The ESC-SESAME Unified Hazard Model for the European-Mediterranean region

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1. Projects on seismic hazard assessment in Europe and the Mediterranean: objectives, strategies and results

During the last ten years several projects on seismic hazard assessment were active at global and regional scales. Within the European-Mediterranean region a number of multinational programs were set up to produce earthquake catalogues, seismic source zoning and hazard assessment, through the following three main project frameworks: (1) GSHAP, (2) IGCP-382 project SESAME, and (3) the ESC Working Group on Seismic Hazard Assessment.

Within the framework of GSHAP (Global Seismic Hazard Assessment Program, 1992-1999), a UN/IDNDR demonstration program, which completed in 1999 the first global map of seismic hazard in terms of peak ground acceleration (Giardini, 1999); IGCP-382 SESAME (Seismotectonics and Seismic Hazard Assessment of the Mediterranean Basin, 1996-2000), which provided the first unified seismic source model and homogeneous assessment of seismic hazard for the whole Mediterranean region (e.g. Jiménez et al., 2001); and the European Seismological Commission Working Group on Seismic Hazard Assessment (ESC/WG-SHA, 1996-2002), aiming at the development of a homogeneous probabilistic seismic hazard assessment procedure for Europe and the Mediterranean, the whole European-Mediterranean region has been unified.

GSHAP produced in 1999 the first seismic hazard map for the European-Mediterranean region in terms of peak ground acceleration, as part of the GSHAP global hazard map, and was based on the compilation and assemblage of hazard results as obtained independently in different test areas and national and multinational programs. As was pointed out in Grünthal et al. (1999), although all of these independent hazard maps were produced following the same basic seismotectonic approach, the harmonization of the hazards in the assemblage of the final GSHAP map required several iterations of smoothing and border matching between the different regions. The greatest difficulties were met in the Mediterranean, owing to the large number of independent areas.

IGCP-382 SESAME developed and completed a more detailed, integrated seismic source model and homogeneous hazard mapping for the Mediterranean region. Main efforts focused in the development of a unified source model throughout the region to allow for a homogeneous hazard assessment procedure. The strategy was based on the integration of regional and national models to avoid ambiguities coming from different approaches, and also to avoid gaps in the geographical coverage through the development of new source models in areas where these were not yet available. Preliminary SESAME results were presented in September 2000 on occasion of the XXVII General Assembly of the European Seismological Commission, in Lisbon, Portugal. Improved results incorporating updates to source model and hazard computation can be found in Jiménez et al. (2001).

ESC/WG on SHA has completed in 2002 a unified seismic hazard modeling for Europe and the Mediterranean. Our approach to obtain a reference seismic hazard model for Europe and the Mediterranean has been entirely based on the integration of regional models and the adoption of a homogeneous hazard assessment procedure. The strategy was based on integrating GSHAP Central Northern Europe results with those from SESAME for the Mediterranean to allow for the first ever homogeneous seismic hazard computational procedure which for the first time is based upon a unified source model throughout the whole European-Mediterranean region. This comprehensive model for seismic hazard assessment allows, for the first time, the generation of hazard maps, expressing ground motion in different parameters, for different soil conditions and probability levels.

2. Development of a unified seismic hazard model for the European-Mediterranean region

The European-Mediterranean ESC-SESAME unified seismic hazard model is based on the Seismotectonic Probabilistic approach

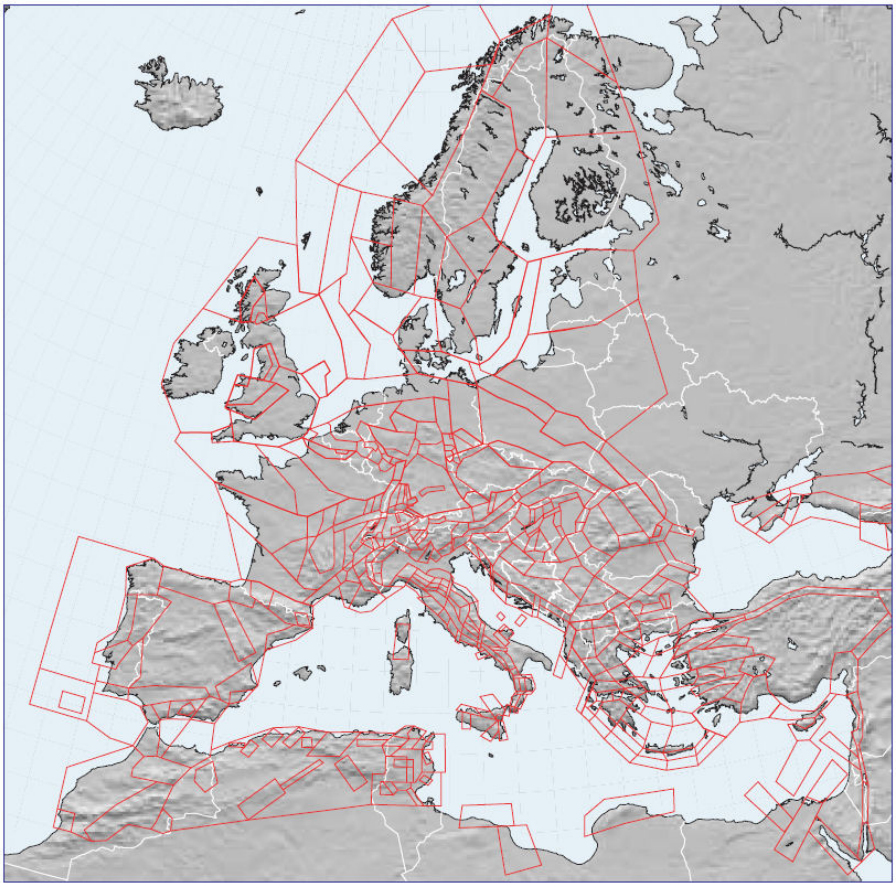

Figure 1: *Unified seismogenic source model for the European-Mediterranean region (463 source zones).*

and thus based on a regional model of seismic source zones (established according to tectonic, geophysical, geological and seismological data) with associated parameters (magnitude-frequency parameters, maximum expected magnitude), through which expected ground motion is computed based on an appropriate attenuation relationship.

The unified source model consists of a total of 463 seismic sources (455 shallow and 8 intermediate-depth). Figure 1 shows the final source model. Each source is characterized by the corresponding seismicity parameters in terms of minimum and maximum magnitude, and earthquake occurrence rates with an associated subcatalogue which stems from the corresponding regional catalogue. Source models developed in regional and multi-national programs within GSHAP have been compiled and then complemented with existing models in the literature to avoid gaps in the geographical coverage. Original background sources, established in the individual models to account for seismicity in neighbouring regions, have been eliminated; and new zones at overlapping border areas were redesigned to harmonize geometries where differences existed. These areas mostly correspond to the Pyrenees, the Alps, the Carpathians, Northern Greece and the Aegean, among others. In the Mediterranean, a new regional model for the Eastern Mediterranean region has been developed in cooperation with GII (Geophysical Institute of Israel), within SESAME and RELEMR (Reducing Earthquake Losses in the Eastern Mediterranean Region) programmes. At different stages during the development of the work, regional source models and associated parameters have gone through improvements and updates according to any new information made available.

Ground motion attenuation models developed by Ambraseys et al. (1996) in terms of peak ground acceleration, PGA, and absolute spectral acceleration, SA, are considered to be adequate for the unified computations for shallow sources, since these relationships were obtained on the basis of a wide European strong motion data set with magnitudes between 4.0 and 7.9 and four categories of soil condition (rock, stiff, soft and very soft soil). Specific attenuation relationships are considered for the eight sources of intermediate-depth seismic activity through the specific attenuation relationships derived in Musson (1999) for Vrancea intermediate source, and in Papaioannou and Papazachos (2000) for intermediate-depth seismic activity sources in the Helenic Arc.

Homogeneous Hazard computation is carried out inside the area stretching from 10ºW-30ºE and 27ºN-72ºN and 30ºE-40ºE and 27ºN-47ºN at a grid interval of 0.15 degrees and is performed through SEISRISK III (Bender and Perkins, 1987). Non-isotropic attenuation for intermediate-depth earthquakes originating in Vrancea (Romania) is handled and computed independently by applying the procedure and code used for the regional hazard mapping of North Balkan region (Musson, 1999). Ground motion variability is incorporated in the computations assuming a lognormal distribution of the ground-motion parameter with standard deviation sa. The number of computation nodes is over 70,000. To ensure that the computation through the established unified procedure gave fully compatible results with the original regional hazards, individual tests were performed for all regions to detect possible misfits and therefore identify the causative reasons. The resulting differences in the hazard results through the unified procedure should arise solely in relation to the harmonization of the basic input data (e.g., source geometries at border areas, attenuation relationship) or specific to the computations for a large geographical region (e.g. larger grid spacing).

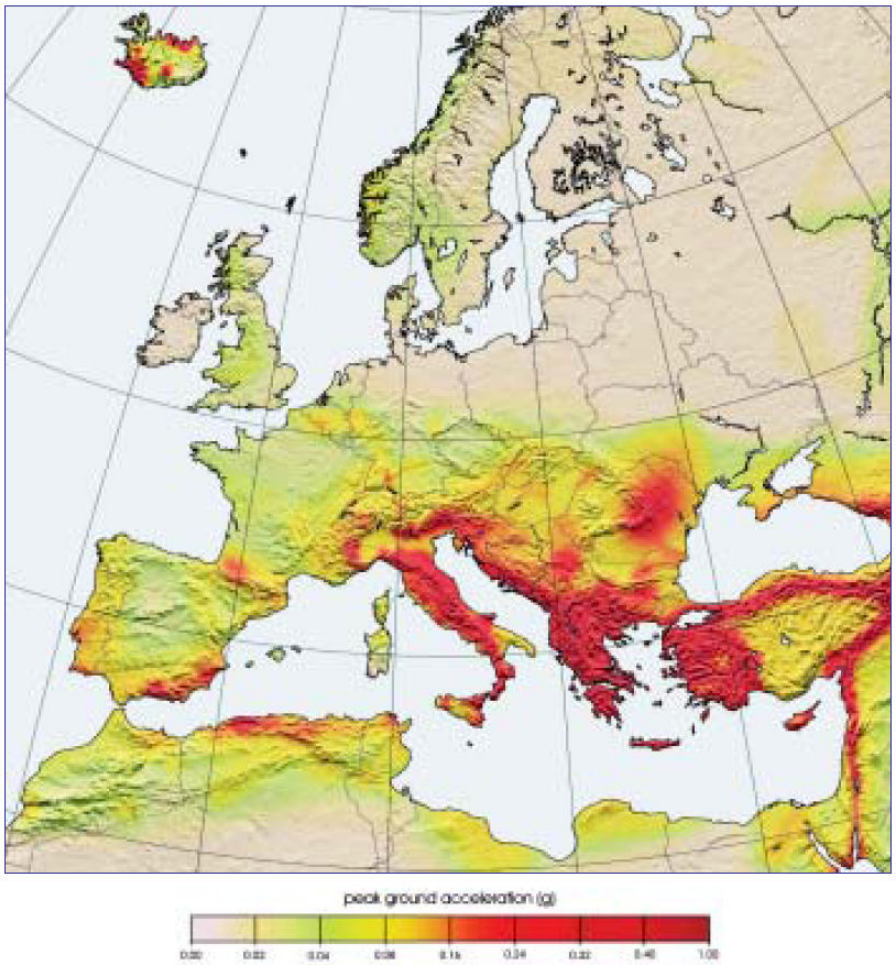

Figure 2: *ESC-SESAME European-Mediterranean seismic hazard map for peak ground acceleration [g] with 10% probability of exceedance in 50 years for stiff soil condition.*

Generation of regional probabilistic hazard maps on the basis of the developed unified seismogenic source model, and the adopted regional and specific ground-motion attenuation relationships, is carried out through a homogeneous probabilistic seismic hazard assessment (PSHA) procedure. It allows for the first time to obtain homogeneously computed regional hazard maps for the European-Mediterranean region in terms of different ground motion parameters (e.g. PGA, 0.3s SA, 1.0s SA), different soil conditions (e.g. rock, stiff soil) and different probability levels (e.g. 1%, 10% and 65% of exceedance in 50 years). The map in Figure 2 depicts the results of homogeneous seismic hazard computation of peak ground acceleration at a 10% probability of exceedance in 50 years for stiff soil; areas in the map not covered by the ESC-SESAME seismic source model (Iceland and Russia) are taken from the GSHAP Global Seismic Hazard map.

3. ESC-SESAME main results for PSHA in Europe and the Mediterranean

Main results achieved through the European-Mediterranean final unified model for PSHA can be summarized as follows:

- First ever common model of seismic sources for Europe and the Mediterranean
- Hazard computations are now based on a unified source model of 463 seismic sources (455 shallow and 8 intermediate-

depth)

- Homogeneous computational procedure for PSHA
- Generation of hazard maps: ground motion expressed in different parameters, for different soil conditions and probability levels
- Establishment of databases incorporating for each seismic source: seismicity parameters (minimum and maximum magnitude), earthquake occurrence rates, and associated subcatalogue (from regional catalogue)

Publications, reports, procedures, maps and results will be loaded on the web and the final seismic hazard map for Europe and the Mediterranean (peak ground acceleration at a 10% probability of exceedance in 50 years for stiff soil) is now published under the auspices of the European Seismological Commission in 5000 copies by the Institut Cartogràfic de Catalunya in March 2003.

4. Outlook

The ESC-SESAME is the first ever unified model for PSHA for Europe and the Mediterranean. It was developed within the framework of several recent projects on global and regional seismic hazard assessment and allows for homogeneous hazard computation throughout the whole European-Mediterranean domain. Still some aspects in its realization have remained unavoidably heterogeneous. Future developments to harmonize and improve models and data can be achieved in the framework of future initiatives at European level through regional close-cooperation and efforts in reasonable periods of time, but these cannot go beyond the limits posed by the differences in the status on background knowledge and quality of the basic data. These differences, if existing, will remain unsolved and will reflect unavoidably in any final regional hazard map.

Nevertheless, this final unified hazard modeling for Europe and the Mediterranean will contribute to the establishment of a regional seismic hazard framework for the region in terms of peak ground and spectral acceleration from which seismologists, geologists and earthquake engineers can profit as a general guideline.

The compiled data bases (e.g. source zoning, attenuation, seismic activity parameters) for the whole European Mediterranean domain and the homogeneous hazard computation scheme constitute a unique tool which opens new possibilities for future research of interest to the seismological and engineering communities. The ESC-SESAME background hazard model for PSHA can serve for re-evaluation of hazard according to different criteria or for improved source models incorporating mixed areal/fault sources, for improved ground motion models (both for sub-regions or for the whole European-Mediterranean region), as the basis for comparative regional studies dealing with both methodological and assessment issues, also as an aid to model seismicity in neighbouring regions for national hazard maps, to establish the basis for a European-Mediterranean seismic hazard server, and for educational projects, among many other applications.

5. Events where the different stages in the development and results were presented

At different stages on the development of the ESC-SESAME unified seismic hazard model, results were presented on occasion of :

- XXVII General Assembly of the European Seismological Commission, Lisbon, Portugal, 10-15 September 2000.
- Mitigation of Seismic Risk. Support to Recently Affected European Countries, EC-Joint Research Centre, Belgirate, Italy, 27-28 November 2000.
- XXVI General Assembly of the European Geophysical Society (EGS). Nice, France, 26–30 March 2001.
- American Geophysical Union Fall Meeting, San Francisco, 10-14 December 2001.
- 3ª Asamblea Hispano-Portuguesa de Geodesia y Geofísica, Valencia, 4-8 February 2002.
- 12th European Conference on Earthquake Engineering, Londres, UK, 9-13 September 2002
- XXVIII General Assembly of the European Seismological Commission, Genoa , Italy, 1-6 September 2002.
- Primer Centenario del Observatorio de Cartuja: 100 años de Sismología en Granada, Granada, Spain, 8-11 October 2002

a number of invited conferences were given at:

- European Seismological Commission Workshop on "Seismicity Modeling in Seismic Hazard Mapping", Poljce, Slovenia,22-24 May 2000
- XXV General Assembly of the European Geophysical Society Nice, France, 26 April 2000.
- UNESCO Workshop on Earthquake Hazard Assessment Practice and Velocity Models and Reference Events in the Mediterranean Region, Santa Susanna, Barcelona, Spain, 20 May 2001.
- PILAR (Program For Increasing Technical Capacity on Natural Disaster Reduction in the Mediterranean Region) planing Meeting, UNESCO, Paris, 24 June 2002.

and a special session on:

- "European Seismology Projects for Hazard and Risk: Sesame, EC8 and the Way Ahead" at the 12ECEE meeting in London, September 2002, was convened by R. Musson as an open discussion to provide a forum to discuss the results achieved, actual status and future direction of earthquake hazard research, and supporting projects, in Europe.

6. What made it possible?

The contributions on data and efforts of many years of work of many individuals and institutions which were active in different projects related to hazard in Europe and the Mediterranean, specially all those groups and individuals active within GSHAP, SESAME and the ESC/SCF WG on SHA, have made it possible. In particular, Mustafa Erdik, Mariano García-Fernández, Roger Musson, Christos Papaioannou, Avi Shapira, Dario Slejko, for your patience and support - thank you!

We are also grateful to every contributor at the different stages of development of the different programs and projects as referenced in the published ESC-SESAME seismic hazard map, but to name all of them here would be impractical.

Proprietary software for hazard computation was made available for ESC-SESAME by R. Musson (BGS,UK). Figures were prepared using GMT software (Wessel and Smith, 1998).

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