used the accurate double difference locations of Chiaraluce et al. (2011). Magnitude and stress drop were estimated from inversion of displacement spectra based on the ω^2 Brune model. Signal to noise ratio threshold was finally fixed to 10 in the frequency range of interest (0.4-10 Hz) in order to maintain high quality seismic data in a broad frequency range. The available focal mechanisms, as deduced by Chiaraluce et al. (2011), indicated for all the aftershock a rupture pattern similar to the one of the main event.

We then analyzed how the choice of the EGFs affect the simulation results. We also showed that the use of several EGF distributed over the fault plane significantly improves the results in comparison to predictions performed using a single EGF, especially for the near source stations. Finally we analyzed how different degree of a priori knowledge on the source parameters (fixed low frequency slip distribution, roughness degree of slip heterogeneity, rupture velocity, nucleation point) may affect the simulations. Comparison between synthetics and real data are shown in terms of Fourier amplitude spectra and response spectra, as shown in Figure 2.

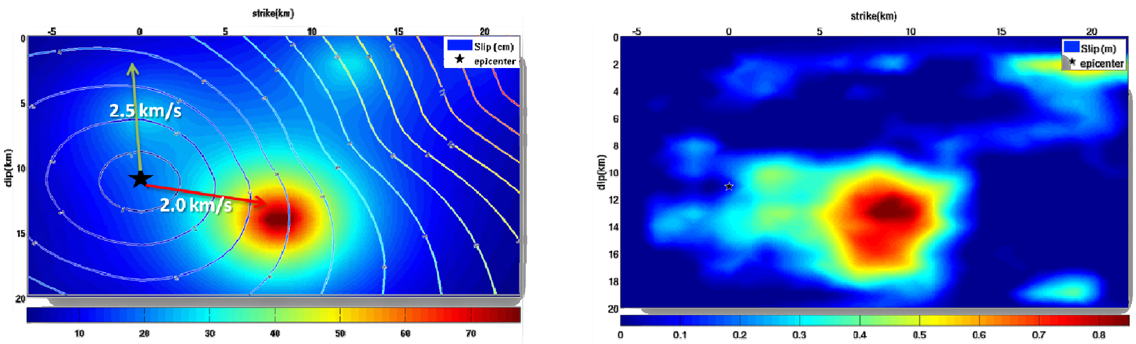

Figure 1. Retrieved slip model for the L'Aquila earthquake on the left. An example of a derived high-frequency model on the right panel, obtained by coupling the low frequency model with a k-2 slip distribution at short wavelengths.

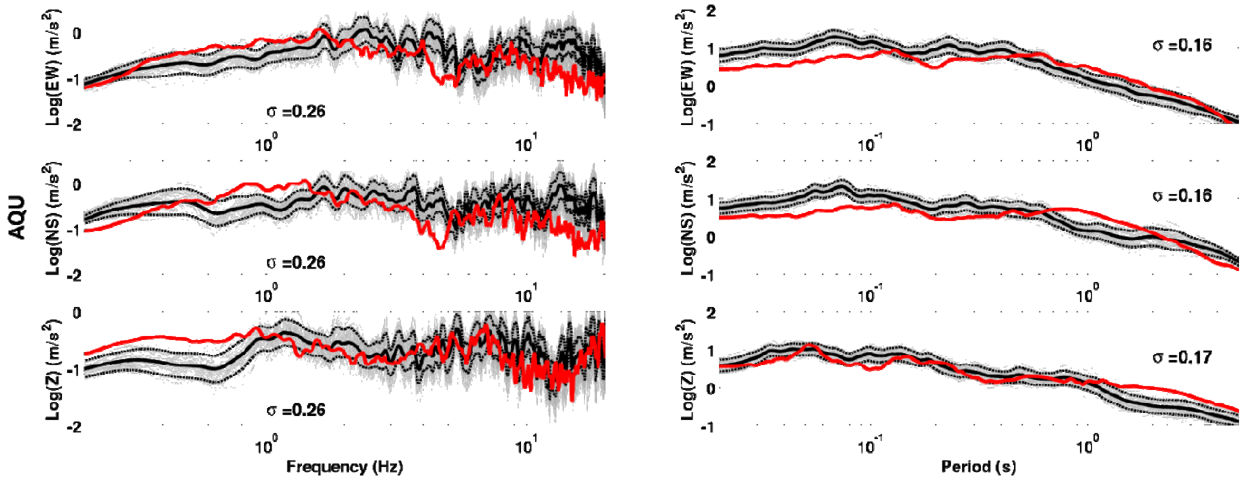

Figure 2. Fourier (Left panels) and response spectra (right panels) for real data (red curves) and simulations (black curves) at the station AQU. For the simulations we represent the average curve and +/- 1 standard deviation curves.

REFERENCES

Causse M, Chaljub E, Cotton F, Cornou C, Bard P (2009). New approach for coupling k-2 and empirical Green's functions: application to the blind prediction of broadband ground motion in the Grenoble basin, *Geophys. J. Int.* , 79 (3), 1627-1644. doi: 10.1111/j.1365-246X.2009.04354.x.

Chiaraluce L, Valoroso L, Piccinini D, Di Stefano R, De Gori P (2011). The anatomy of the 2009 L'Aquila normal fault system (central Italy) imaged by high resolution foreshock and aftershock locations, *J. Geophys. Res.*, 116, B12311, doi:10.1029/2011JB008352.

Cirella, A, Piatanesi A, Cocco M, Tinti E, Scognamiglio L, Michelini A, Lomax A, Boschi E(2009). Rupture history of the 2009 L'Aquila earthquake from non-linear joint inversion of strong motion and GPS data, *Geophys. Res. Lett.*, 36, L19304, doi: 10.1029/2009GL039795.

Gallovič F, Zahradník J (2012). Complexity of the Mw6.3 2009 L'Aquila (Central Italy) earthquake: 1. Multiple finite-extent source inversion, *J. Geophys. Res*., 117, B04307, doi: 10.1029/2011JB008709.

Lucca E, Festa G, Emolo A (2012). Kinematic inversion of strong motion data using a Gaussian parameterization for the slip: application to the 2008 Iwate-Miyagi, Japan, earthquake, *Bull. Seism. Soc. Am.,* 102(6), 2685-2703.