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MODELING THE 1980 IRPINIA EARTHQUAKE BY STOCHASTIC SIMULATION. COMPARISON OF SEISMIC SCENARIOS USING FINITE-FAULT APPROACHES

G. ZONNO[1] and A. CARVALHO[2]

[1] INGV - Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, Italy

[2] LNEC - Laboratório Nacional de Engenharia Civil, Lisbon, Portugal

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SUMMARY

To define more accurately the near field and the directivity effect, different methodologies of finite-fault modelling have been used to describe the behaviour of ground shaking based on deterministic, stochastic and hybrid stochastic-deterministic approaches as in the framework of the ongoing European project **"LESSLOSS – Risk Mitigation for Earthquakes and Landslides"**.

In this study, we simulate and compare seismic scenarios obtained from the **complex source characteristic** of the **1980 Irpinia earthquake, M 6.9,** Southern Italy, using models based on the source models hypothesized in **Bernard and Zollo (1989)** and in **Valensise et al. (1990)**. Furthermore, two finite-fault numerical approaches are used:

1. The approach **RSSIM** [Carvalho et al., 2004] that is a ***non-stationary stochastic simulation*** method that synthesizes the ground motion due to an extended source;
2. The approach **EXSIM** [Motazedian and Atkinson, 2005] that is a new version of FINSIM [Beresnev and Atkinson, 1998] introducing a new variation based on a **"dynamic corner frequency".**

The shaking scenarios are computed in terms of Response Acceleration Spectra (PSA), time series, peak ground acceleration (PGA) at bedrock level. Source and path propagation parameters taken from other studies were tested and the computed shaking scenarios are compared to acceleration records to eight different stations. Preliminary results are here presented in terms of PGA maps for the Campania region (Southern Italy).

PRESENTION of the DATA BASE DISS 3.0.2

Database of Individual Seismogenic Sources, (version 3.0.2)

Figure 1. DISS 3 is available through the internet at the URL: http://www.ingv.it/DISS/. The database can be navigated through a user-friendly cartographic interface. Data tables forming DISS are also available for download in several GIS formats.

The main object of the database is the seismogenic source, intended as a simplified and georeferenced 3D representation of a fault plane. Two categories of geological/geophysical data are stored in the database: individual seismogenic sources and seismogenic areas. The database stores only seismogenic sources that are capable of earthquakes of M ≥ 5.5.

The individual seismogenic source is identified through geological and geophysical investigations, is capable of primary slip during a large earthquake and is assumed to exhibit "characteristic" behavior with respect to rupture length/width and expected magnitude. Each record of this category includes data on surface ruptures – when present and an evaluation of the uncertainties associated with the source. All records are fully parameterized and, thus, are ready to use in computer applications. (Yellow rectangles).

Seismogenic areas are crustal bodies for which a geographic outline, predominant faulting mechanism, effective depth, and expected maximum magnitude are supplied. Seismogenic areas are drawn with consideration of known large-scale tectonic structures, major earthquakes not associated with obvious tectonic structures, seismicity patterns, and long- and short-term strain observations. (Orange ribbons).

Unlike its predecessors, both the structure and the content of DISS 3 put significant emphasis on potential applications in the assessment of seismic hazard.

DISS Working Group (2005). Database of Individual Seismogenic Sources (DISS), Version 3.0.2: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. http://www.ingv.it/DISS/,

The 1980 Irpinia Earthquake

On 23 November 1980 a violent earthquake hits the Campania and Basilicata regions, causing nearly 3,000 deaths and severely damaging homes and infrastructures. The 1980 Irpinia Earthquake is a complex event that involves at least three distinct ruptures in a time span of approximately 40 sec. The main event (0s) was followed by a rupture episode about 20s after and one 40s after the starting of the earthquake. Different analogic accelerograms were recorded during the events but only 8 of them were within 50km from the hypocenter. This earthquake was widely studied and a complete review was published in the proceedings of the Special issue on the meeting "IRPINIA 10 ANNI DOPO" (Annals of Geophysics, Vol. XXXVI, n. 1, April 1993). Other main references are indicated in the bottom box.

The sub-event (20 s)

While the main features of the first (0 s) and of the last (40 s) sub-events are widely accepted, the second sub-event (20 s) is still controversial and very different models have been assumed in the available literature.

The research of some elements to support a model against the other ones is out the scope of this study.

To perform this study we have assumed basically only the models of Bernard and Zollo (1989) and in Valensise et al. (1990) as shown in **Figure 3** and with the parameters represented in **Table 1**.

Model A : used slip distributions

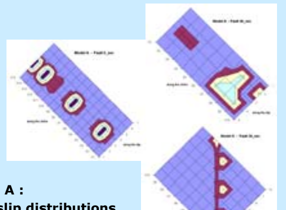


Figure 2. The total amount of slip distribution is given from the assigned value of Mw (Table 1) and is concentrate, for each fault, following a simple schematic geometry.

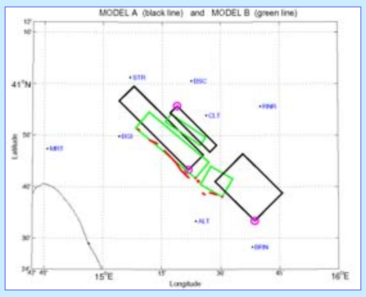


Figure 3. The figure shows the fault geometry of the **Model A** and **Model B** that are coming respectively from a modification of the original model of Bernard and Zollo (1989) and from the model of Valensise et al. (1990) as it is stored in the Data Base DISS 3.0.2. The solid red traces represent the outcrop lines close to the most superficial edge of the faults while the pink circles are the origins of three faults following the convention defining strike direction is that fault always dips to the right of it (used in the EXSIM program).

Parameters of the faults models	Model A* from Bernard & Zollo (1989)			Model B (DISS 3.0.1 from Basili et al. 2006)		
Nick-name of faults	0_sec	20_sec	40_sec	0_sec	20_sec	40_sec
Mw of modeled (target) event	6.7	6.3	6.2	6.8	6.2	6.2
Fault strike (degrees)	315	315	135	310	300	124
Fault dip (degrees)	60	20	70	60	60	70
Depth top of rupture (degrees)	2.2	4	2.2	1	1	1
Fault length along strike (km)	35	20	20	28	9	15
Fault width downdip (km)	15	15	10	15	15	10
Number of subfaults along strike	15	10	10	14	5	7
Number of subfaults along dip	7	8	5	7	7	5
Indices of enucleation point subfault	(3;5)	(10;8)	(2;5)	(7;4)*	(3;4)*	(4;3)*
Lat.X & origin EXSIM (degrees)	40.7224	40.5571	40.9286	40.6964	40.6347	40.9028
Lon.X & origin EXSIM (degrees)	15.3631	15.6445	15.316	15.3931	15.5006	15.2883

* the used model is different from the original one (i.e the length is longer along strike in case of the 0_sec fault)
* the bilateral rupture is assumed (enucleation point is located on the barycentre of the fault)

Table 1. Parameter of the fault models used in this study (Model A and Model B; see the Figure 3). In the table are indicated the position of the nucleation points in respect to the number of the sub_faults.

RECORD	#	CODE	NAME	LATITUDE	LONGITUDE
RA00621	1	BGI	BAGNOLI IRPINO	40.8306	15.0681
RA00627	2	MRT	MERCATO S.SEVERINO	40.7894	14.7628
RA00629	3	STR	STURNO	41.0208	15.1130
RA00636	4	CLT	CALITRI	40.8989	15.4369
RA00643	5	RNR	RIONERO IN VULTURE	40.9272	15.6650
RA00644	6	BSC	BISACCIA	41.0067	15.3769
RA00640	7	ALT	AULETTA	40.5581	15.4050
RA00624	8	BRN	BRIENZA	40.4778	15.6344

Table 2. Name references (ENEL-ENEA) of the used records at the stations: Bagnoli Irpino, Sturno, Rionero in Vulture, Auletta, Mercato San Severino, Calitri, Bisaccia and Brienza (see also the Figure 3).

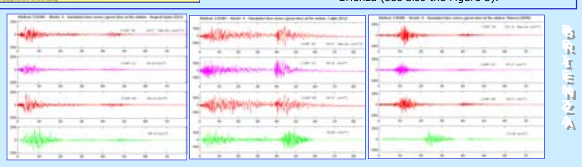
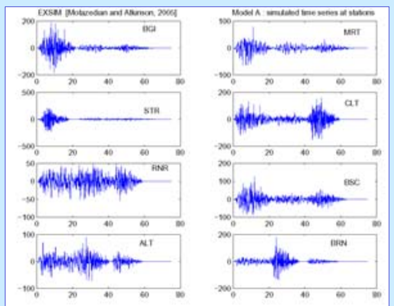


Figure 4. Left: comparison of the accelerometric components NS, DU and WE at the station Bagnoli Irpino (BGI), Calitri (CLT) and Brienza (BRN) with the respectively simulated time series (green line) using the program **EXSIM** and the **Model A.** At the station of Brienza the Model gives a simulated time series more comparable with the observed one.



A stochastic reference PGA map using the Data Base DISS 3.0.2

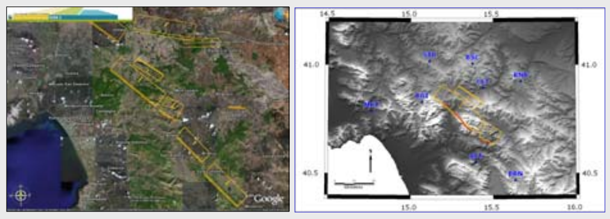


Figure 6. – **Left:** geometry of the faults of the Irpinia region from DISS 3.0.2; **Right:** a spot of DISS 3.0.2 on the geometry of the faults (yellow lines) of the **1980 Irpinia Earthquake** (after named as **MODEL B**) and the locations (blue triangles) of the accelerometric stations used in this study.

A reference PGA map coming from 3D Finite-Fault geometry of Individual Seismogenic Sources of the Italy, represented in the data base DISS 3.0.2, could give important constrains and improvements in the assessment of local seismic hazard. The total contribution of the seismic scenarios (an example is given in the following in terms of PGA parameter) could give a general reference (at the bedrock) for the ground motion shaking overcoming the paucity of available accelerometric records.

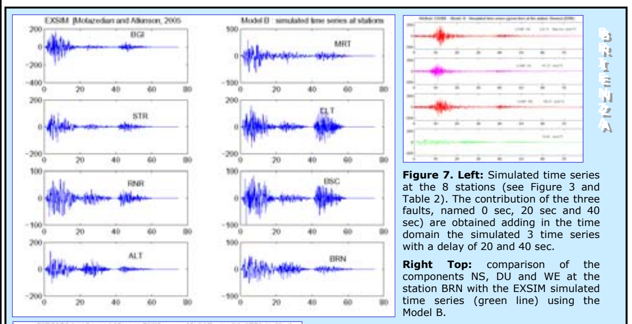


Figure 7. Left: Simulated time series at the 8 stations (see Figure 3 and Table 2). The contribution of the three faults, named 0 sec, 20 sec and 40 sec are obtained adding in the time domain the simulated 3 time series with a delay of 20 and 40 sec.

Right Top: comparison of the components NS, DU and WE at the station BRN with the EXSIM simulated time series (green line) using the Model B.

Stochastic shaking simulations

As first we did stochastic shaking simulations of the Finite-Fault approaches **RSSIM** and **EXSIM** comparating the observed 5% damped response spectra with the simulated response spectra (Figure 5 and Figure 8). The main input parameters of this stochastic simulations are the fault geometry, the location of the nucleation point, the average elastic properties of the propagation media, such as crustal shear velocity, density and attenuation factors, and source related parameters as seismic moment and slip distribution on the fault. **We don't use** the random slip distribution because it gave a vorser fit between the computed and simulated response spectra. We assumed that both **Model A** and **Model B** have a regular geometric distribution in the slip distribution (see Figure 2 and Figure 9). The position (,) of the sub-fault of the nucleation points are shown in the Table 1. For the Model A we used the location of nucleation points (from literature) that takes better results but for the Model B we assumed a bilateral rupture that means a nucleation point in the centre of the fault.

Using EXSIM (*we have changed EXSIM code so to perform multiple ruptures*) we have adopted the option of dynamic corner frequency model (with the value of 50% of the fault actively slipping at any time in the rupture) with a **stress drop** of 100 bars, a value of **Q** equal to 100 and a value of ***k*** of 0.03. We have used the given slip distributions shown in the Figures 2 and 9. On the subdivision of fault we keep values to have the grid size of about 2 km x 2 km for all three faults (0 s, 20 s and 40 s).

Using RSSIM the same stress drop, Q and k values were adopted as well as the same slip distribution and fault parameters. In this method, a impedance function, f1, is used to take into account the impedance effect caused by the change in the density and S-wave propagation velocity from the source region to the prediction site [see Ferrer and Sánchez-Carratalá, 2004]. It was adopted the expression f1(f)=2/[1+(fzi/f)2] for f>fzi, with fzi=0.32 Hz according to Faravelli [1987].

NOTE 1. Legend of Figure 5 Left. The colors mean: **YELLOW** - original scaling factor, all station with f1 filter; **GREEN** - original scaling factor, f1 filter only distances > 30 km; **BLUE** - original scaling factor, without filter and **RED** - Boore scaling factor, all f1 filter.

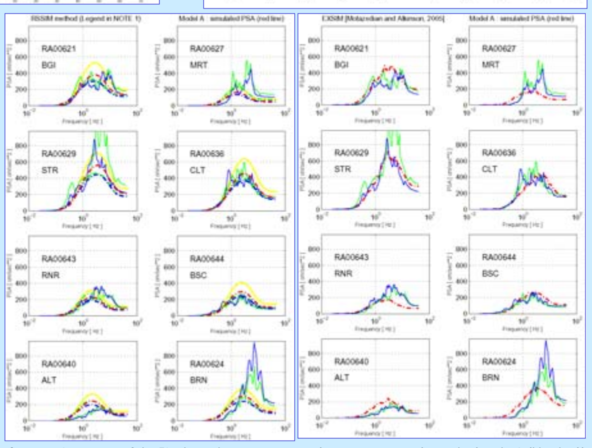


Figure 5. Comparison of the 5% damped response spectra (components: WE (green line) and NS (blue line)) from the observed data [correction ORMSBY filter in the time domain: .50 - .70 and 25. – 27. Hz] with the simulated response spectra using the Model A. **Left:** results from the method **RSSIM** using different options (see **Note 1**); **Right:** results from the method **EXSIM** [5% damping and SARAGONI-Hart window 0.1 – 40. Hz].

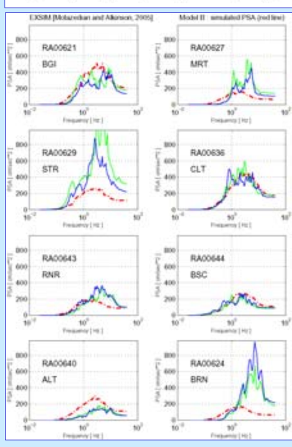


Figure 8. Comparison of computed response spectra from records of Irpinia data set (ENEL – ENEA) and the EXSIM simulated response spectra (red line), using the **Model B.**

Model B : used slip distributions

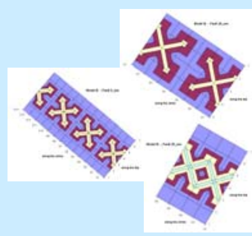


Figure 9. The total amount of slip distribution is given from the assigned value of Mw (Table 1) and is concentrated, for each fault, following a regular simple schematic geometry around the nucleation point. In the Model B the nucleation points are always located in the centre of faults (see Table 1). The dip angle of the fault is not shown in this projection, the same appears for the Figure 2.

The comparison of PGA maps

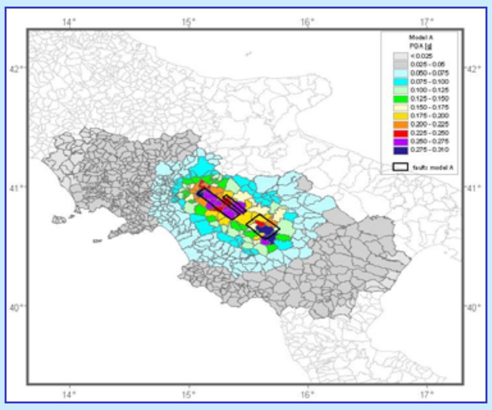


Figure 10. This map presents Campania region and also Basilicata region where it is located 20s fault. The stochastic PGA map is obtained from **RSSIM** using the 1980 Irpinia Earthquake fault model **MODEL A** (modified Bernard & Zollo, 1989). The computation has been done at level of municipalities.

http://zonesismiche.mi.ingv.it/mappa_ps_apr04/griglia002/campania.html

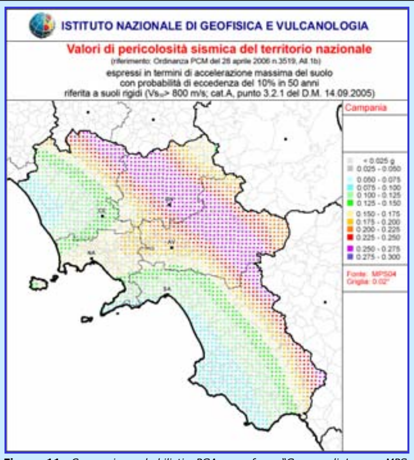


Figure 11. *Campania probabilistic PGA map from "Gruppo di Lavoro MPS (2004). Redazione della mappa di pericolosità sismica prevista dall'Ordinanza PCM 3274 del 20 marzo 2003. Rapporto Conclusivo per il Dipartimento della Protezione Civile, INGV, Milano-Roma, aprile 2004, 65 pp. + 5 appendici"*

Stochastic reference PGA maps using the Data Base DISS 3.0.2

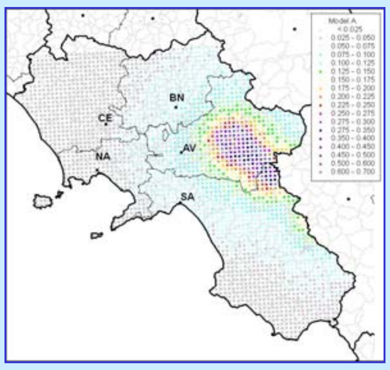


Figure 12. Campania stochastic PGA map (for a grid of 0.02 x 0.02 degree) from **EXSIM** using the 1980 Irpinia Earthquake fault model **MODEL A** (modified from Bernard & Zollo, 1989). **Warning**: the results are preliminary because we have used only 3 trials.

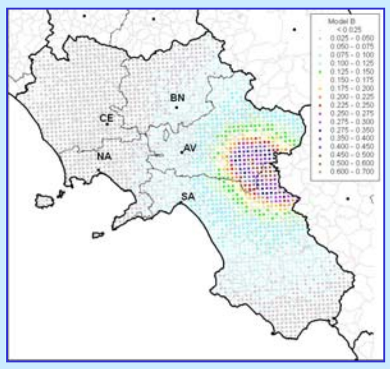


Figure 13. Campania stochastic PGA map (for a grid of 0.02 x 0.02 degree) from **EXSIM** using the 1980 Irpinia Earthquake fault model **MODEL B** [DISS 3.0.2, DISS Working Group (2005)]. **Warning**: the results are preliminary because we have used only 3 trials.

Short description on the used simulation methods

The **RSSIM** (Carvalho et al., 2004) approach is a non-stationary stochastic simulation method that synthesizes the ground motion due to an extended source. This method has been implemented starting from the classic simulation code **FINSIM** (Beresnev and Atkinson, 1998).

Like FINSIM, the RSSIM method assumes that the fault plane is a rectangle, subdivided into an appropriate number of sub-faults, which are modelled as point sources characterized by an ω2 spectrum.

Differently from FINSIM, RSSIM avoids the computation of acceleration time series representing the contribution of each sub-fault, but synthesizes the ground motion due to the entire fault from the Power Spectral Density Function (PSDF) radiated by each sub-fault, using the random vibration theory and the extreme values statistics. The **RSSIM** program is a part of **LNECloss system** (Sousa et al., 2004)

The **EXSIM** program (Extended Finite-Fault Simulation, Motazedian and Atkinson, 2005) is an updated version of FINSIM. The modifications to FINSIM introduce the new concept of a "Dynamic corner frequency". The model has several significant advantages over previous stochastic finite-fault models, including independence of results from sub_fault size, conservation of radiated energy, and the ability to have only a portion of the fault active at any time during the rupture (simulating self-healing behaviour (Heaton,1990)).

Comment on the used methods

*The **RSSIM** method, coming from **FINSIM**, is customized for engineering applications and is devoted to take into account the soil effects in a very efficient way.*

*It has a disadvantage when working in the frequency domain with a non-stationary stochastic approach, as it loses the capacity to produce time series at the analyzed sites. For this reason both the methods are to be used following the necessity of the specific applications. Of course, all the new features like those of the **EXSIM** program will be updated in the RSSIM method too.*

MAIN OUTCOMES

In this study we have obtained some preliminary results in:

- producing a reference PGA map coming directly from DISS 3.0.2;
- comparing two fault models (Model A and Model B) of the 1980 Irpinia earthquake in terms of simulated time series;
- comparing the capacity of two finite-fault methods (RSSIM and EXSIM) in terms of simulated 5 % damped response spectra;
- trying to study some of the features of the complex source characteristic of the 1980 Irpinia earthquake, Southern Italy, using simple kinematic source models.

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