Rapid estimation of ground shaking for emergency in Campania region (Southern Italy)

[1]Convertito V., [2]De Matteis R., [3]Cantore L., [3]Zollo A., [1]Iannaccone G. and M. Caccavale[3]

1. Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano – Rissc-Lab Napoli, Italy, 2. Dipartimento di Studi Geologici ed Ambientali Università degli Studi del Sannio Benevento, Italy, 3. Dipartimento di Scienze Fisiche Università degli Studi "Federico II" di Napoli - Rissc – Lab., Italy

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Introduction

The present work is part of an Earthquake Early Warning System (EEWS) prototype under development in the Campania-Lucania region, Southern Apennines (Italy). The core of the EEWS is the Irpinia Sesismic Network (ISNet) (Fig. 1) which is deployed around and over the active fault system that generated the M 6.9 1980 Irpinia earthquake. ISNet is a dense (10 km inter-station distance), wide dynamic range network equipped with an advanced data-acquisition and data-transmission technologies. It has been designed for real-time estimation of earthquake location and magnitude and for providing rapid ground-shaking maps to be used for planning emergency actions by regional Civil Protection.

Taking advantage from the main characteristics of ISNet, and based on the idea of ShakeMap®, a procedure for rapid estimation of ground shaking maps after moderate-to-large earthquakes has been developed. It uses an optimal data gridding scheme aimed to account for bi-dimensional features of strong ground motion field such as directivity, radiation pattern, focal mechanism etc. to which larger part of damages can be correlated.

Figure 1: The Irpinia Seismc Network (ISNet) configuration.

The method has been tested off line by using a simulated M 6.6 earthquake located at the center of ISNet and applied to the data of the 23 November 1980 Irpina M 6.9 earthquake recorded at a sparse network.

Site correction

Before computing ground shaking maps, recorded data are reduced to bedrock by using the approach proposed by Park and Ellrick (1998). This approach is based on a site map classification for the southern Apennines region. At each class a constant coefficient for the amplification is assigned. This goal is pursued by grouping the main geological units present in the area in four macro-classes described by units having similar age. The macro-classes have been considered representative of alluvium (Quaternary), volcanic rock (Volcanic), soft rock (Tertiary) and hard rock (Mesozoic), respectively. Then, based on a set of geotechnical soundings, borehole measurements and surface geology a range of shear-wave velocities and densities for the near-surface layer (Vs30) has been assigned to each previously defined class. The map reporting this classification for southern Apennines is indicated as a "QVTM" map following the notation for a similar map proposed by Park & Ellrick (1998) (Fig. 2). In particular, blue corresponds to Mesozoic; green to Quaternary, yellow to Tertiary and red to Tertiary-Quaternary. Concerning the corrective coefficients for PGA and PGV estimates at rock site, we used the ones reported by Wald *et al.* (1999a) except for the Volcanic lithology for which, based on geological information, we assumed as preliminary value 1.25.

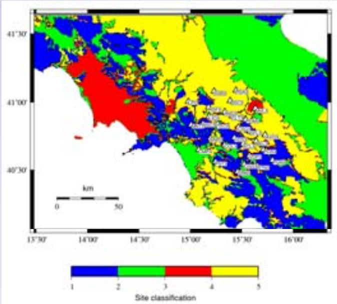

Figure 2: The QVTM site Geological Classification Map.

Methodology outlines

The proposed technique is designed to work both for dense and sparse seismic networks. It performs automatic selection of the parameters controlling the distribution of phantom grid based on seismic stations average spacing and earthquake fault extension along with automatic identification of outliers. A key aspect which makes the proposed technique original, is the local nature of the estimates correction aimed at preserving the azimuthal properties of the recorded peak-ground motion field when using either interpolation or extrapolation. Furthermore, the fact that data domain areas and external areas are considered as different areas in terms of the estimates correction.

Triangulation of the area of interest:

- Recorded values are reduced to rock-site condition by using the QVTM classification and the related corrective coefficients.
- Seismic stations are the vertices of the triangles. For each triangle, the barycentre is identified and used as additional seismic station.
- The maximum acceptable area of each triangle cannot exceed NA×Aave where NA is an integer that depends on seismic network configuration and Aave is the average area of all the triangles. When a given area exceeds the fixed threshold, it is recursively triangulated by using the new barycentres as additional vertices.
- Epicenter is considered as additional station. Datum at the epicenter is the estimated by using the attenuation relationship and corrected by an average residual computed at a number of stations surrounding the epicenter.
- For earthquake located outside the data domain area, triangulation is made denser and denser until a uniform station distribution is obtained.

Residual estimation

At each vertices of the triangles, the residuals are calculated by comparing the observed and predicted ground motion values obtained by using the attenuation relationships. The average residual is then used to correct the predicted value at each barycentre. The correction scheme is aimed at estimating azimuthal effects not accounted for by classical attenuation relationships, such as, directivity, radiation pattern and fault geometry. The maximum acceptable residual value depends on the location of the vertices with respect to the estimated fault length obtained by using Wells and Coppersmith (1994) relationships for a generic fault mechanism. If, for the selected magnitude value, L is the estimated fault length, then all the vertices enclosed into a circle with radius $L/2$ cannot exceed a given number N of σ_{logPGX} where σ_{logPGX} is the standard error of the selected attenuation relationship (Figure 3).

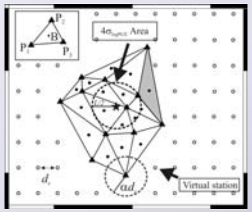

Figure 3

Extrapolation of peak motion outside the region covered by the seismic network

In the proposed technique, the area of interest is covered with a uniform grid of virtual stations, whose spacing interval is fixed to a fraction of the average distance between the stations and barycenters (d_c). Among all the nodes of the grid, only those located at distances larger than the threshold distance (αd_c) value from the closest recording station are retained for extrapolation (circles in Figure 3). At each node, the peak ground motion parameter is predicted by using the attenuation relationship and corrected by the residual weighted for the epicentral distance. The residual is evaluated considering seismic stations having azimuth (Φ) with respect to the epicenter, comparable with that of the considered virtual station (Figure 4).

Estimated and recorded data are integrated and used to generate the shaking-ground map by re-interpolating onto a finer regular grid uniformly spaced at an arbitrary spacing interval. This map is finally corrected for site effect by using the simplified map for site classification and the corresponding corrective coefficients.

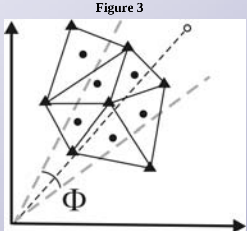

Figure 4

convertito@ov.ingv.it

Test and applications

The proposed technique has been applied to two earthquakes: a simulated M 6.6 seismic event at ISNet stations and the M 6.9 23 November 1980 Irpinia earthquake recorded at the ENEL seismic network. The simulated earthquake is used for testing the procedure on a large earthquake recorded at ISNet, while the choice of the Irpinia earthquake has been driven by the fact that it is the largest earthquake occurred in the area of interest for which recordings are available. The selected attenuation relationship is the one proposed by Convertito et al. (2007), while the instrumental intensity has been calculated by using the weighted average scheme and relationships proposed by Wald et al. (1999b) to convert PGA and PGV in instrumental intensity.

The simulated M 6.6 earthquake at ISNet

Broad-band synthetic seismograms have been computed by using the simulation technique proposed by Gallovič and Brokešhová (2007). The parameters selected for the simulation reproduce the parameters characterizing the first triggered fault segment of the 23 November 1980 Irpinia earthquake (M 6.9). The average area of the triangles is about A = 67 km² while the threshold distance and phantom spacing grid is 30 km. Triangulation scheme and maps for PGA in percentage of gravity acceleration (g), PGV in cm/s and instrumental intensity calculated by using the proposed technique are shown in Figure 5.

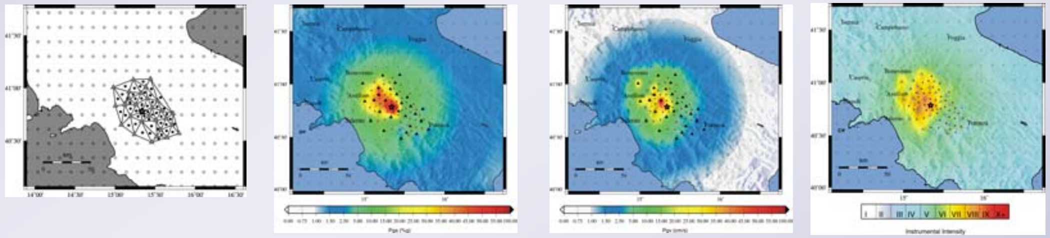

Figure 5

Validation test

In order to validate the technique, the PGA and PGV maps have been re-computed by excluding some stations from input data-set. Next, given the new maps, PGA and PGV data at points corresponding to the excluded stations have been extrapolated from the maps and compared with the original input data. Figure 4 shows the results of the test in terms of residuals between observed and observed data. The proposed technique provides estimates with a lesser residual with respect to the attenuation relationships. The value of the residuals depends on the epicentral distance and, in particular, on the azimuth of the excluded stations. The difference between the two residuals decreases with the increasing number of excluded stations as a consequence of the fact that, when a larger number of stations is excluded, the estimates have a larger weight with respect to the observations.

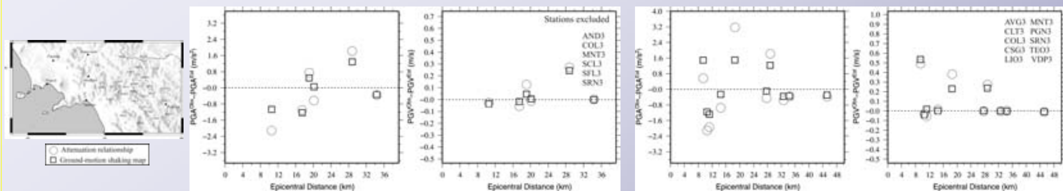

Figure 6

The 23 November 1980 Irpinia earthquake (M 6.9)

The 23 November 1980 Irpinia earthquake (M 6.9). It was characterized by a complex normal faulting that ruptured three different sub-parallel fault segments (F1, F2 and F3 in Fig. 7) of the Southern Apenninic belt chain. Strong-motion records at 18 seismic stations of the ENEA-ENEL network are available to compute ground-shaking maps. Figure 7 shows the location of seismic stations and instrumental epicenter (gray star). In the same panel, the phantom grid (circles), the triangulation scheme and the barycentres (black dots) are also shown. The average area of the triangles is about A = 473 km², while the threshold distance and phantom spacing grid is 62 km.

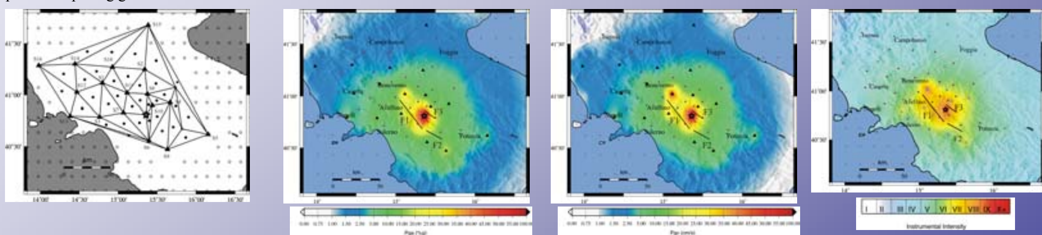

Figure 7

Although the predictive attenuation model is based on the assumption of a point-like source, the maps reproduce the extension of the three fault segments and the associated complex ground motion pattern. This can be ascribed to the use of recorded data and corrected estimates at the barycentres that provides an improved coverage of the source area.

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