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Zoning of the Italian region with synthetic seismograms computed with known structural and source information

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ABSTRACT: An automatic procedure for the seismic zonation of a territory has been developed. The final results consist of a map showing the distribution of peak ground acceleration over the territory. For the estimation of the accelerations, complete synthetic seismograms are computed by the modal summation technique. In this work the new procedure has been applied to the Italian territory. The structural models and the sources necessary to compute the synthetic signals have been fixed after an extensive bibliographic research. Seismogenic areas have been defined in the framework of the GNDT (Gruppo Nazionale per la Difesa dai Terremoti of the Italian Consiglio Nazionale delle Ricerche) research activities dedicated to the definition of the kinematic model of Italy. Historical and recent seismicity has been taken from the most updated Italian earthquakes catalogues. The estimated peak ground accelerations have been found to be compatible with available data, both in terms of intensity (historical earthquakes) and accelerations (recent earthquakes).

1 INTRODUCTION

The zonation of a territory in terms of seismic hazard is essential expecially in densely populated areas. Maximum expected peak ground acceleration (PGA), at different frequencies, is a very important parameter considered by civil engineers.

At the Institute of Geodesy and Geophysics of the University of Trieste we have developed an automatic procedure which allows us to estimate PGA (at frequencies as high as 10 Hz) starting from the available information on the Earth structure parameters, the seismic sources and the level of seismicity of the investigated area. Theoretical accelerations are computed by the modal summation technique (Panza, 1985; Florsch et al., 1991). The use of synthetic seismograms allows to estimate in a realistic way the seismic hazard also in those areas for which scarce (or none) historical information is available. It is also possible to simulate quite easily different kinds of source mechanisms, to consider different structural models and to compare the relative results in order to evaluate the influence of each parameter. To reduce the amount of computations, the seismic sources have been grouped in homogeneous seismogenic areas, and for each group the focal mechanism has been kept constant. The seismic moment associated with each source is determined from the analysis of the maximum magnitude observed in the epicentral area during historical and recent times.

The final result of the procedure is a map showing the distribution of PGA over the investigated territory. The synthetic signals used for the prediction of the accelerations can be conveniently used as input data for more detailed zoning, based on the 2D modeling of wave propagation (Fäh et al., 1990; Iodice et al., 1992). In this way, also the local soil effects can be taken into account.

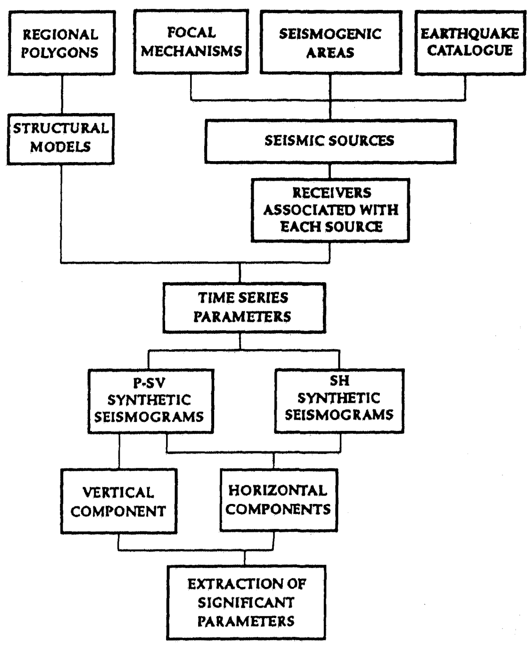

Fig. 1. Flow chart of the procedure.

The flow-chart of the procedure is shown in Fig. 1. In the following text, references to the flow chart are written in *italics*.

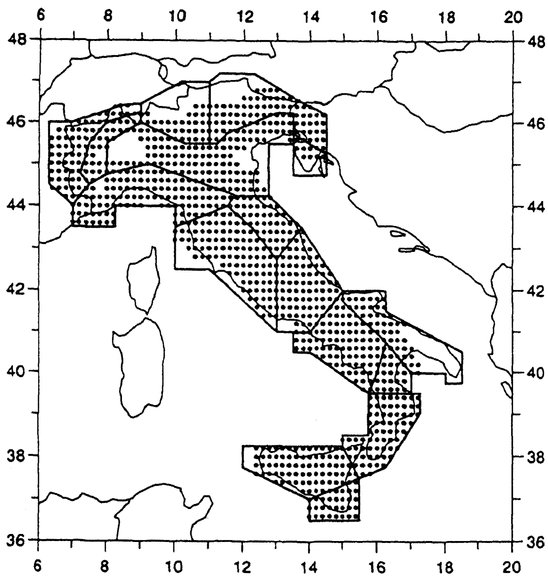

Fig. 2. Regional polygons used to define the different structures. Dots represent the receivers where the synthetic seismograms are computed. Dots are missing within the polygons if the source-receiver distance is outside the selected range.

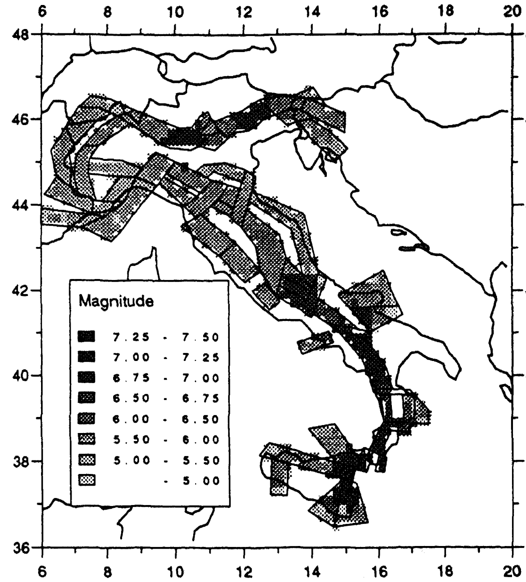

Fig. 3. Magnitude associated with the cells belonging to the seismogenic areas, which are indicated by polygons.

2 DATA

On the basis of the geologic characteristics, the Italian territory has been divided into 16 *polygons* (Fig.2). A flat, layered *structural model* has been then associated with each region. The different layers are defined by their thickness, density, P- and S-wave velocities and attenuation.

The definition of the *seismic sources*, has been made as follows. At first, 57 *seismogenic areas* have been defined on the basis of seismological observations, of the monitoring of past and recent seismic activity, and of seismotectonic informations obtained by structural geologists during field surveys (e.g. Patacca et al., 1992).

375 fault-plane solutions, distributed over the whole territory, have been collected (Suhadolc, 1990; Suhadolc et al., 1992). The computer file contains a standard definition of the *focal mechanisms*, both in terms of strike, dip and rake of the nodal planes and in terms of compressional, tensional and null axes.

For the analysis of seismicity, an *earthquake catalogue* (PFGING) has been prepared merging the data from the PFG (1985) catalogue, for the years 1000-1979, with the data from ING (1982-1991) bulletins, for the years 1980-1991. The original catalogues have been corrected for some obvious mistakes, like the presence of double or multiple events, time disorder and evident errors in the focal depths. Furthermore, only main shocks have been considered, removing aftershocks according to the algorithm suggested by Keilis-Borok et al. (1980).

We have considered only earthquakes which occurred within the PFG polygon (PFG, 1985), therefore, the seismicity might be underestimated near political borders (see Fig. 3), and this could influence also the final results of Fig. 4 in the regions close to the boundaries.

3 COMPUTATIONS

To derive the distribution of the maximum observed magnitude over the territory, the image of the seismicity given by the earthquake catalogue has been smoothed. At first, the area has been subdivided into 0.2° x 0.2° cells. Each cell has been assigned the magnitude value of the most energetic event that occurred within it. The smoothing obtained through this procedure, however, was not found to be satisfactory, since each cell does not contain a statistically meaningful number of events. Therefore, the maximum magnitude to be associated with each cell has been searched for also in the cell surroundings, through the application of a centered smoothing window. For the definition of the seismic sources that are used to generate the synthetic seismograms, only the cells located within a seismogenic area are retained, and a double-couple point source is placed in the centre of each cell. The map shown in Fig. 3 is the result of the application of this method to the PFGING earthquake catalogue.

The orientation of the double couple associated with each source is obtained from the database of the fault-plane

Table 1. Magnitude-seismic moment relation.

M	M_0 (1Hz) (dyne cm)
8.00≥ >7.75	$4.00\ 10^{25}$
7.75≥ >7.50	$2.50\ 10^{25}$
7.50≥ >7.25	$1.60\ 10^{25}$
7.25≥ >7.00	$1.25\ 10^{25}$
7.00≥ >6.75	$5.00\ 10^{24}$
6.75≥ >6.50	$3.15\ 10^{24}$
6.50≥ >6.00	$1.60\ 10^{24}$
6.00≥ >5.50	$4.00\ 10^{23}$
5.50≥ >5.00	$1.40\ 10^{23}$
5.00≥	$4.00\ 10^{22}$

solutions. For each seismogenic area, a representative focal mechanism is selected through an automatic procedure. As a first simple hypothesis, the tensor elements of this mechanisms have been defined as the arithmetic average of the tensor elements of the available mechanisms. This choice appears to be reasonable when the mechanisms to average are not too different, and this condition has been checked for each seismogenic area.

Once the structures and the sources have been defined, *receivers* are placed on a grid (0.2° x 0.2°) covering the whole territory and synthetic seismograms are efficiently computed by the modal summation technique (Panza, 1985; Florsch et al., 1991). In this first example, the synthetic signals are computed for an upper frequency content of 1 Hz, and the point-source approximation is still acceptable. When shorter periods will be considered, it will be no longer possible to neglect the finite dimensions of the faults and the rupturing process at the source.

To reduce the number of the computed seismograms, the source-receiver distance is kept below an upper threshold, which is taken to be a function of the magnitude associated to the source. The maximum source-receiver distance has been fixed equal to 25, 50 and 90 km, respectively for $M<6$, $6\leq M<7$ and $M\geq 7$ is 90 km. All seismograms have been computed for a constant hypocentral depth (10 km), but it is also possible to assign to each source an average depth determined from the analysis of catalogues of past seismicity. The reason to keep the hypocentral depth fixed and shallow is to be found in the large errors affecting the hypocentral depth estimates in the PFGING catalogue and in the fact that strong ground motion is mainly controlled by shallow sources (e.g. Vaccari et al., 1990).

P-SV (radial and vertical components) and *SH* (transverse component) *synthetic seismograms* are originally computed for a seismic moment of 1 dyne cm. The amplitudes are then properly scaled according to the (smoothed) magnitude associated with the cell of the source. For the moment-magnitude relation, we have chosen the one given by Boore (1987). To obtain the values given in Table 1, which are valid for the frequency of 1 Hz, we have used the scaling law proposed by Gusev (1983). The idea of a constant magnitude within each seismogenic area (choosing the maximum available value) has been discarded because for the larger seismogenic areas it lead to an over-estimation of the seismicity.

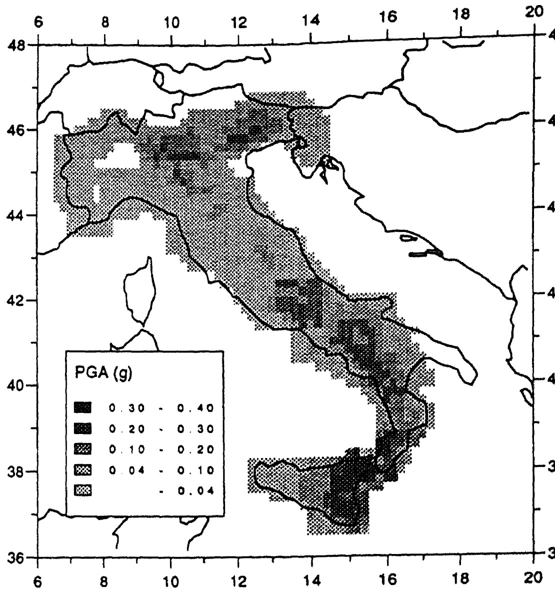

Fig. 4. Distribution of estimated PGA.

At each receiver, the horizontal components are first rotated to a reference system common to the whole territory (North-South and East-West directions) and then the vector sum is computed. For the *significant parameters* representative of the strong ground motion we have, for the moment, focused our attention on the peak ground acceleration values (PGA). Since we compute the complete time series we are not limited to this choice, and it is also possible to consider other parameters, like Arias intensity or other integral quantities which can be of interest in

Table 2. Intensity - acceleration relation (from Boschi et al., 1969).

Intensity	Acceleration	
	cm/s^2	g
XII	492.5	0.50
XI	370.9	0.38
X	284.4	0.29
IX	222.1	0.23
VIII	176.5	0.18
VII	142.9	0.15
VI	117.7	0.12
V	98.7	0.10
IV	84.3	0.09

seismic engineering. Since recordings of many different sources are associated to each receiver, but one single value is to be plotted on a map (Fig. 4), only the maximum value of the analysed parameter is considered.

4 CHECK OF THE RESULTS

The intensity-acceleration relation proposed by Boschi et al. (1969) has been used to compare the results of Fig. 4 with the historical data, for which only macroseismic intensity estimates exist (see Table 2). We have checked that the computed PGA values are compatible with the above mentioned relation.

A more quantitative check has been made using the observed accelerograms recorded during the Irpinia earthquake on November 23, 1980. It is well known that the source rupturing process of that event is very complex (e.g. Bernard and Zollo, 1989), and the dimension of the source has been estimated to be of the order of several tenths of km. Nevertheless, it looks like the signal recorded at the station of Sturno is mostly due to a single sub-event that occurred rather close to the station itself, while the energy contributions coming from other regions of the source seem irrelevant (Vaccari et al., 1990). We have low-pass filtered the NS accelerogram recorded at Sturno with a cut-off frequency at 1 Hz in order to compare it with one of the computed signals for the Irpinia region (Fig.5). The early phases and the PGA of the two time series are in very good agreement. The late part of the observed recordings is more complicated and this is related to the complexity of the source, which has been neglected in the computation of the synthetic.

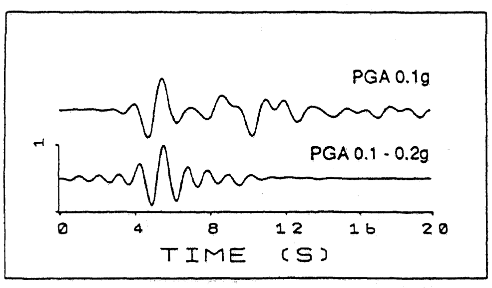

Fig. 5. Comparison between the NS component recorded at Sturno during the Irpinia 1980 earthquake (above), and the synthetic signal expected in that area (below) accordingly to our method.

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