SEISMIC HAZARD ASSESMENT: PARAMETRIC STUDIES ON GRID INFRASTRUCTURES

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Abstract

Seismic hazard assessment can be performed following a neo-deterministic approach (NDSHA), which allows to give a realistic description of the seismic ground motion due to an earthquake of given distance and magnitude. The approach is based on modelling techniques that have been developed from a detailed knowledge of both the seismic source process and the propagation of seismic waves.
This permits us to define a set of earthquake scenarios and to simulate the associated synthetic signals without having to wait for a strong event to occur. NDSHA can be applied at the regional scale, computing seismograms at the nodes of a grid with the desired spacing, or at the local scale, taking into account the source characteristics, the path and local geological and geotechnical conditions. Synthetic signals can be produced in a short time and at a very low cost/benefit ratio. They can be used as seismic input in subsequent engineering analyses aimed at the computation of the full non-linear seismic response of the structure or simply the earthquake damaging potential.
Massive parametric tests, to explore the influence not only of deterministic source parameters and structural models but also of random properties of the same source model, enable realistic estimate of seismic hazard and their uncertainty. This is particular true in those areas for which scarce (or no) historical or instrumental information is available.
Here we describe the implementation of the seismological codes and the results of some parametric tests performed using the EU-India Grid infrastructure.

1 Neo-deterministic seismic hazard assessment

The typical seismic hazard problem lies in the determination of the ground motion characteristics associated with future earthquakes, at both the regional and the local scale. Seismic hazard assessment can be performed in various ways, e.g. with a description of the groundshaking severity due to an earthquake of a given distance and magnitude (‘‘groundshaking scenario’’), or with probabilistic maps of relevant parameters describing ground motion.
Seismic hazard assessment can be performed following a neo-deterministic approach (NDSHA), which allows to give a realistic description of the seismic ground motion due to an earthquake of given distance and magnitude. The procedure for neo-deterministic seismic zoning (PANZA et al., 2001) is based on the calculation of synthetic seismograms. It can be applied also to areas that have not yet been hit by a catastrophic event in historical times, but are potentially prone to it. The neo-deterministic method allows to quantitatively model the effects of an earthquake which may happen in the future and therefore is a very effective technique in seismic hazard assessment, even in the regions with scarce or no historical or instrumental information available.
Starting from the available information on the Earth’s structure, seismic sources, and the level of seismicity of the investigated area, it is possible to compute complete synthetic seismograms and the related estimates on peak ground acceleration (PGA), velocity (PGV) and displacement (PGD) or any other parameter relevant to seismic engineering (such as design ground acceleration, DGA) which can be extracted from the computed theoretical signals.

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In the NDSHA approach, the definition of the space distribution of seismicity accounts only for the largest events reported in the earthquake catalogue at different sites, as follows. Earthquake epicenters reported in the catalogue are grouped into 0.2° x 0.2° cells, assigning to each cell the maxim um magnitude recorded within it. A smoothing procedure is then applied to account for spatial uncertainty and for source dimensions (PANZA et al., 2001). Only cells located within the seismogenic zones are retained. This procedure for the definition of earthquake locations and magnitudes for NDSHA makes the method pretty robust against uncertainties in the earthquake catalogue, which is not required to be complete for magnitudes lower than 5. A double-couple point source is placed at the center of each cell, with a focal mechanism consistent with the properties of the corresponding seismogenic zone and a depth, which is a function of magnitude.
To define the physical properties of the source-site paths, the territory is divided into 1°x1° cells, each characterized by a structural mod el composed of flat, parallel anelastic layers that represent the average lithosphere properties at regional scale (Brandmayr et al., 2010). Synthetic seismograms are then computed by the modal summation technique for sites placed at the nodes of a grid with step 0.2° x 0.2° that covers the national territory, considering the average structural model associated to the regional polygon that includes the site. Seismograms are computed for an upper frequency content of 1 Hz, which is consistent with the level of detail of the regional structural models, and the point sources are scaled for their dimensions using the spectral scaling laws proposed by GUSEV (1983), as reported in AKI (1987).

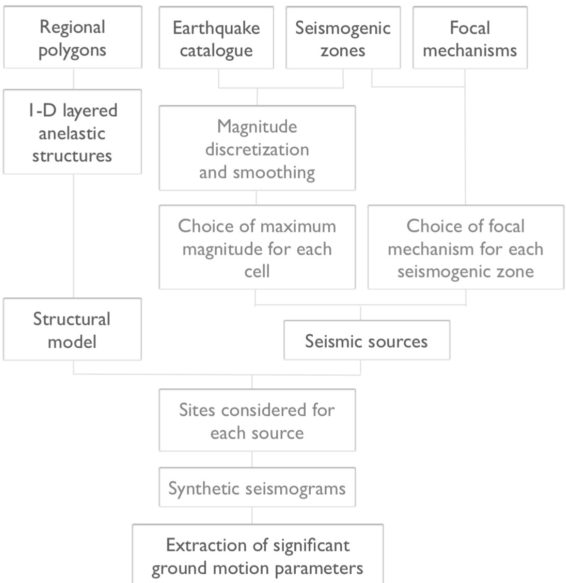

Figure 1: flow chart of national scale hazard package

From the set of complete synthetic seismograms, various maps of seismic hazard describing the maximum ground shaking at the bedrock can be produced. The parameters representative of earthquake ground motion are maximum displacement, velocity, and acceleration. The acceleration parameter in the NDSHA is given by the design ground acceleration (DGA). This quantity is obtained by computing the response spectrum of each synthetic signal for periods of 1 s and longer (the periods considered in the generation of the synthetic seismograms) and extending the spectrum, at frequencies higher than 1 Hz, using the shape of the Italian design response spectrum for soil A (Norme Tecniche D.M. 14/09/ 2005), which defines the normalized elastic acceleration response spectrum of the ground motion for 5% critical damping. For more details see PANZA et al. (1996).

The neo-deterministic method has been recently adapted to account for the extended source process by including higher frequency content (up to 10 Hz) as well as the rupture process at the source and the consequent directivity effect (obtained by means of the PULSYN algorithm by GUSEV (2011)).

The most common approach to the simulation of the earthquake source consists in adopting a kinematic model; the kinematic description is merely phenomenological but, also their simplest versions (e.g. Haskell, 1964) are able to describe the gross features of the rupture process by simply using five source parameters: the fault dimensions (length, L, and width, W), the amount of slip at any point of the fault, the rise-time, and the rupture velocity. In order to describe the source microstructure, i.e. its roughness, one can use a stochastic or a deterministic (or a combination of both) distribution of barriers and asperities on the fault surface resulting in a non-uniform distribution of slip. Actually dynamic considerations should underlie this choice, but a kinematical model simply takes into account the existence of fault irregularities. Thus, at a given site the motion is dependent on the size and the duration of each of the sub-sources, and on their distribution in space and in time. Furthermore, at epicentral distances comparable with the dimensions of the fault, the relative positions of the sub-sources with respect to a site receiver can play a fundamental role in the interference of the different wavetrains, resulting in the so-called directivity effect. For an earthquake with a given radiated energy, the decay of the source spectrum at high frequencies shows a strong azimuthal dependence, since the corner frequency at a given receiver in the near-field is a function of all the kinematic source parameters.

The seismic waves due to an extended source are obtained by approximating the fault with a rectangular plane surface, on which the main rupture process is assumed to occur. The source is represented as a grid of point subsources, and their seismic moment rate functions are generated considering each of them as realizations (sample functions) of a non-stationary random process. Specifying in a realistic way the source length and width, as well as the rupture velocity, one can obtain realistic source time functions, valid in the far-field approximation. Furthermore, assuming a realistic kinematic description of the rupture process, the stochastic structure of the accelerograms can be reproduced, including the general envelope shape and peak factors. The extended earthquake source model allows us to generate a spectrum (amplitude and phase) of the source time function that takes into accounts both the rupture process and directivity effects, also in the near source region.

Slip on the fault varies in space and increases weakly monotonously in time, so that the dislocation rate is non-negative. Its unit moment tensor (defined by slip direction and fault-normal direction) does not vary over this area or in time. Therefore, the description of the source in space-time is essentially scalar, in terms of the distribution over the fault area of the seismic moment (and its time rate). To specify temporal and spectral properties of the simulated sources, the equivalent point source (SSPS) moment rate time history $\dot{M}_0(t)$, its Fourier transform $\dot{M}_0(f)$and corresponding amplitude spectrum (“source spectrum”) $\left|\dot{M}_0(f)\right|$ have been widely used (e.g. Panza et al., 2001).

2 Uncertainties in hazard maps

In NDSHA, the treatment of uncertainties is performed by sensitivity analyses for key modelling parameters. Fixing the uncertainty related to a particular input factor is an important component of the procedure. The input factors must account for the imperfectness in the prediction of fault radiation, and for the use of Green functions, for a given medium, that are only imperfectly known. At present, the following factors are selected as assumedly dominating ones.

- Fault radiation factors:
    - parameters related to the point source position/orientation representing the fault in world coordinates: centroid depth, strike/dip/rake. The point source horizontal position within the cell is not perturbed.
    - intrinsic fault parameters describing the extension of the fault, like fault length and width vs. Mw (moment magnitude) relationship, Brune's stress drop, fault-average rupture velocity, directivity effects.
    - random seeds that define space-time structure of a particular realization of the random source, including random subsource time functions.

-Path factors
    - parameters that specify uncertainties in the assumed 1D bedrock velocity-density-Q profiles.

3 Implementation of seismological codes on grid

The use of the EU-India Grid infrastructure (http://www.euindiagrid.eu/) allows to conduct massive parametric tests, to explore the influence not only of deterministic source parameters and structural models but also of random properties of the same source model, to enable realistic estimate of seismic hazard and their uncertainty. The random properties of the source are specially important in the simulation of the high frequency part of the seismic ground motion.
We have ported and tested seismological codes for national scale on the Grid infrastructure. The first step was the speed optimization of this package by the identification of the critical programs and of the hot spots within programs. The critical point in the algorithm was the computation of synthetic seismograms. The optimization was performed in two ways: first by removing of repeated formatted disk I/O, second by sorting of seismograms by source depth, to avoid the repeated computation of quantities that are depth-dependent.
The second step was porting of the national scale hazard package on EU-IndiaGRID infrastructure. Two different types of parametric tests were developed: on the deterministic source parameters and on the random properties of the source model. The first experiment is performed by perturbing the properties of the seismic sources selected by the algorithm before the computation of synthetic seismograms. In the second test different sets of curves of source spectrum generated by a MonteCarlo simulation of the source model are used for scaling the seismograms. In both cases there are many independent runs to be executed, so a script for generation of the input and other scripts for checking the status of jobs, retrieving the results and relaunching aborted jobs were developed.

4 Preliminary results

One preliminary test over deterministic source parameter for whole Italy ("persut Italy"), and two different tests over random properties ("seed1Hz" and "seed10Hz") for the whole Italian territory, with different frequency content and different maximum distance for the computation of seismograms, were conducted. The performance of

the package over the grid in terms of computational time and number of successful jobs was tested, and submission of job and retrieval of its output were refined.
The number of seismograms that must be computed determines the duration and the storage requirement of the run. This parameter seems critical for the success of the job. The test runs on the random component of the source gave an indication on the effective number of jobs that must be computed to have a good estimate of the distribution of the ground shaking peaks at each receiver.
The first runs have provided a preliminary evaluation of the uncertainty of the hazard maps due to the random representation of the source and to the uncertainty on source parameter. Figure 3 shows an example of results of the test on the random component of the source model. The variability on the different random realizations of the source model (right) is shown in terms of ratio between standard deviation and average at each receiver.

	seed1Hz	persut Italy	seed10Hz
type of submission	direct to CE	WMS	WMS
total n. of job	216	526	600
% of successful job	26	65	80
total time of computation of successful job	948 h	1200 h	791 h
average time of computation for one job	17 h	3.5 h	1.6 h
number of computed seismograms for one job	197720	91398	29232

Table 1: performance of the three test runs.

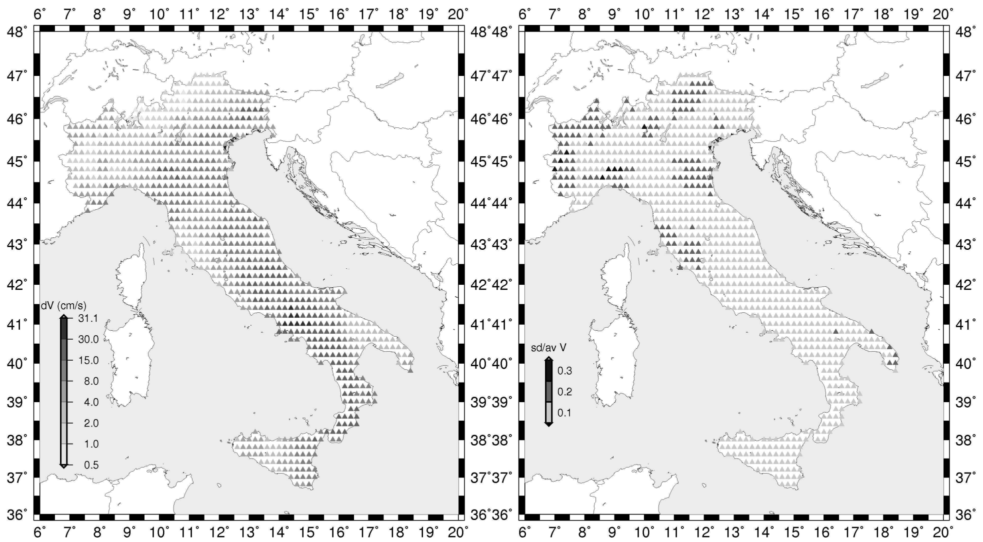

Figure 2: maps of average of PGV (peak ground velocity) on different random realizations of source model (left) and variability of the PGV in terms of ratio beetwen standard deviation and average of the maximum peaks at each receiver.

5 Conclusions and perspectives

We have ported and tested seismological codes for seismic hazard assessment at national scale on the Grid infrastructure. The use of the EU-India Grid infrastructure allows to conduct massive parametric tests for evaluating the uncertainties in the computed hazard maps. Two different types of parametric tests were developed: on the deterministic source parameters and on the random properties of the source model. The performance of the package over the grid in terms of computational time and number of successful jobs were tested and submission of job and retrieval of its output were refined. The tests on the random component of the source gave an indication on the effective number of jobs that must be executed to have a good estimate of the distribution of the ground shaking peaks at each site. At the same time, they provided a preliminary estimate of the uncertainty of the hazard maps due to the random representation of the source.

The procedure followed for porting the package on the grid infrastructure can be implemented for other seismological programs as well.

A Cooperation Project, aimed at the definition of seismic and tsunami hazard scenarios by means of indo-european e-infrastructures in the Gujarat region (India), has been recently funded by the Friuli Venezia Giulia Region. This two-years project, starting in November 2011, involves three Italian partners (DiGeo, University of Trieste; ICTP SAND Group; CNR/IOM uos Democritos) and two Indian partners (ISR, Gujarat; CSIR C-MMACS, Bangalore). The project aims to set up a system for the seismic characterization, integrated with the e-infrastructures distributed amongst India and Europe, to allow for the optimization of the computation of the ground shaking and tsunami scenarios. This goal will be attained thanks to the strict connection with the European project EU-IndiaGrid2, that will provide the necessary infrastructure. Thus, the project will permit developing an integrated system, with high scientific and technological content, for the definition of scenarios of ground shaking, providing in the same time to the local community (local authorities and engineers) advanced information for seismic and tsunami risk mitigation in the study region.

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