Near fault earthquake scenarios for the February 20, 1818 M=6.2 ‘Catanese’ event

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Abstract

We build-up a near-fault ground shaking scenario for the municipal area of Catania (Sicily, Italy). The reference earthquake is the February 20, 1818 M=6.2 earthquake, whose epicenter was close to the northern part of the present settlement of the city. This earthquake is considered a tectonic earthquake and is associated to the northern continuation of the Ibleo-Maltese fault system. This fault system is the major seismogenic structure of Eastern Sicily, and it is considered the responsible of the major historical earthquakes which struck that area, such as the January 11, 1693, M=7.0 event. Despite of its lower magnitude, the ‘Catanese’ earthquake has to be accounted for the seismic hazard assessment of Catania, because of its vicinity to the city.

The near-fault strong ground motion is computed through a hybrid stochastic-deterministic method (EXWIM). This method simulates rupture propagation along finite fault and solves the 3-D full-wave propagation in anelastic media with a vertically heterogeneous structure. In order to evaluate an exhaustive scenario, different slip distributions and hypocenters are considered. The structural model assumed is representative of the Eastern Sicily area, however local site conditions are taken into account at each site in a simplified way (i.e. the VS\textsubscript{30} value). The ground motion is computed for a regular grid of receivers sampling the urbanized area of Catania.

The results consist of three-component waveforms, acceleration and displacement response spectra and other relevant parameters used to describe the ground motion.

Keywords: earthquake scenario, ground motion, extended source.
1 Introduction

Catania is one of the Italian cities more exposed to seismic risk. Two large earthquakes struck the surrounding area in the last thousand years, i.e. the $M_S = 7.3$ in 1169 and the $M_S \geq 7.0$ in 1693 (Monachesi and Stucchi, [1]), the latter caused as many as 54,000 deaths in Eastern Sicily (Boschi et al. [2]). The absence of strong earthquakes for a long time period — about three hundred years—, the high density of population, industries and infrastructures, and the fact that earthquake-reinforced buildings are by far the minority, are the key factors that contribute to increasing seismic risk.

A number of national projects have been carried out, or are still ongoing, with the goal of estimating and reducing the seismic risk of the city (Faccioli and Pessina [3]; Maugeri [4]) and its surrounding areas (Decanini and Panza [5]). Most studies have focused on developing destructive scenarios, assuming the $M_S \geq 7.0$ event of January 11, 1693 as a reference earthquake. Some of them, as well as this study, also tried to estimate damaging scenarios using weaker, medium size reference earthquakes, such as the 1818, $M_S = 6.2$ and 1848, $M_S = 5.5$ events (Monachesi and Stucchi, [1]). All these events are associated to the northern segments of the Ibleo-Maltese fault system, the major seismogenic structure of Eastern Sicily which is considered the responsible of the main historical earthquakes.

We build-up a near fault ground shaking scenario for the February 20, 1818 $M=6.0$ earthquake. According to historical data, the epicenter is located along the south-eastern flanks of the Etna Volcano, close to the municipal area of Catania. Despite of its lower magnitude, a medium size, local earthquake, such as the 1818 event, has to be accounted for the seismic hazard assessment of Catania, since it may cause heavy damage to the most urbanized area.

Figure 1 (top panel) shows the study area, the fault position and the location of the 470 receivers used for the simulations. The source position and the focal mechanism of the January, 11, 1693, $M=7.0$ event and December 13, 1990, $M = 5.8$ earthquakes are also displayed. The bottom panel shows the simplified map of the geotechnical units, which characterizes the municipal area of Catania (Pastore and Turello [6]).

2 The February 20, 1818 $M=6.2$ ‘Catanese’ earthquake

The 1818 event caused damage and ruin in many localities of the Etna eastern flanks, and was felt in a large area of Eastern Sicily. The broad distribution of the ground shaking is typical of a crustal regional earthquake (Barbano and Rigano [7], Azzaro et al. [8]) rather than a shallow depth volcanic Etnean event. The macroseismic field of this earthquake is represented in figure 2. The maximum damage is localized eastward of the epicentre. However, the damage distribution seems incomplete towards West and South, probably because of the scarcity of human settlements.
The hypothesis of activation of a deeper, blind fault of the Malta escarpment beneath the eastern side of the volcano during the 1818 earthquake is supported by the evidence of secondary faulting of the Ibleo-Maltese system, NNW-SSE oriented, along the eastern flank of Mt. Etna as well as the occurrence of a tsunami along the Ionian coast (Azzaro et al. [8]).

Figure 1: Top: the study area; bottom: simplified map of the geotechnical units and location of the receivers.
3 Geological setting

On the regional scale, the crustal structure of Eastern Sicily is quite complex. A simplified cross-section of the geological structure along the N-S direction is shown in Figure 3.

The main units are: i) the carbonatic basement of the Hyblean Foreland (gray colored in Figure 3), ii) the sedimentary formations of the Northern Chain (pink and orange), which underlie iii) the volcanic body of Mt. Etna (blue), iv) the Ibleo-Maltese escarpment running offshore in the NNW-SSE direction, and, at a smaller scale, v) the Gela-Catania Foredeep, with the sedimentary basin of the Catania Plain (green). The geology and structural set-up of the region has been studied by a number of authors. A summary of references and a synthesis of the results can be found in a number of papers (e.g., Lentini [9], and Sirovich and Pettenati [10]).

The surface geology of the Catania municipal area features a strong spatial variability, with the presence of both volcanic and sedimentary units (Pastore and Turello [6]). The ages of these units range between the mid-lower Pleistocene and the upper Holocene. Figure 1 shows the simplified geotechnical map of the main lithological units.

The lava flows cover a great part of the Catania downtown. Slightly at South of the urban area, in the zone called the ‘Terreforti’ hills, a sedimentary series of Pleistocene age outcrops. This series belongs to the Northern Chain structural unit. It consists of clays, interbedded with layers of sands, and tufaceous levels. The upper part of the formation displays layers of pebbles and conglomerates. The overall thickness of the Terreforti formation is thought to reach a few hundred meters. At the base of this series there are grey-light blue clays, which are sandy clays showing a grey-light blue color at fresh cuts.
South of the Terreforti hills lies the Catania Plain, a lowland characterized by recent and ongoing alluvium deposits grading to coastal deposits.

![Geological section of Eastern Sicily around Catania.](image)

**Figure 3:** Geological section of Eastern Sicily around Catania.

### 4 Numerical method

We use a hybrid stochastic-deterministic method to compute strong motion seismograms in the near-field of extended earthquake sources. This method (EXWIM) solves the 3-D full-wave propagation in anelastic media with a vertically heterogeneous structure. The computational kernel is the wavenumber integration method (Herrmann [11]). We model the fault rupture using the kinematic approach by Herrero and Bernard [12]: the moment density is described by a deterministic-stochastic $k^2$ distribution, and instantaneous slip release. In this study, the rupture propagates from the nucleation point with constant velocity $v_R = 0.8 \, V_S$ on the fault plane.

In our hybrid approach, composite broadband seismograms, that span the entire frequency range of interest, are obtained as a sum of deterministic low-frequency complete seismograms and a stochastic high frequency contribution. The need of using such approach comes from a common acceptance among authors (e.g.: Pitarka *et al.* [13]) of the fact that the signal looses its coherence in the high-frequency band as an effect of the wavefield propagation through the real earth.

Our computational procedure consists of: 1) discretizing the area into a grid of elementary point sources; 2) computing the wavefield generated by each point source with unitary seismic moment; 3) computing seismograms for each point source according to the given distribution of slip; and 4) summing up each contribution synchronized in time to simulate the propagation of the rupture.

In this work, seismograms have been computed up to a maximum frequency of 20 Hz. The deterministic-stochastic transition has been set at 1.5-2 Hz. The maximum fault size has been set at 26.6 km $\times$ 16.6 km, and it has been discretized into 4895 elementary sources, with inter-spacing of 300 m.
5 Structural model and source parameterization

The ground motion is computed at a regular grid of receivers covering the Catania municipal area. This area is sampled with 470 receivers, with inter-spacing of 320m. The model (figure 4) represents the average structure of Eastern Sicily (Priolo [14]). To take into account the local site conditions, the $V_{S30}$ values have been specified at each receiver according to the simplified geotechnical map shown in figure 1. In particular, the area which features the presence of the Terreforti formations and light blue clays at surface (pink colour, figure 3) is taken as the ‘reference’ model (figure 5a). In the northern part of the Catania area these sedimentary formations are covered by lava flows, which have been represented by $V_{P30} = 1730$ m/s and $V_{S30} = 1000$ m/s (figure 5b). In the coastal area, the sedimentary formation of the blue clays are overlaid by fine alluvium deposits, which are represented by a layer with $V_{P30} = 430$ m/s, $V_{S30} = 220$ m/s (figure 5c).

![Figure 4: Reference velocity model.](image)

![Figure 5: Shallow velocity models.](image)
A pure normal fault mechanism is assumed for ‘Catanese’ earthquake. Fault strike and dip are set at values already used by previous studies (Priolo [14]; Zollo et al. [15]) for the Ibleo-Maltese system, i.e. $\phi = 352^\circ$ and $\delta = 80^\circ$, respectively. Two different rake distributions are considered, i.e. constant ($\lambda = 90^\circ$) and variable ($45^\circ \leq \lambda \leq 135^\circ$) over the fault plane, respectively. In the latter, the average value corresponds to that of the constant rake.

We model three different fault sizes, corresponding to large, medium and small size, respectively. The average value (16 km $\times$ 10 km) is estimated by the classical scaling law of Wells and Coppersmith [16], while the others correspond to an increase/decrease of 2/3 of the average length. The corresponding stress drop values are $\Delta\sigma = 0.2$ MPa, $\Delta\sigma = 1$ MPa and $\Delta\sigma = 15$ MPa, respectively. Three different $k^2$ slip distributions are used for each fault size. When defining the three fault sizes, the fault centre has fixed depth. It turns out that the fault top ranges from 3.5 km to about 9.5 km of depth.

Nucleation points are regularly distributed with inter-spacing of 1600 m (one point every six elementary sources). Figure 6 shows an example of large size source: contour lines, black arrows, and blue circles indicate the seismic moment distribution, slip vector, and nucleation points, respectively.

6 Results and discussion

Three-components seismograms are computed at each of the 470 receivers, for a total number of 1188, 360, and 48 seismograms for the large, medium, and small fault sizes, respectively.

Figure 7 shows the average PGA scenario, which consists of the mean value obtained considering the three fault sizes (small, medium and big), three slip...
distributions, two rake models (constant and variable) and all nucleation points, computed at each receiver. The left and right panels refer to the horizontal and vertical components, respectively.
The amplification effect of the different soil types is remarkable: the receivers located on the fine alluvium of the Catania plain feature the highest PGA, which are about 1.5 and 2.0 times larger than the values obtained at the receivers located nearby, on the Terreforti formation and lava, respectively. High PGA values can also be observed in the Northern part of Catania, where the sedimentary formation outcrops from lava.
Figure 8 shows an example of the seismograms and acceleration response spectra computed at receivers located close each other for two different soil conditions, i.e. on the fine alluvium of the plain (left panel) and lava (right), respectively. The figure concerns the ‘medium’ size fault, variable rake distribution and up-dip rupture.

Figure 7: Mean PGA. Note the different colour scale.

Figure 8: Site response.
The effect of the constant and variable rake distribution is shown in figure 9. It can be seen that the variable rake results in a small increase of the ground motion, although the amount depends on the slip distribution. The figure concerns the ‘medium’ size fault and all nucleation points. Finally, figure 10 shows how the fault size (or, equivalently, the average stress drop) affects the ground motion. The higher the stress drop the higher the resulting acceleration. The maximum PGAs are about 6 m/s² and 0.8 m/s² for the small and large fault size, respectively. The ratio between the two static stress drops is about 30.
Note that the values obtained for the small size do not feature a regular attenuation with distance. On the contrary, normal attenuation with distance is shown by considering the other two fault sizes. This is a combined effect of both larger source-receiver distance and deeper source, which causes wavefield reflection/refraction at deep velocity interfaces.

7 Conclusions

The scenario simulated for the ‘Catanese’ earthquake predicts average accelerations ranging from less than 1 m/s$^2$ to about 3.5 m/s$^2$ on rock (i.e. lava) sites. These values are quite close to those predicted for the January 11, 1693 M$>7$ earthquake by previous studies (Faccioli and Pessina [3]), and demonstrate the importance of taking into account smaller -but closer events in estimating the seismic hazard of a given area.

Earthquake scenarios are computed by assuming a simplified local seismic zonation based on the average velocity of the shallowest 30 m. Large discrepancies in the near fault strong ground motion seismograms are found when different soil types are accounted for.

A large variability of PGA is predicted in the near-fault, thus demonstrating the need of having a more accurate definition of the input source parameters to model the expected ground motion.

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References


