

SYNTHESIS 0.1: BETA RELEASE OF A SYNTHETIC WAVEFORMS REPOSITORY

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1. Introduction

Earthquake engineering analysis requires, as seismic input, a reliable and complete characterization of ground motion both in time and frequency domains.

For time-series analysis, engineers often use a suite of observed accelerograms from past earthquakes, selected from worldwide databanks on the base of specific criteria, suitable for their particular purpose, such as strong-motion parameter, magnitude, distance, site class, tectonic environment, spectral matching, etc..

One reason of promoting the use of synthetic seismograms is the paucity of recorded strong motion data in near-source range for moderate to strong events that are of great concerns for seismic hazard evaluation, risk assessment and seismic microzonation.

Synthetic waveforms, generated by broadband simulation procedures, have the potential to represent a valid alternative to observed motions. Several simulation techniques have been recently proposed to this aim (Graves and Pitarka 2004; Pacor et al., 2005; Liu et al., 2006; Gallovič and Brokešová, 2007; Ameri et al., 2008; among many others). They vary in methodological approach and complexity, but all of them model source processes, path effects, and local site response. The numerical models require the definition of a quite large number of input parameters whose values rarely can be fixed "a priori". While reasonable hypothesis can be done on the causative fault and properties of the propagation medium, kinematic parameters describing the rupture can hardly be set.

To handle this lack of knowledge, a strategy is to generate, for each fault, a large number of shaking scenarios (all equally probable), assuming the input values in a plausible range. Each scenario corresponds to a specific combination of input parameters used to simulate the ground motion. In this way, for each site, a number of ground motion synthetics become available. The synthetics can be statistically analyzed to evaluate the probability distribution of ground motion values (PGA, PGV, PSA, etc.).

In this study we present a prototype of the database SYNTHETic SeISmograms (SYNTHESIS 0.1). It is designed to archive and distribute synthetic waveforms computed for earthquake hazard analysis and engineering applications. The database is complemented with all associated information describing each scenario-event. The structure of SYNTHESIS is adopted from the ITACA database (<http://itaca.mi.ingv.it>), developed to archive and distribute recorded strong motion data in Italy. The main features of the SYNTHESIS database and the web portal for data dissemination are illustrated. The web database can be accessed at <http://dyna.mi.ingv.it/synthesis/>. A wide range of search tools enables the user to interactively retrieve synthetic waveforms, parameters of the scenario-events and geographic information on simulation sites. A range of display options allows users to view data in different contexts, extract and download synthetic waveforms and display maps of selected peak ground parameters.

2. Simulation techniques

Seismic scenarios reported in the SYNTHESIS database are characterized by various complexity levels which are defined by the typology of the computing techniques used to simulate seismograms. In the first release of the database we have considered seismograms generated by stochastic (EXIM, Motazedian and Atkinson, 2005), deterministic-stochastic (DSM, Pacor et al., 2005) or hybrid methods (HIC, Gallovič and Brokešová, 2007), as summarized in Tab. 1. Deterministic methods are those that can reproduce in a more realistic way the path effects in a well defined heterogeneous media through a full numerical simulation of the fault-to-site wavefield. On the other hand, they require a greater amount of computational resources.

Stochastic finite fault methods, in spite of their theoretical limitations, are more efficient in terms of computational resources, and can be widely used to simulate accelerograms in the engineering frequency-range of interest (0.2 - 20 Hz).

3. Scenario-event

In the SYNTHESIS prototype database we have included the case of the 1980 Irpinia earthquake (M 6.9). This earthquake was the largest seismic event ever recorded in Southern Italy by strong motion instruments (Cocco and Pacor, 1993; Improta et al., 2003; Cultrera et al., 2010; Ameri et al., 2011). It was recorded by only 21 analog accelerometric stations, 8 of them located close to the source ($R_{jb} < 40$ km), belonging to the National Accelerometric Network (RAN, Rete Accelerometrica Nazionale) operated by Italian Department of Civil Protection (DPC). This event was characterized by subsequent rupture episodes of three distinct normal fault segments. For simplicity, we considered just the first strongest rupture episode that occurred on a NW-SE oriented and NE dipping fault plane (Length = 35 km, Width = 15 km, Fault Top Depth = 2.2 km). The synthetics were computed at a dense grid of 144 virtual receivers located around the fault up to R_{jb} distance of 100 km. In addition, synthetics waveforms were also simulated for 8 near fault accelerometric stations. For all simulations, a normal fault-plane embedded in a 1D propagation medium with bedrock surface condition was assumed. On the fault, 54 different rupture models were simulated varying the source kinematic parameters such as: i) position of the nucleation point, ii) rupture velocity, and iii) final slip distribution. The synthetic dataset is composed of three groups of more than 10000 simulated accelerograms, each of them corresponding to three different finite-fault simulation techniques (EXSIM, DSM and HIC codes).

4. Data dissemination

The synthetics are distributed as ASCII files, whose name contain the information on the virtual grid of receivers, the site code, the type of simulation, the site conditions, and the ground motion component.

The ASCII files contain a header of 55 rows, where the main information describing the synthetic waveforms are included (hypocentral location, magnitude, simulation technique, frequency range, etc.), being followed by a column with ground motion amplitudes.

Prior to uploading into the SYNTHESIS database, the synthetic data are processed adopting different standard procedures depending on the considered simulation technique, in order to also distribute velocity and displacement waveforms, and to compute the associated ground motion parameters (peak and integral values).

The dissemination of SYNTHESIS is performed through the web portal <http://dyna.mi.ingv.it/synthesis/>, where a fully relational database is stored. It can be explored through three groups of user-friendly interfaces, which allow performing queries on selected scenarios, stations and waveforms parameters. Each group can be explored specifying search key fields: 11 for the scenarios, 13 for the stations, and 10 for the synthetic waveforms.

The first group (*scenarios*) manages the information flow regarding the input parameters used for the ground motion simulations (seismogenic source, magnitude, hypocentral location, crustal velocity model, rupture velocity, slip distribution, etc.). As the primary key field (Fig. 1) we introduce an univocal alphanumeric code (e.g. ID = SY-2012-000101) composed of 3 parts specifying : a) recorded earthquakes (EQ) or scenario-events (SY); b) year of simulation (2012); c) simulation counter (000101). From the list of outcomes the user can access the scenario details, where all the simulation input parameters, together with related references, can be retrieved (Fig. 1). Epicentre, sites and seismogenic sources are mapped through the Google-Map data©, together with the simulated PGA values (cm/s^2) (Fig. 1). Detailed information on the synthetic accelerograms (station, magnitude, fault distance, ground motion parameter, frequency range, etc.) are identifiable either by a waveforms list or through Google-Map (Fig. 1). The waveforms that satisfy the required conditions can be displayed with the aid of a Java applet. It allows the user to perform simple operations like zoom in/out, modify display options (axis labels, axis limits, background and foreground color, etc.) and plot saving or printing (Fig. 1).

The second group (*stations*) controls the information related to the sites at which the ground motion simulations is performed (location, geomorphologic and geotechnical features). The simulations can be associated with different virtual grids or at existing accelerometric stations.

The third group (*synthetic waveforms*) is related to the synthetic waveforms. The waveform query can be made through a simple or an advanced search. Simple searches allow selecting synthetics for a limited number of relevant key fields (PGA, PGV, PGD, magnitude, source distance etc.). Fig. 2 shows an example of a simple search, where data are constrained by: EXSIM code, magnitude range (M_w or M_l) between 5.0 and 7.0, epicentral distance less than 50 km, PGA between 400 and 600 cm/s^2 . An advanced search allows retrieving the synthetics using all the available key fields of the SYNTHESIS database.

The waveforms resulting from the queries can be downloaded in a compressed file format, which contains unprocessed and processed acceleration, velocity, displacement time-series and acceleration response spectra. An image gallery is also included in the web portal to quickly display and download pictures related to seismic scenarios (PGA, PGV, PGD or SA maps) or earthquake photo collections for historical events (Fig. 3).

5. Final considerations and future improvements

The synthetic waveform database has been designed to be a useful tool for scientific research or practical applications in seismology and earthquake engineering fields (Chiauzzi et al., 2012). Indeed, waveforms and associated information can be used in a variety of applications, such as, to constrain ground motion prediction equations, to define damage scenario for seismic risk mitigation and as seismic input for site response or structural response analyses. The web portal of the database allows to explore data with a user-friendly interface and to examine seismogenic source geometries, slip distributions, crustal velocity models or other parameters of interest for the ground motion simulations.

For the future we plan to include additional synthetic seismograms for a wider range of scenario-events which are representative of the seismogenic potential of the Italian peninsula. In particular, the repository will be enriched by the synthetics for L'Aquila (central Italy) earthquake (April, 2009 M_w 6.3). This earthquake was recorded by 14 near field digital strong motion stations which can be used to validate the synthetics generated in this area (Ameri et al., 2012). Data coming from the MASSIMO project (Monitoraggio in Area Sismica di Sistemi Monumentali, Cultural Heritage Monitoring in Seismic Area) will be also included. This project is devoted to the assessment of the seismic response of several test buildings which are relevant from the cultural heritage conservation point of view. All the test buildings are located in Southern Calabria, a seismogenic area that in the last three centuries was struck by disastrous earthquakes (epicentral intensity greater than VIII MCS, Working Group CPTI, 2011).

Moreover, since a single event can be simulated through several scenarios and therefore produce thousands of waveforms, the next step of our research will be the establishment and implementation of a selection criterion to facilitate and retrieve (within the entire available dataset) synthetic seismograms, based on the statistical distribution of the ground motion parameters (i.e. mean, median, percentiles, etc.).

Finally, a further improvement will be the implementation of a web service to search synthetic waveforms that are compatible with target design spectra, as required by the Italian National Building Code (CS.LL.PP., 2008, 2009) or the EUROCODE 8 (CEN, 2003). The data selection will be performed in analogy with the ITACA data base (REXELite, Iervolino et al., 2011), by a simplified online version of the computer program REXEL (Iervolino et al., 2009,2010).

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Captions

Fig.1 Schematic representation of geographic selection of the EW component of the ground motion simulated by HIC code in the case of the Irpinia scenario-event SY-2012-000101 for a virtual receiver (S004, located ~40 km north of the fixed epicentre). The frame of the scenario details reports the main scenario parameters together with their bibliographic reference. The PGA (cm/s^2) distribution at each receiver is represented on a Google-Map© inset. The seismogenic source box and the simulated epicenter location are also reported. Each receiver can be selected in order to export or display the simulated waveform.

Fig.2 Schematic representation of a *simple search* of waveforms simulated by the EXSIM code. The data query was carried out with the following constraints: magnitude range (M_w or M_l) between 5.0 and 7.0; epicentral distance less than 50 km; absolute Peak Ground Acceleration between 400 and 600 cm/s^2 . The picture also reports an example of data downloading both for processed acceleration and response spectra.

Fig.3 PGA values (geometric mean of NS and EW components) for the 1980 Irpinia earthquake generated by the DSM code as shown in the SYNTHETIS database images gallery. The presented scenario corresponds to an unilateral rupture propagation (from SE to NW), constant velocity rupture (2.4 km/s) and heterogeneous slip distribution. The adopted slip distribution (SLIP1_0s_IRP) mimics the one inferred by Cocco and Pacor (1993) for the 1980 Irpinia earthquake. The star represents the instrumental hypocenter (40.76°N , 15.31°E) location. Black triangles and red triangles with a dot indicate, respectively, the virtual receivers and the actual recording stations (Ameri et al., 2011). In the right portion of the frame an overview of the strong motion maps produced for the selected scenario is also shown.

Tab.1 Overview of the main characteristics of the simulation techniques that are included in the present release of the SYNTHESIS database (modified after Ameri et al., 2011).

EXSIM (Motazedian and Atkinson, 2005)	<i>stochastic finite fault method</i>	An extended fault plane is divided in an appropriate number of subfault, each of them is considered as a point source (Boore, 1983; 2003) radiating an ω^2 spectrum. Ground motion produced by subfaults is summed in the time domain, with a proper time delay depending on the rupture time distribution, to obtain the expected ground motion for the entire fault. Spectral shape depends on geometrical spreading, anelastic attenuation and kappa effects. In contrast to the previous version (FINSIM, Beresnev and Atkinson, 1987), this code implements the concept of dynamic corner frequency. Frequency-dependent crustal amplification function can be introduced to account for wave amplification effect to the layered propagation media (Boore and Joyner, 1997).
DSM (Pacor et al., 2005)	<i>deterministic- stochastic approach with approximated Green's functions</i>	An acceleration envelope is computed by isochrones theory for a 1D layered medium at each simulation site: the duration is defined by rupture propagation + crustal propagation. The deterministic envelope is used to taper a white noise time series that is then multiplied in the Fourier domain by an ω^2 reference spectrum (Boore, 1983, 2003). The finite fault characteristic such as distance, radiation pattern and corner frequency are parameters of the spectrum. Frequency-dependent site amplification function can be introduced to account local seismic site response.
HIC (Gallovič and Brokešová, 2007)	<i>broadband hybrid integral-composite technique with full- wavefield Green's functions</i>	The rupture process at the seismic source is described in terms of slipping of elementary overlapping subsources with fractal number-size distribution (fractal dimension 2), randomly placed on the fault plane. At low frequencies representation theorem is employed assuming final slip distribution composed from the subsources (providing k-squared decay at high wavenumbers k). At high frequencies the ground motion synthesis is performed by summing the point-source contributions from each subsurface assuming ω^2 Brune's pulse radiation. Low and high frequency waveforms are combined in the frequency domain taking into account an appropriate cross-over frequency band. Full-wavefield Green's functions are computed by means of the DWN technique in a 1D layered medium. Spectral attenuation is defined by quality factor and kappa value.

Tab. 1

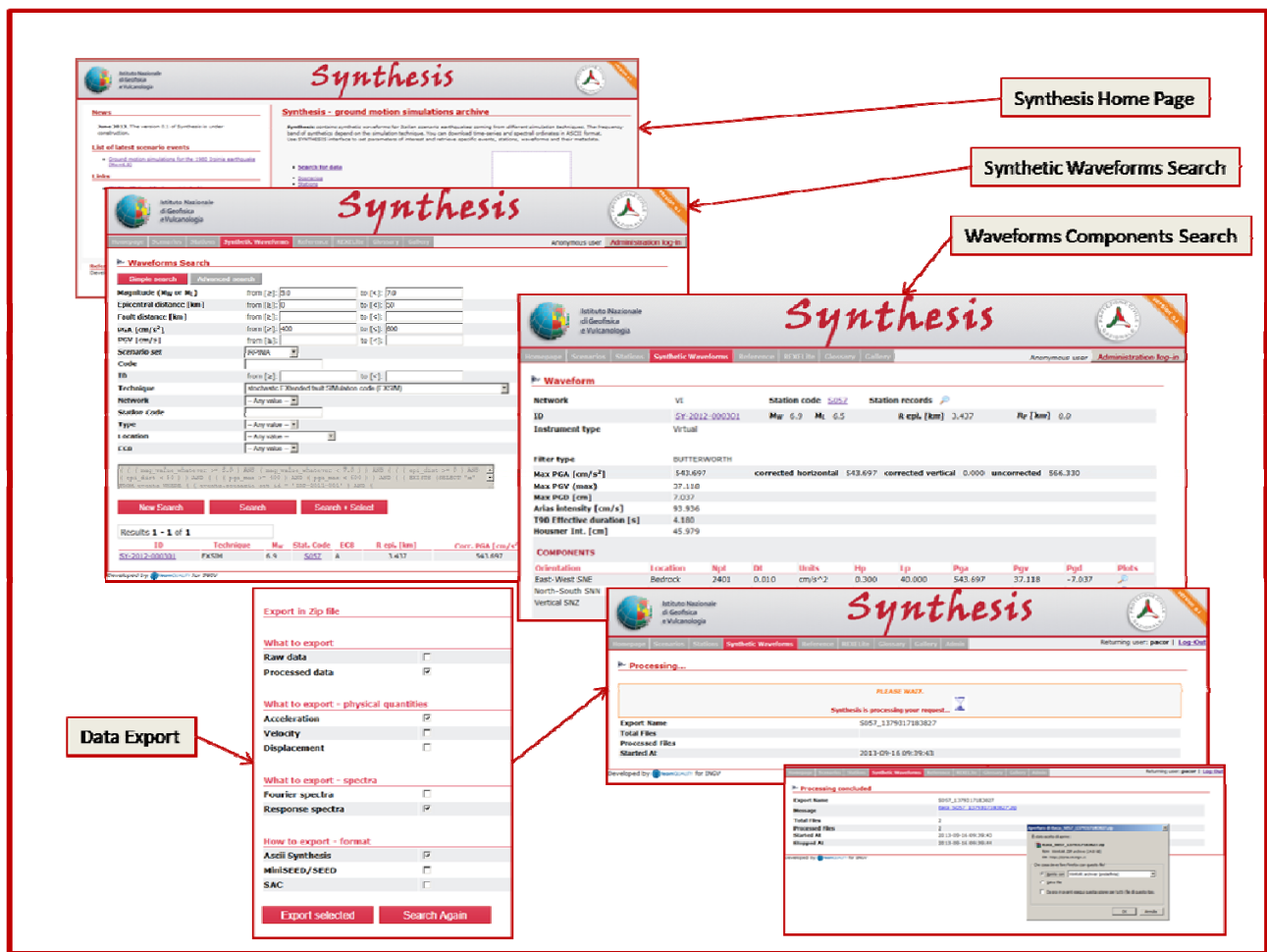


Fig.2

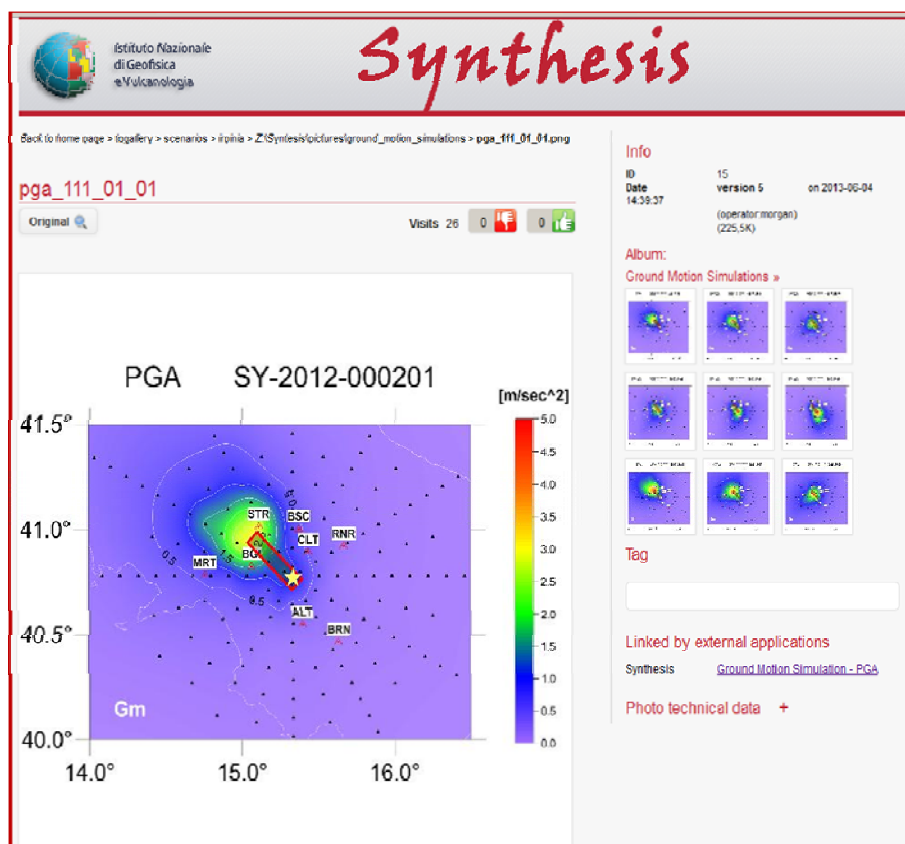


Fig.3