# Ground motion shaking scenarios for the 1997 Colfiorito earthquake

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## 1. The statistical-deterministic approach

In the recent years, two Italian research projects have been devoted to the simulation of ground shaking scenarios in different areas. A large part of the activities has been performed in the Umbria region and was in particular related to the 1997 Colfiorito earthquake.

In general the statistical-deterministic approach was adopted for evaluating the scenarios for strong motion parameters (peak values, spectral ordinates, signal integral quantities, and so on) associated with the occurrence of a characteristic earthquake on a given fault.

This approach is based on the realistic occurrence of a single earthquake related to the fracture of an *a priori* well identified active fault. According to the characteristic earthquake model, an earthquake rupture can repeatedly occurs along the same fault (or fault system) with an almost constant geometry, mechanism and seismic moment, these parameters being mainly related to the direction and intensity of the large scale tectonic stress regime. These ideas are supported by numerous paleoseismic studies of active faults in different tectonic environments [e.g., Pantosti and Valensise, 1990]. On the other hand, each faulting process may not repeat the same style of nucleation, propagation and arrest during successive rupture episodes occurring along a given fault zone, depending these characteristics on the pre-fracturing conditions of rock strength and/or yielding stress along the fault zone. It is therefore assumed that the large scale source characteristics (i.e., fault size and position, focal mechanism and seismic moment) are *a priori* known as the result of previous geological, geophysical and historical seismicity investigations.

The variability of the rupture process is expected to produce variable strong ground motions at the earth surface, depending on the distribution of the kinematic parameters (final slip distribution, rupture velocity, slip duration …) along the faulting surface. In order to account for the possible variation of the source process from one rupture event to another, a large number of synthetic seismograms should be computed for different (and possible) rupture histories occurring along the characteristic fault selected, so to provide a representative set of strong motion records to be used for hazard estimation. By this strategy, the massive computation of synthetics for different possible rupture models does not provide a single earthquake scenario (as for the standard deterministic approach) but a set of possible scenarios whose variability substantially reflects the heterogeneity of the source process. The advantage of this approach is that the variability of the selected strong ground motion parameter at a given site can be described by the statistical quantities inferred from the large number of simulations available. The earthquake scenario can then be represented, for example, by a couple of maps, one describing the spatial distribution of the mean value of the considered ground motion parameter and the other representing the associated variability for example in terms of standard deviation.

## 2. Ground motion simulation techniques

The Colfiorito earthquake was simulated using different numerical approaches that provide both approximated and full wave field. We will discuss only the results from the approximated techniques Asymptotic Method (hereinafter, ASM) and Deterministic-Stochastic Method (hereinafter, DSM). Although these techniques are approximated, they are suitable to generate shaking scenarios near an extended fault where the direct S wave field is generally dominant in amplitude with respect to the reflected, converted and surface phases.

According to the ASM method [Zollo et al., 1997], the seismic wave field associated with the rupture of a finite fault (or fault system) is computed solving numerically the representation integral. Since the technique is aimed at simulating the high frequency radiation, the Green function are computed by the ray theory in a flat layered propagation medium [Farra et al., 1986]. The fault is discretized in rectangular sub-faults whose size is chosen so as to reduce the numerical spatial aliasing. The space-time slip distribution on the fault is obtained assuming a ramp time function parameterized by the rupture time, the rise time and the final slip for each sub-fault. The final slip distribution on the fault is computed in accordance to the k-squared model [Herrero and Bernard, 1994].

The DSM technique [Pacor et al., 2005] starts from the simulation of an acceleration envelope modelled using the isochron formulation [Bernard and Madariaga, 1984] for a kinematic source process. The normalized envelope is then used to window a Gaussian white noise, thus reproducing the phase incoherency of high frequency acceleration. The Fourier spectrum of the resulting time series is then multiplied by a target spectrum defined by seismic moment of the target earthquake and contains source, attenuation and site terms. The target spectrum is site-position dependent because its corner frequency is computed as the inverse of the envelope duration as seen by the receiver. Thus the corresponding acceleration time series will contain information on the directivity effects as modelled by the isochron formulation.

## 3. Simulation facts and results

Computations were performed for the M6, September 26, 1997, Colfiorito earthquake. The geometry, mechanism and position of the causative fault were inferred from the inversion of near source accelerometric data [Capuano et al., 2000]. As explained before, there parameters were kept constant in all simulations. On the other hand, final slip distributions and rupture velocity were allowed to vary. Scenarios for bilateral and unilateral rupture propagations were considered accounting for different rupture nucleation point positions. Synthetic seismograms were computed for each source rupture process considered at a regular grid of 64 virtual receivers regularly distributed on an area on 60km x 60km around the fault.

We found that results are strongly dependent on the rupture velocity value assumed. In particular, the higher is the rupture velocity the higher are the peak values. Moreover, the DSM technique provides scenarios that are dominated by the directivity effect while for the ASM the spatial distribution of ground motion parameters is mainly determined by the radiation pattern. In any case, the variability of ground motion parameters obtained by both simulation techniques is comparable or smaller then the standard deviation associated with the empirical model UMA2005 [Bindi et al., 2006].

The ground motion variability observed for the Colfiorito earthquake is well reproduced when an unilateral rupture propagation toward the NW is considered with rupture velocity of about 2.7 km/s. However, the data can be modelled only in some particular frequency bands due to the relevant amplification associated with the site effects (e.g., the case of Nocera Umbra).

One of the main lesson learnt form the Cofiorito earthquake is that the extended fault effects (e.g., the rupture directivity) are important also in the case of moderate size earthquake.

## 4. Seismic hazard assessment: integrating probabilistic and deterministic approaches

The characteristics of the Colfiorito earthquake were also used to introduce a new technique aimed at integrating the probabilistic and deterministic approaches for seismic hazard assessment. This technique (Convertito et al., 2006) is based on the site-dependent evaluation of the probability of exceedance for the chosen strong motion parameter. The probability is obtained from the statistical analysis of the synthetic waveform database produced for a large number of possible rupture histories occurring on a characteristic earthquake fault, as described before. This integrated technique is aimed at overcoming some of the limitations of both purely probabilistic and purely deterministic approaches for seismic hazard evaluation. In particular it allows the time variable (in terms of return period and time of interest) to be accounted in the deterministic scenario studies and the source characteristics and effects (e.g., fault geometry, radiation pattern, directivity, …) to be accounted in the probabilistic technique. Due to the availability of synthetic waveforms, the analysis can be easily extended to any desired ground motion parameter. Moreover, the site effect can be taken into account if the site transfer function was available.

The method has been applied to the hazard evaluation in the Umbria-Marche region, assuming as threat a fault having the same geometry and mechanism as the Colfiorito earthquake.

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