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Mapping Europe's Seismic Hazard

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From the rift that cuts through the heart of Iceland to the complex tectonic convergence that causes frequent and often deadly earthquakes in Italy, Greece, and Turkey to the volcanic tremors that rattle the Mediterranean, seismic activity is a prevalent and often life-threatening reality across Europe. Any attempt to mitigate the seismic risk faced by society requires an accurate estimate of the seismic hazard.

In Europe and Turkey, on regional and national scales, seismic hazard estimates are typically updated on an infrequent and uncoordinated schedule. Consequently, forecasts of ground-shaking hazard differ across national boundaries, a situation that poses large challenges when designing structures.

From 2009 to 2013 the Seismic Hazard Harmonization in Europe (SHARE) project worked to develop a consistent model of seismic hazard covering Europe and Turkey (see Figure 1). The project delivered a reference model of seismic hazard for the current application of the European seismic regulations for building design, Eurocode 8, which entered into force in 2010.

The resulting European Seismic Hazard Model (ESHM13) consists of more than 500 maps displaying the ground shaking that is expected to be reached or exceeded over return periods ranging from 70 to 5000 years for more than 120,000 on-land sites equally spaced every 10 kilometers. The maps are produced for frequencies of ground acceleration on rock conditions from 0.1 to 100 hertz, which spans the frequency range to which the built environment—from private homes to high-rise buildings and critical infrastructures—is vulnerable.

Goal: A Harmonized Seismic Hazard Model for the Future

The European seismic hazard model produced by the SHARE program is the first regional assessment completed since the Global Seismic Hazard Assessment Program (GSHAP) in 2000. ESHM13 provides a complete assessment of seismic hazard and associated uncertainties generated using common methods to assess input data and to compute earthquake activity rates and ground-shaking attenuation across the region.

Critically, the model uses inputs that have been harmonized from heterogeneous and disparate data sets from all over Europe. It will serve as a reference for updating the seismic norms first on the European level and then at national and regional scales across the continent.

Thus, future safety assessments of and improvements to the built environment will be able to rely on these calculations. The model also aims to provide valuable input for updating the seismic hazard and risk models used by the insurance sector. Further, it is a living product, meant to be updated as the scientific understanding of hazard changes.

The ESHM13 results constitute a new reference but are not meant to replace existing mandatory input to the national design regulation and seismic provision, which must be obeyed for current seismic design and building construction.

Building the SHARE Model: Creating a Continent-Wide Picture

SHARE used a logic tree approach to capture uncertainties of future earthquake activity and strong ground motions, with more

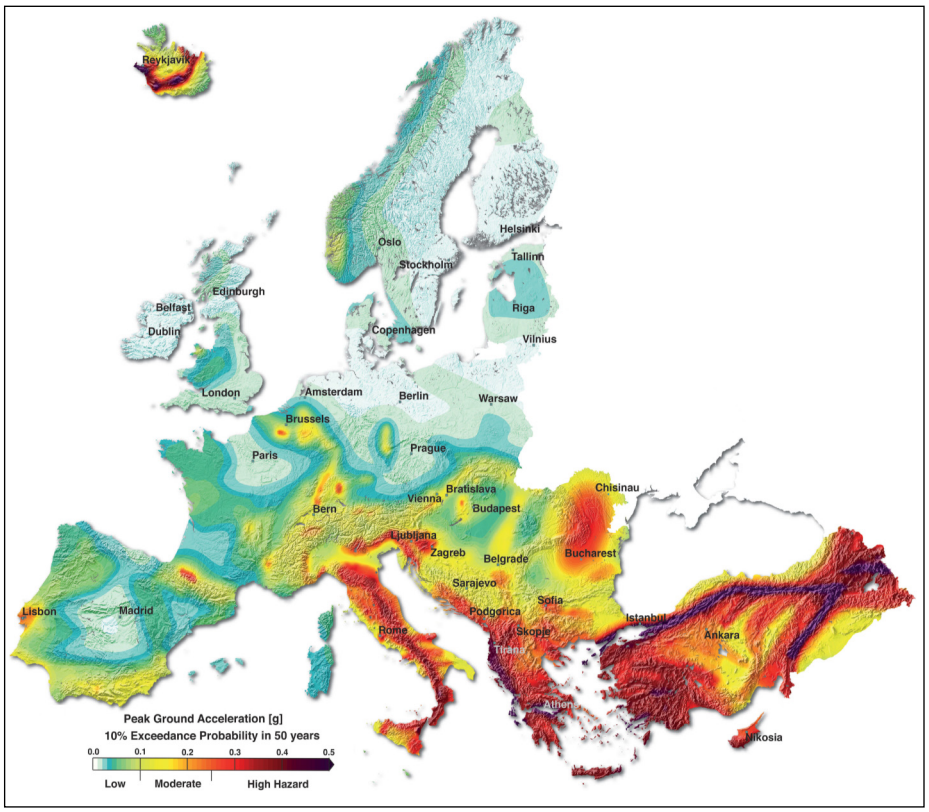


Fig. 1. European Seismic Hazard Map (ESHM13) displaying the 10% exceedance probability in 50 years for peak ground acceleration (PGA) in units of gravity (g). Cold colors indicate comparatively low hazard areas (PGA ≤ 0.1g), yellow and orange indicate moderate-hazard values (0.1g < PGA ≤ 0.25g), and red colors indicate high-hazard areas (PGA ≥ 0.25g).

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than 900 independent branches representing the beliefs of the modelers and their different parameterizations and assumptions.

The foundation of the SHARE model is the development of three embedded earthquake source models to describe the expected rate of future earthquake activity in terms of spatial, depth, and frequency-magnitude distributions, as well as the style of faulting in different regions.

One model is an area source model, which assumes a homogeneous distribution of earthquakes within each zone. The second is a zoneless model that distributes activity rates in space based on a combination of smoothed earthquake density and accumulated moment on faults. The third, a fault source model, infers future seismic activity from estimated slip rates on active faults.

All three models are based on a time-independent assumption—that is, all earthquakes occur independent of one another, and the model has no memory of when and where the last large earthquakes took place and only records their average frequency.

Inputs From Newly Compiled Homogeneous Data Sets

Newly compiled regional data sets contributed to these models; the data sets include the following.

Earthquake catalog. More than 30,000 earthquakes of magnitude 3.5 and higher in the period 1000–2007 were collected in the new SHARE European Earthquake Catalog. More recent earthquakes were assessed using modern instrumental seismic networks, whereas older earthquakes were documented by assessing their damaging effects.

Fault source database. More than 68,000 kilometers representing about 1200 mapped active faults were compiled in the new European Database of Seismogenic Faults.

Crustal strain rate model. Deformation rates of the Earth's crust recorded by modern GPS networks and geological assessments were used to infer the ongoing tectonic movement.

Maximum magnitude model. SHARE inferred a new model of the possible maximum earthquake magnitude expected across Europe that considers its earthquake history and fault database.

Strong ground motion model. To capture the variability of expected strong ground motions, the SHARE ground motion model was built following an iterative procedure. First, the selected candidate models were objectively tested and ranked against the European data sets. With this information, the ground motion logic tree was finalized based on the recommendation of key European experts.

This process ultimately led to the selection of 14 empirical relations, termed ground motion prediction equations, which characterize the expected ground motions for all geological conditions and magnitude, depth, and distance ranges in Europe.

A Shared Vision: Multidisciplinary Effort, Built-in Relevance

SHARE was a community-based effort that operated outside of the constraints of national borders. The 4-year-long project was conducted by a core group of 50 leading Earth scientists and engineers from European countries and Turkey who worked to homogenize data and harmonize methods. In addition, the contributions of more than 250 other European and worldwide experts were integrated during many working group meetings held to prepare high-quality data sets, to construct earthquake source models, and to model ground motions. All of the work followed rigorous procedural standards and was quality controlled in an extensive and iterative review process.

The SHARE seismic hazard model presents significant improvements over previous efforts, including the compilation of harmonized databases of all parameters required for probabilistic seismic hazard assessment; the adoption of rigorous, standardized procedures in all steps of the process; a full accounting of epistemic uncertainties for model components and hazard results; and full transparency and open availability of all data, results, and methods.

SHARE took a multidisciplinary approach, relying on input from all branches of earthquake science and engineering. Involving the members of the European Committee for Standardization subcommittee for earthquake resistance design (CEN/TC250/SC8) ensured the definition of proper output specifications relevant for Eurocode 8.

How well ESHM13 actually describes future ground shaking, however, can be established only by subsequent statistical evaluation. Today, testing of model components, specifically the rate of occurrence of future earthquakes, has started so that scientists understand whether model outputs are consistent with observed data. Definitive conclusions are, however, hampered by the short testing period and the low occurrence probabilities of large earthquakes and strong ground shaking.

The ensemble of SHARE-created products has societal relevance throughout Europe and Turkey. The procedures designed for SHARE are now also setting the standard for future large-scale collaborations in the framework of the Global Earthquake Model (GEM).

Data and Result Availability

All data and results [*Giardini et al.,* 2013], as well as print material, including the official poster of the reference hazard map (Figure 1), are openly accessible online at http://www.efehr.org, the portal of the European Facility for Earthquake Hazard and Risk, and at the SHARE project website, http://www.share-eu.org.

Acknowledgments

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