INQUA Focus Group Earthquake Geology and Seismic Hazards

The new Italian seismic hazard model

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Abstract: *In 2015, the Seismic Hazard Centre (CPS) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) was commissioned to engage and coordinate the national community with the aim of elaborating a new reference seismic hazard model, which is expected to be released in mid 2018. CPS outlined a roadmap to describe the main features of this complex endeavour, including the different scientific tasks, milestones and timelines. The scientific tasks focus their work on i) improving the quality and the accuracy of the input data (e.g. historical seismic catalogue, seismotectonic zonation, etc.); ii) building new earthquake rate models based on these new input data, iii) selecting the most proper ground motion prediction equations, iv) testing the overall seismic hazard model as well as each component; v) combining the results of the statistical testing phase and the outcome of an expert's elicitation session to assign a weight to each component of the final seismic hazard model. The new seismic hazard model is based on an innovative coherent probabilistic framework, which allows a proper description of the aleatory variability and epistemic uncertainty, and the validation of the seismic hazard model. Here, we describe the progresses made up to now, the comparison between the new and the official national model, and finally we discuss the scientific aspects that have the most significant impact on the new picture of PSHA in Italy.*

Key words*: Italy, Seismic Hazard, Building Code.*

INTRODUCTION

In 2004-2006 a new seismic hazard model for Italy (MPS04; http://zonesismiche.mi.ing.it) was released; it was based on the most recent data, approaches, and available software tools. At that time, it was considered one of the most advanced models in Europe, and, for the first time in Italy, it was possible to define the seismic code on the uniform hazard spectra assessed on a regular 5 km spaced grid over the whole national territory. Previously, the territory was classified into 4 seismic categories, each one described by a single response spectrum. Interestingly, the new building code based on MPS04 had not been mandatory until 2009, few months after the Mw6.1 L'Aquila earthquake.
In the following years, the update of MPS04 was not considered as a priority, since the professional engineers needed time to become familiar with the proper application of the new EuroCode 8 building code.

In 2013, a new seismic hazard model for Europe (the European SHARE hazard model, http://www.share-eu.org/) has been delivered, which shows marked increases in the 10% in 50 years peak ground acceleration (PGA) with respect to MPS04. These differences were somehow surprising because SHARE and MPS04 used very similar area source models (Meletti et al., 2008) and historical seismic catalogue. A detailed investigation carried out by Meletti et al (2014) shows that the use of more recent ground-motion prediction equations (GMPE) in SHARE explains the largest discrepancies between SHARE and MPS04 (Meletti et al., 2014).

Besides the developments of these new GMPEs, during the last ten years many new data became available, and the computational codes have been significantly improved. Therefore, in 2015 the Italian scientific community led by the Seismic Hazard Centre (Centro Pericolosità Sismica – CPS hereafter) of the National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia – INGV hereafter) proposed to build a new national seismic hazard model that may be used to revise the design spectra for the building code. This proposal has been funded by the Italian government through the Department of Civil Protection (Dipartimento di Protezione Civile, DPC hereafter), and it is still ongoing mostly because of the continuous and intense interaction with the review panel (namely the High Risks Commission of the Italian Civil Protection Department; http://www.protezionecivile.gov.it/jcms/en/home.wp).

DISCUSSION

From the beginning of 2015, DPC is funding CPS to build a new seismic hazard model, which is aimed to replace MPS04 (MPS Working Group, 2004; Stucchi et al., 2011). Since the beginning CPS and DPC representatives agreed

on fixing some key constraints that must be honoured in building a seismic hazard model for practical purposes.

These points, which basically aim to guarantee a large participation and the scientific and non-scientific consensus, can be summarized as follows: (i) use of international standards according to the state of the art in Probabilistic Seismic Hazard Assessment (PSHA) (e.g. SHAAC, 1993 and Woessner et al., 2015); (ii) open and transparent procedures that guarantee completely reproducible outcomes; (iii) use of formats that have to be approved by the decision makers; (iv) the involvement of the whole Italian scientific community in proposing data, models and approaches; (v) a full and coherent exploration and representation of the epistemic uncertainty in the final seismic hazard model; (vi) the implementation of a robust testing phase, and of an elicitation session with national and international independent experts, in order to check the reliability of each component of the seismic hazard model.

Concerning the point (iii) above, CPS representatives and the national earthquake engineering community discussed the most proper outcomes of the new seismic hazard model for the building code purpose. Specifically, the time-independent model has to consider only declustered seismicity (in order to maintain a coherence with the past); the model has to cover the whole national territory, the reference soil is rock (Vs30 > 800m/s); the hazard has to be expressed in terms of PGA, PGV, PGD, spectral acceleration, velocity, displacement, macroseismic intensity; the spectral ordinates have to be in the range between 0.05 and 4 seconds, and the return periods from 30 to 5000 years.

The project of the new seismic hazard model has been organized in 6 tasks, each one of them is led by 2 coordinators. All the coordinators, together with 4 external experts on seismic hazard, form the task 1 ("Project coordination") that is in charge of evaluating any aspect of the project, and checking the effective interaction among the researchers. The other tasks are: "Input Data", "Seismicity models", "GMPEs", "Computation and rendering", "Testing phase".

The Task 2 "Input Data" is in charge of selecting all the useful basic data for the project, in order to have a common dataset of information. Many deliverables have been already released by this task; probably the most important one is the new historical earthquake catalogue that updates the previous versions. This catalogue, named CPTI15 (http://emidius.mi.ingv.it/CPTI15), contains more than 4500 records, from 1000 AD to 2014, that have been compiled with homogeneous criteria for location and magnitude of each event; for the pre-instrumental period, the moment magnitude has been assessed on the basis of the distribution of macroseismic intensities, now available for every earthquake in the Italian territory. The catalogue has been then declustered with the Gardner and Knopoff (1974) algorithm and its time-interval completeness has been also defined according both an historical and a statistical approach. The choice of exploiting this declustering technique is arbitrary but it is the best way to obtain a Poisson time-distribution for the mainshocks.

Other types of data have been released or updated, such as: the catalogue of focal mechanisms and moment tensors, the GPS velocity solution for the Mediterranean area, the DISS database of seismogenic sources capable of $Mw \geq 5.5$ earthquakes, the flat file of accelerometric recordings for $Mw \geq 4.0$ earthquakes that represents the reference information for the tasks "GMPEs" and "Testing Phase".

The main goal of Task 3 "Seismicity models" is to provide a set of seismicity models that have been proposed independently by different groups of researchers. The Task's 3 coordinators have to ensure the compatibility of these models with the OpenQuake engine platform (Pagani et al., 2014), and the coherency of the outcomes (all of the models have to provide forecasts of the same quantity). Besides these activities, this task acts as a link between the groups of modellers and task 2 that furnish common databases.

Each earthquake rate model has to be reproducible; this means that modellers have to clearly explain how the model is built and which data have been used. Moreover, modellers have to explore the epistemic uncertainty related to their model, i.e., how the model outcome varies as a function of the variability of the parameters of the model itself. This step is crucial to estimate an overall epistemic uncertainty of the final model, which includes the uncertainty of each model and the uncertainty among models.

Task 3 has collected 12 models that cover the national scale and 1 specific model for the Mt. Etna volcanic area. The 12 models were grouped according to the (main) typology of seismogenic sources: areas (5 models), faults (2 models) and points (5 models).

The Task 4 "GMPEs" aims at identifying the most proper GMPEs to be used for the new seismic hazard map. A first selection of the many GMPEs in literature has been performed taking into account the following basic requirements: i) the GMPEs should uniformly cover the Italian territory and surrounding areas (with exception for volcanic zones); ii) rocky soil conditions and flat topography have to be considered (although hazard maps for different soil classes could also be released); iii) the hazard has to be estimated in terms of peak ground acceleration, velocity and displacement (PGA, PGV, PGD), response spectra in acceleration, velocity and displacement (if PGD or the velocity and displacement spectra are not available, they are derived by integration from PGA and acceleration response spectra, respectively), macroseismic intensity and possible additional parameters, such as Housner or Arias intensity; iv) horizontal motion has to be represented by the geometrical mean of the horizontal components; v)

GMPEs have to estimate 12 spectral periods, in the range 0.05-4 seconds.

The forecasting performance of each GMPE has been evaluated through the comparison with accelerometric records available in the Italian (itaca.mi.ingv.it; Luzi et al., 2008; Pacor et al., 2011) and European (esm.mi.ingv.it; ESM Working Group, 2015) strong-motion databases and with Italian macroseismic data (DBMI15; http://emidius.mi.ingv.it/DBMI15). In this way, each GMPE has been ranked according to different specific metrics, so that the best performing GMPEs can be identified. The ranking procedure has been established in collaboration with the task 6 "Testing phase".

This selection procedure allows us to identify a set of GMPEs to use for the new seismic hazard model, among the GMPEs that have been calibrated for Italy (e.g., Bindi et al., 2011), for the European region (Douglas et al., 2014), and among the NGA-West2 models (Bozorgnia et al., 2014), that were developed for the latest seismic hazard maps of United States by the USGS (Petersen et al., 2014). The decision to select the best GMPEs for different classes of GMPEs is due to the need of considering GMPEs that may be suitable for the different Italian geodynamic contexts. A similar analysis has been carried out also for the macroseismic intensity prediction equations (IPE).

The task 5 “Computation and Rendering” is using the code OpenQuake (www.openquake.org; Pagani et al., 2014) because of several reasons: it is free and it is open source, so everyone can reproduce the outcomes and verify how the code works. Moreover, since OpenQuake is developed by GEM (www.globalquakemodel.org), it is possible to interact with the developer team to modify or integrate the code, as well as to ask for the development of new dedicated functions. No less important, OpenQuake guarantees rapid assistance for problems concerning the elaboration or installation issues. One of the main goals of Task 5 is to disseminate the outcomes of the seismic hazard model in the form of graphs, tables, maps, through both paper and electronic tools. The previous experience gained in disseminating the outcomes of the previous MPS04 model was very positive and successful (Martinelli and Meletti, 2008): specifically, a webGIS application allows any user to view hazard maps, hazard curves and uniform hazard spectra. For the new seismic hazard model, the hazard will be disseminated by developing an analogous web tool, with new and extended features, which allow the users to receive more information with additional formats.

The task 6 “Testing phase” is an important and innovative aspect of the project. In common practice, the reliability of a seismic hazard model is based on the consensus of the scientific community on the model's outcomes. A more objective approach is based on testing the seismic hazard model, or its components such as the earthquake rate models and the GMPEs, using the available data. Despite the obvious importance of this step if we want to keep seismic hazard into a scientific domain, there is not yet a commonly accepted framework for testing seismic hazard models, and only a few approaches based on different assumptions have been proposed. The role of subjective expert opinion, the heterogeneous probabilistic approaches used to build the models, and the scarcity of independent data for evaluation make this issue extremely challenging, both from a theoretical and a practical point of view.

In Task 6 we adopt the probabilistic framework introduced by Marzocchi and Jordan (2014), which allows a meaningful testing and validation of a seismic hazard model, accounting for properly the epistemic uncertainty. (We defer to this paper and references therein for a detailed discussion on this topic). As far as long-term seismic hazard models are concerned, seismologists cannot usually evaluate models using independent data. Some efforts in this direction are ongoing, but with some limitations (e.g. Mak et al., 2014). Most of the times, as for the new seismic hazard model, only past data, which have been used more or less directly to build the hazard model, can be used for testing. Hence, instead of using the term validation, we prefer to use the less ambitious term “consistency” of the model's output with data. In other words, the model should describe the data that have been used to build the model. Specifically, the main goal of Task 6 is to test the consistency of the new seismic hazard model, as well as of its components, i.e., the seismicity rate models and the GMPEs.

A second goal of Task 6 is to score the models. Specifically, we compare different models that form the new seismic hazard model to rank them according to their retrospective forecasting (hereafter pastcasting) performances; we named this procedure “scoring”. All hazard models, and every single component have been scored according to few pre-selected specific metrics. The goal of scoring is to facilitate the merging of models in a final seismic hazard assessment; in fact, the final weight of each component of the hazard model is assigned accounting for its scoring, and the outcomes of an experts' elicitation session with independent national and international experts.

To sum up, the testing of the new seismic hazard model consists of 4 different phases. In testing phase 1, we evaluate the consistency of the final hazard model using the past accelerometric data that are available in Italy, accounting for properly the epistemic uncertainty. In testing phase 2, we test the new seismic hazard model in terms of macroseismic intensity. We compare the outcomes of the model with the intensity observations that occurred in the last centuries. In testing phase 3, we test for consistency every single seismicity rate model, comparing the rates with the seismicity that has been observed in the last centuries (taken from the CPTI15 catalogue). In testing phase 4, we provide a quantitative score for each model based on the comparison of their past casting. This score could be useful to establish the weight of each model, but we underline that scoring a

model is entirely based on data analysis, while establishing weights could require more subjective assessment, for instance, when the dataset used for scoring is not particularly large. The scoring is applied to the set of final hazard models as well as to single components such as the seismicity rate models and the GMPEs, using the databases described for the previous testing phases.

CONCLUSIONS

The Italian scientific community is going to release soon a new seismic hazard model for Italy. This effort has started in 2015 and has involved more than 150 researchers. With respect to the previous model, we have been taking advantage of the significant updates of several input data, such as the historical seismic catalogue, and of a richer set of models for earthquake rates and GMPEs. The new seismic hazard model contains also some important novelties, such as a new probabilistic framework that allows the validation of the model and a proper and coherent description of the epistemic uncertainty. We have also introduced a strong testing phase, which allows a more objective evaluation of the hazard model and of its components. Last but not least, the final model is going to be fully transparent and reproducible. This will facilitate any posterior evaluation of the model by independent groups of researchers.

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