European Seismic Risk Model – Insights and Emerging Research Topics

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Abstract. A new European Seismic Risk Model (ESRM20) was recently released to the scientific community (http://risk.efehr.org). This model combines the European Seismic Hazard Model (ESHM20), a regional model of site response based on proxy data (topography and geology), an exposure model describing the distribution of building classes for 44 countries, and vulnerability models for over 200 building classes, in order to estimate key seismic risk metrics at the European scale, including average annual losses and return period economic losses and loss of life. This Chapter explores some of the insights from this model, including the regions of highest risk in Europe, the building classes contributing most to the losses, and the potential impact of retrofitting those building classes. All of the models, as well as the underlying datasets, workflows and software have been openly released, thus allowing reproducibility of the results, but also providing a set of resources that can be used to kick-start additional research. Examples of how these resources can be used by researchers will be given herein, as well as new research topics emerging from the models.

Keywords: Seismic risk · Exposure · Vulnerability · Europe

1 A New Seismic Risk Model for Europe

There have been many European projects dealing with aspects of seismic hazard and risk over the past 30 years (e.g. RISK-UE, LESSLOSS, SHARE, SYNER-G, STREST), but the first opportunity for the scientific community to integrate key aspects of this research towards the development of an open seismic risk model for Europe (denoted ESRM20 herein) came about during the SERA (Seismology and Earthquake Engineering Research Infrastructure Alliance) project (2017–2020). Following a period of calibration, testing and validation that was undertaken after the end of the SERA project, ESRM20 was

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openly released to the scientific community by the European Facilities for Earthquake Hazard and Risk (EFEHR - a consortium of European organisations aimed at advancing earthquake hazard and risk assessment) in December 2021.

The main components of the ESRM20, namely the hazard, site response, exposure and vulnerability models, have been developed and integrated by a core team made up of the authors of this report. However, this effort would not have been possible without the contributions from over 100 scientists and researchers, through participation in SERA project workshops, population and building census data retrieval and translation, local expert knowledge on buildings, expert recommendations and feedback on modelling and methodologies, risk results review, specification of user/stakeholder needs, and website/software/web services development[1]. This model is therefore the first attempt to develop a community-based seismic risk model for Europe and, through its open and transparent release, an even greater participation is expected for all future versions.

The EFEHR Consortium decided in its first General Assembly in September 2020 to openly release, with Creative Commons Attribution 4.0 International license[2], all products of the European hazard and risk models. This includes source data, input models, software and outputs of ESRM20. This license allows reusers to distribute, remix, adapt, and build upon the material in any medium or format (even for commercial use), as long as attribution is given to the creator(s). Each product of ESRM20 is being released with a clear notice on how it should be cited in order to allow users to easily abide by the license. All data, models and results presented in this Chapter can be accessed via http://risk.efehr.org.

This Chapter provides a succinct summary of ESRM20, and interested readers can find more details in the full technical report (Crowley et al. 2021a [1]). In addition, some examples of how the resources related to ESRM20 have been or could be used for seismic risk research purposes are illustrated herein, with the aim of encouraging their use by a wide variety of researchers involved in the field of seismology, and possibly also other natural hazards.

2 Summary of Key Components

2.1 Stochastic Catalogues and Ground Motion Fields

The OpenQuake-engine (Pagani et al. 2014 [2]; Silva et al. 2014 [3]) has been used to calculate the seismic risk metrics from ESRM20 (see Sect. 3). The risk calculations have been undertaken with the so-called "eb-risk" calculator of the OpenQuake-engine which first uses the hazard library of the OpenQuake-engine (hazardlib) to compute stochastic catalogues and associated ground motion fields, and then combines these with the exposure and vulnerability models.

1 http://risk.efehr.org/contributors/.
2 https://creativecommons.org/licenses/by/4.0/.

The stochastic catalogues and ground motion fields have been calculated using the latest seismogenic source model for Europe, developed as part of the ESHM20 (the 2020 European Seismic Hazard Model). A detailed discussed of this source model is provided in Danciu et al. (2021) [4]. A collapsed version of the ESHM20 seismogenic source model logic tree has been used for the risk calculations, with two main source branches representing the source model types: an area source model and a hybrid kernel smoothed seismicity and active faults model, each with an equal weighting. The collapsed source model logic tree implies the use of a weighted mean of earthquake activity rates for each of the two source models.

For the ground motion logic tree, a so-called regionalised backbone approach has been adopted for each of the three main seismotectonic region types in Europe: shallow crustal seismicity, seismicity in the stable craton region of northeastern Europe, and subduction and deep seismicity. More details on the logic tree can be found in Danciu et al. (2021) [4], as well as in a number of journal publications that have arisen from this work (Kotha et al. 2020, 2022 [5, 6]; Weatherill et al. 2020a [7]; Weatherill and Cotton 2020 [8]).

Three proxies have been used to model the regional site response in ESRM20: topographic slope, inferred V_{S30} (from topographic slope, using the methodology of Wald and Allen 2007 [9]) and geological unit/era. The site amplification function of the backbone ground motion model for shallow seismicity in active and low seismicity non-cratonic regions in the ESHM20 logic tree (Kotha et al. 2020 [5]) has been developed using the regression between the site-to-site variability and topographic slope, with geological unit as a random effect, as described further in Weatherill et al. (2020b) [10] and Weatherill et al. (2022) [11]. Instead, in both the craton and the subduction/deep seismicity regions, the site amplification terms from the appropriate models are directly adopted together with inferred V_{S30} values. A tool for users to prepare site response input files for the OpenQuake-engine has been made available[3].

The OpenQuake-engine hazard library uses the seismogenic source model to create an earthquake rupture forecast (i.e. a list of all of the possible ruptures that can occur in the region of interest), which is then sampled (with Monte Carlo sampling) to generate a number of stochastic event sets (SES), each with a duration of 1 year. Due to the random nature of the process, a large number of SES is required in order to reach statistical convergence in both the seismic hazard and risk assessments (Silva 2018 [13]), and it has been found that 10,000 are sufficient for adequate convergence of the European risk model for the return periods of interest. The combination of these stochastic event sets is referred to herein as a stochastic catalogue.

The epistemic uncertainty in the seismogenic source models and ground motion models is propagated through the use of logic trees (Pagani et al. 2014 [2]). For the ESRM20, when run at the European scale, only 100 branches of the full logic tree (which, as mentioned previously, includes the collapsed seismogenic logic tree and the ground motion characteristic model) have been randomly sampled. A stochastic catalogue of 10,000 years, and ground motion fields for each event in the stochastic catalogue, are generated for each of the sampled logic tree branches (also referred to as ‘realisations’), considering only earthquakes with magnitude above 5.0. The ground

[3] https://gitlab.seismo.ethz.ch/efehr/esrm20_sitemodel.

motion fields consider the tectonic regions and the site response model within 300 km of the epicentre of the event and provide the amplified ground motions at the locations in the exposure models. For each event, a sample of the inter-event variability from the ground motion model is applied to all sites, whereas the intra-event variability is sampled at each location in the exposure model. Spatial correlation of the intra-event residuals has not been currently modelled as it increases computational complexity, it does not influence the average annual loss and it has been found not to have a significant impact on the considered return period losses for large-scale risk assessment.

Researchers interested in exploring further the hazard inputs to the risk calculations, and modifying some of the default configuration parameters described above, can obtain the final OpenQuake-engine input files from the ESRM20 repository[4]. This repository provides access to the hazard input models and the OpenQuake-engine settings used for the computationally efficient calculation of the selected European seismic risk metrics with an event-based approach.

2.2 Exposure Models

The development of the exposure models for 44 European countries has been described in two peer-reviewed publications: Crowley et al. (2020) [14] and Crowley et al. (2021b) [15]. Since these publications were released, however, the models have continued to be developed, and a definitive summary of the final data, assumptions and workflow used to develop the exposure models used in ESRM20 can be found in Crowley et al. (2021a) [1]. All of the data used to develop the exposure models has been made available in a GitLab repository (Crowley et al. 2021c [16]).

There are three occupancy classes considered in the risk model: residential buildings, commercial buildings and industrial buildings. Different approaches have been adopted in each country for each of these occupancy classes as a function of the data availability. The main steps to develop the exposure models for each country can however be summarized as follows:

- Spatially distributed source data on the number of buildings has been collected, mainly from public census data, for each country and occupancy type. In some cases, it has been necessary to use proxy data, such as number of employees, to spatially distribute the total number of buildings across the country. For residential and commercial buildings, the data is distributed in terms of administrative units, whereas for some counties the industrial exposure is available on a 30-arc second grid (as used in the source of this data: Sousa et al. 2017 [17]).
- Coordinates have been assigned to each administrative unit (or grid cell). Based on the study by Dabbeek et al. (2021) [18], each administrative region has been represented by a single coordinate which represents a density-weighted centroid, which is calculated from a 30 arc-seconds grid of built-up area density, interpolated from the 250 × 250 m resolution built-up area density map (Pesaresi et al. 2015 [12]).

[4] https://gitlab.seismo.ethz.ch/efehr/esrm20.

- The buildings have been distributed across a number of building classes, which are classified according to the latest version of the GEM Building Taxonomy (Silva et al. 2022 [19]). Expert judgment, together with extensive literature reviews, have been used to identify the building classes, and for residential buildings it has been possible to infer the building classes from the available attributes in the building/dwelling census (such as age, external material and number of storeys).
- The area per building class has been assumed and validation of the total built area has been made using national data.
- The reconstruction costs per square metre (for structural and non-structural elements) for residential, commercial and industrial buildings for each country have been assigned, based on local expert input and values identified in the literature. A distinction has been made between urban, rural and big cities. Additional costs to cover the contents for each occupancy class have been added.
- The population (residential or employed) has been distributed between the different building classes according to the number of dwellings or construction area, and then further distributed during the day, night and transit times.

The final set of exposure models for Europe contain an estimated 143 million buildings, which contain an average of 460 million occupants (over a typical 24-h period), and a total replacement cost (structural, non-structural and contents) of 50 trillion Euros, of which 66% is from the residential building stock. Table 1 presents a summary of the number of buildings, average number of occupants (over a 24-h period) and total replacement cost of buildings in each country in the European exposure models. Table 2 presents the top ten building classes in Europe (according to a simplified taxonomy). This table shows the dominance of unreinforced masonry in the building stock, especially when the number of buildings is considered, though it should be considered that reinforced concrete buildings have been separated into a number of separate classes. If all reinforced concrete building classes are combined, it is found that they contribute the most in terms of occupants and total replacement cost, but not in terms of number of buildings, which is still dominated by unreinforced masonry.

A number of GIS layers and maps of the exposure models have been prepared and are available to view, query and download (with web services) through a web-based geo-viewer[5]. Figure 1 shows one of these maps, wherein the exposure models have been disaggregated onto a hexagonal grid, with a height of 0.17 decimal degrees, using the Global Human Settlement Layer (GHSL) 2019 spatial raster dataset of population[6].

[5] https://maps.eu-risk.eucentre.it/tags/exposure/.

[6] https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php.

Table 1. Summary of the number of buildings, average number of occupants (over a 24-h period) and total replacement cost of buildings (residential, commercial and industrial) in the European exposure models.

Country	Number of buildings (thousands)	Occupants (average) (thousands)	Replacement cost (M EUR)
Albania	644	2043	30365
Andorra	18	56	8331
Austria	2316	6572	1086647
Belgium	3847	8439	1297493
Bosnia and Herzegovina	1099	2487	62981
Bulgaria	2193	5104	290548
Croatia	1670	2961	157490
Cyprus	287	625	90447
Czechia	2373	7824	616284
Denmark	1687	4274	876430
Estonia	235	971	63904
Finland	1339	4064	606109
France	15347	47581	7448179
Germany	19935	58029	10651811
Gibraltar	6	25	3484
Greece	3352	7743	608960
Hungary	2824	7270	528346
Iceland	74	262	62178
Ireland	1929	3619	508573
Isle of Man	20	60	8244
Italy	12188	43803	5262975
Kosovo	292	1348	20031
Latvia	383	1397	95219
Liechtenstein	14	27	11205
Lithuania	599	2050	160848
Luxembourg	131	464	82029
Malta	117	376	30247
Moldova	813	1968	43351
Monaco	10	29	6857
Montenegro	165	476	15490
Netherlands	5498	12875	2596802
North Macedonia	494	1523	41134
Norway	1761	3888	878738
Poland	7025	27916	1445547
Portugal	3629	6865	706579
Romania	5507	13818	337233
Serbia	2341	5164	227816
Slovakia	996	4021	287869
Slovenia	512	1497	84052
Spain	10013	32897	3738161
Sweden	2379	7576	1318713
Switzerland	1874	6083	1294150
Turkey	9160	61765	822174
United Kingdom	15475	49256	5548205

Table 2. Top 10 building classes (according to the simplified taxonomy) in the European exposure model

Simplified taxonomy	Number of buildings	Occupants (average)	Total replacement cost
Unreinforced masonry, low rise	49.7%	29.1%	26.5%
Concrete frame with infill panels, mid rise, low/moderate code	3.0%	10.2%	9.4%
Concrete frame with infill panels, low rise, low/moderate code	9.3%	6.9%	8.0%
Concrete frame with infill panels, mid rise, pre code	5.3%	7.4%	7.8%
Concrete wall, mid rise, pre code	3.6%	6.9%	7.0%
Steel, low rise	0.9%	4.2%	6.2%
Wood, low rise	8.2%	4.1%	5.2%
Concrete wall, mid rise, low/moderate code	1.0%	4.2%	5.0%
Concrete frame, low rise, pre code	0.4%	1.7%	2.9%
Concrete frame, low rise, low/moderate code	0.7%	2.2%	2.9%

2.3 Vulnerability Models

The Vulnerability Modeller's Toolkit, a resource developed and released by the GEM Foundation has been used to develop the fragility and vulnerability models (Martins et al. 2021 [20]). This toolkit is a set of Python scripts that read capacity curves (Fig. 2a), produce SDOF hysteretic models, and launch OpenSeesPy (Zhu et al. 2018 [21]) to run nonlinear dynamic analyses. Then, the toolkit applies a linear censored regression to the cloud of nonlinear responses (Fig. 2b) to compute fragility functions for different damage states, based on the user-defined damage state thresholds (Fig. 2c). These fragility functions can then be converted into vulnerability functions using damage-loss models. The complete toolkit, including source code and GUI, is currently hosted in a publicly available GitHub repository[7].

[7] https://github.com/GEMScienceTools/VMTK-Vulnerability-Modellers-ToolKit.

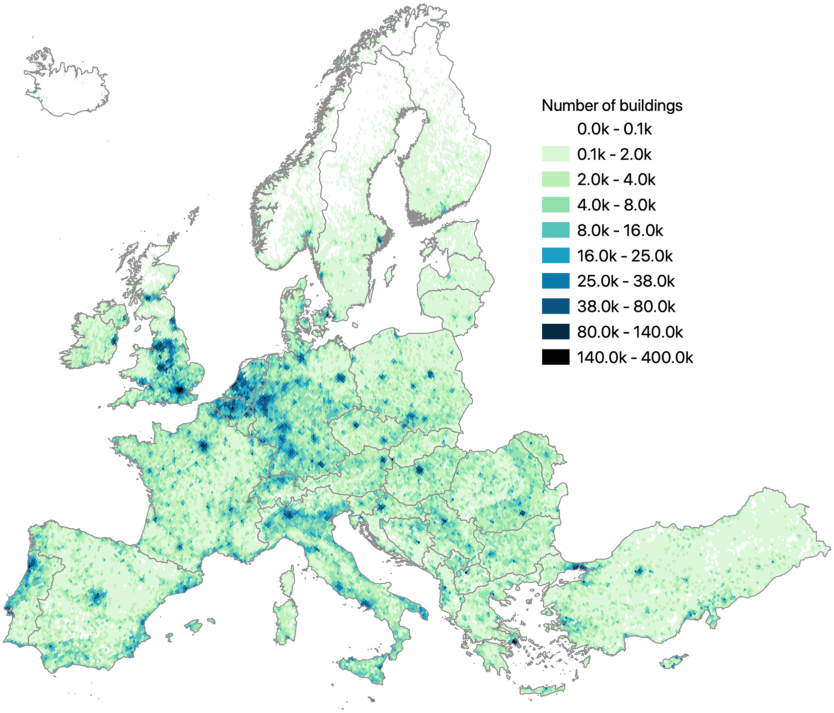

Fig. 1. Distribution of the number of residential, commercial and industrial buildings in Europe, dis-aggregated onto a hexagonal grid (data downloaded from https://maps.eu-risk.eucentre.it/map/european-exposure-gridded-data-viewer)

The European customization of the toolkit, together with all European capacity curves, SDOF hysteresis assumptions, accelerograms, cloud regression results, and scripts to produce lognormal fragility functions and vulnerability models for both economic loss and loss of life are available on a separate GitLab repository (Romão et al. 2021 [23]). A vulnerability viewer has been prepared for viewing and comparing the final fragility and vulnerability functions[8].

[8] https://vulncurves.eu-risk.eucentre.it/.

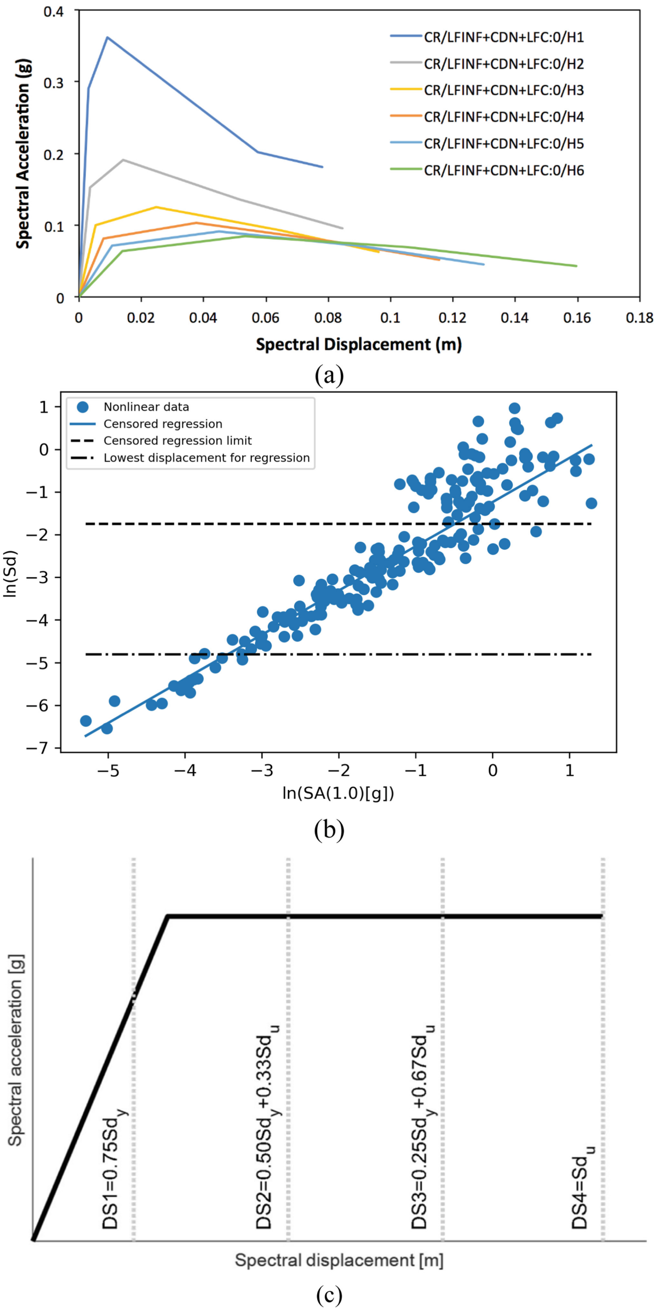

Fig. 2. (a) Example median capacity curves for reinforced concrete infilled frame buildings (b) regression plots showing the response of an SDOF and the censored linear regression using a lower limit displacement (c) damage thresholds assumed in the development of the fragility functions (from [22] Martins and Silva 2020)

A number of tests have been carried out to check the vulnerability models and to increase the confidence in the estimated losses from these models. These tests include comparisons with empirical vulnerability models, as well as comparisons between the losses predicted by the ESRM20 vulnerability models with the losses observed in recent damaging earthquakes in Europe, through a number of scenario models. The scenarios and input files used to validate the models have all been made available on a GitLab repository[9].

3 Summary of Risk Results

There are two main risk metrics that can be computed with this first version of the European seismic risk model:

- Economic loss due to direct costs to repair/replace the buildings in Europe (residential, commercial and industrial)
- Loss of life of occupants due to damage/collapse of those buildings

The probability of these losses is accounted for in the risk model, leading to estimations of the average annual losses (i.e., the long-term mean loss per year due to earthquake ground shaking) and losses with specific return periods, which can also be presented as loss exceedance curves (i.e., the long-term mean loss value due to earthquake ground shaking that is expected to be equalled or exceeded at least once every X years, where X varies from 50 to 1000).

According to the model, the total average annual economic loss in Europe is around 7 billion EUR, with almost 70% of this loss occurring in Italy, Turkey and Greece. The average annual loss of life is estimated to be around 900 fatalities, with over 75% of those fatalities in Italy and Turkey alone. Fig. 3 shows how the relative losses (i.e., average annual loss divided by replacement cost) vary across Europe at administrative level 1 resolution. From a more detailed evaluation of the results, it has been found that mid-rise reinforced concrete frames with infill panels designed to low/moderate seismic design codes, together with low-rise unreinforced masonry buildings, are the two building classes that contribute most to both economic losses and loss of life in Europe. More detailed results of the model are available in Crowley et al. (2021a) [1], as well as through a number of web GIS maps.[10]

[9] https://gitlab.seismo.ethz.ch/efehr/esrm20_scenario_tests.

[10] http://risk.efehr.org/esrm20.

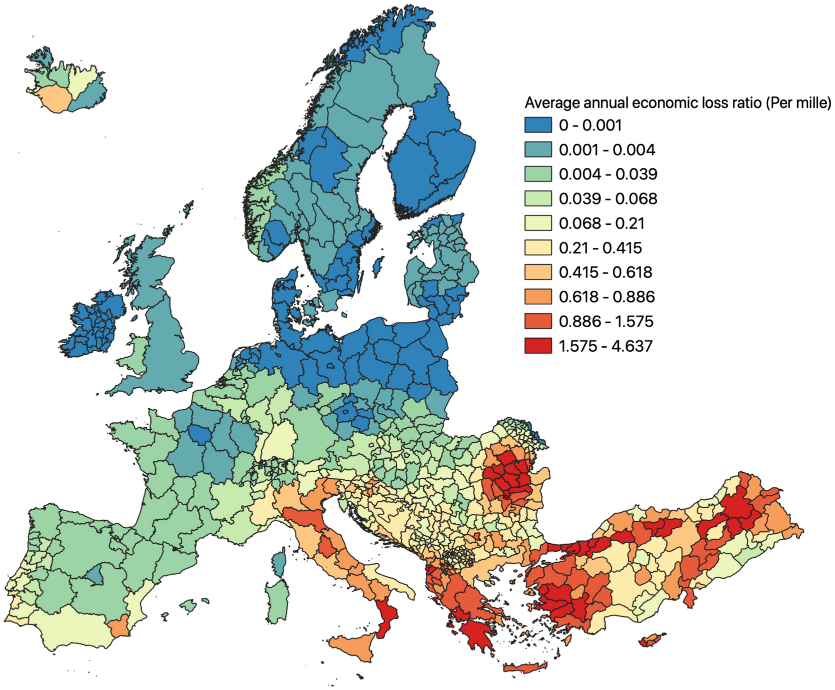

Fig. 3. Map of average annual economic loss ratio (per mille) aggregated at administrative level 1 in each of the 44 European countries (data downloaded from https://maps.eu-risk.eucentre.it/map/esrm20-admin1-viewer)

The European loss results have been validated through a number of tests using empirical data, and by comparing with other loss models covering Europe including the GAR15 (GAR 2015 [24]) and GEM's Global Seismic Risk Map v2018.1 (Silva et al. 2020 [25]). Figure 4 shows comparisons of empirical loss curves based on the economic losses in the NatCatService (Munich Re 2009 [26]) –brought to 2017 values– and fatalities from the Centre for Research on the Epidemiology of Disasters (CRED)'s EM-DAT international disasters database (EM-DAT, n.d. [27]), with loss curves for the whole of Europe from the model. For the modelled loss curves, the epistemic uncertainty in the loss curves has been presented by showing the loss curves for each of the 100 samples of the logic tree: these are represented in grey in the figures, and the mean loss curve is shown in black.

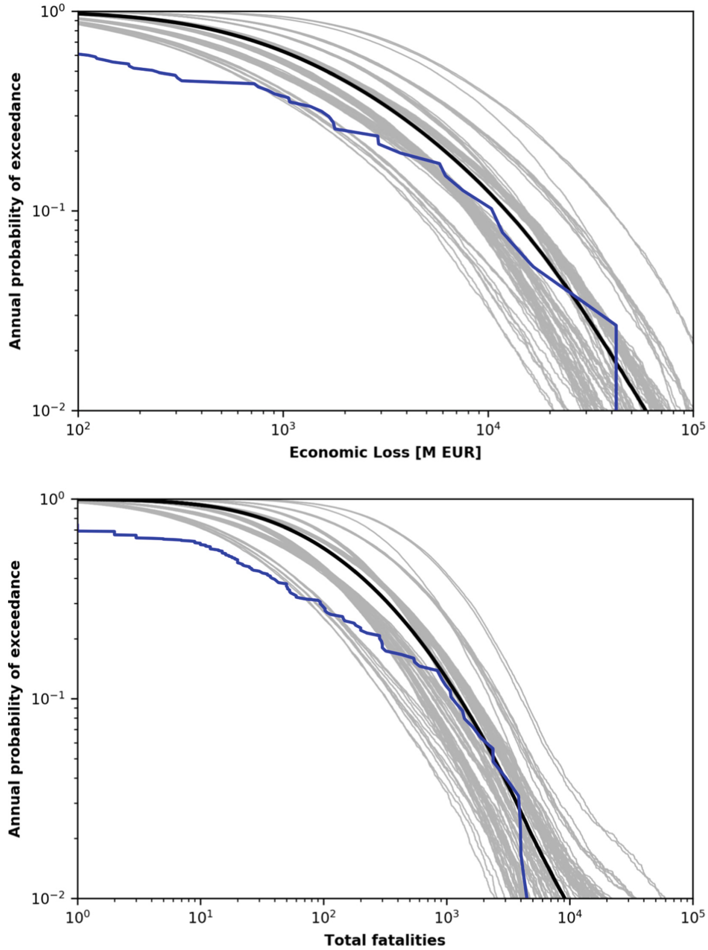

Fig. 4. (Top) Empirical loss curve for Europe in terms of economic loss using data from NatCat-Service for the past 37 years (blue curve) compared with the modelled loss curves: each branch of the logic tree shown in grey and the mean loss curve is shown in black. (Bottom) Same plot in terms of loss of life using data from EM-DAT for the past 100 years (blue curve).

These comparisons indicate that the model appears to be overestimating the more frequent, lower return period losses. There are various reasons that can explain this discrepancy in this region of the loss curve: i) these international databases only cover the very recent history and they focus on the larger events that are widely publicized, ii) the large aleatory variability in the ground motion models can lead to significant ground shaking, even for low magnitude events, iii) the ground motion models are ergodic, and thus they naturally have higher variability than the actual variability that can be expected at any given site, iv) the tails of the vulnerability models have a large influence on the low return period losses, iv) the correlation of the inter-event variability between different intensity measure types was not modelled (though this has since been included as a feature of the OpenQuake-engine).

4 Use of ESRM20 and Associated Resources

In this section, a number of different users and associated use cases are presented, both real and hypothetical, to show how the resources associated with ESRM20 can be used in future research and risk mitigation activities. The aim of this section is to inspire and encourage the wider scientific community to make use of these resources and to help improve the future of European seismic risk modelling.

4.1 European Disaster Risk Management Agencies

A simple investigation into the impact of retrofitting on the European losses has been undertaken by increasing the code or ductility level of building classes contributing most to the risk in Italy and Turkey. This exercise showed that such interventions could reduce the average annual number of fatalities in Europe by over 50% and the average annual economic losses by at least 30%. This demonstrates one important potential use of the model: to plan, prioritise and communicate interventions for risk mitigation at the European scale.

In fact, the ESHM20 hazard and ESRM20 exposure and vulnerability models have recently been used in the REEBUILD project (Integrated techniques for the seismic strengthening and energy efficiency of existing buildings) in order to prioritise regions across the 27 EU Member States (EU-27) for integrated seismic strengthening and energy efficiency interventions. At least 30% of European buildings are located in areas of moderate seismic hazard where the design peak ground acceleration (PGA) is at least 0.1g (Crowley et al. 2020 [13]), whereas the European building stock is reportedly responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU, making it the single largest energy consumer in Europe (COM (2020)662). Hence, the reduction of seismic vulnerability of European buildings together with an increase in their energy efficiency is of utmost importance for the European economy, and can be most efficiently addressed through a holistic approach. Gkatzogias et al. (2022) [28] present the methodology that has been applied to combine risk metrics from ESRM20 (for the EU-27) with metrics for the energy performance of buildings and socioeconomic vulnerability. These multi-sectorial integrated indicators are used to prioritise regions in an effort to highlight areas where the renovation of buildings is expected to have a multidimensional impact on various metrics. Figure 5 shows the spatial variation of one of the indicators across NUTS-3 (Nomenclature of Territorial Units for Statistics) that integrates the following metrics: average annual economic loss ratio and average annual economic loss per building (considering both earthquakes and energy efficiency), energy consumption per building and heating degree days (HDD), average annual loss of life (due to earthquakes), energy consumption and socioeconomic indicators.

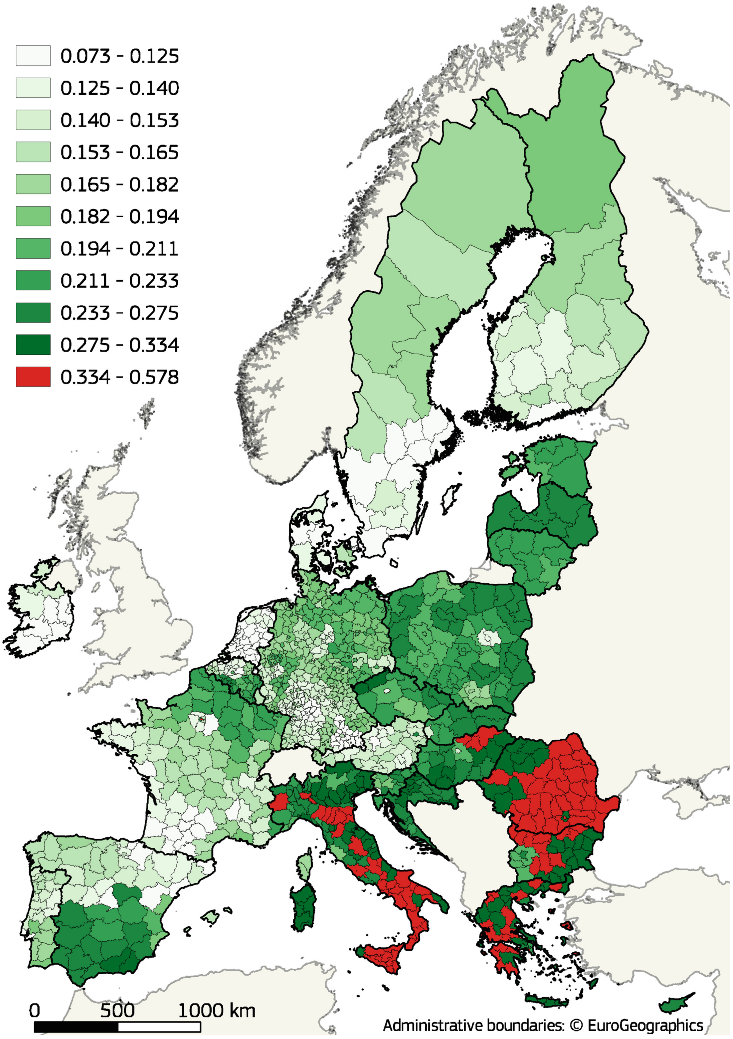

Fig. 5. Spatial variation across NUTS-3 (for the EU-27) of a multi-sectorial integrated indicator that combines risk metrics from ESRM20 with metrics for the energy performance of buildings and socioeconomic vulnerability (Gkatzogias et al. 2022 [28])

4.2 National Risk Assessment Developers

The ESRM20 provides a framework for national seismic risk assessment that can be used, for example, as part of the reporting on "*national risk assessment* (*NRA*)" and "*information on the priority prevention and preparedness measures with a focus on* (*a*) *key risks with cross-border impacts, and, where appropriate,* (*b*) *low probability risks with a high impact*" (see amendment of the European Union Civil Protection Mechanism (EUCPM) of March 2019 (Decision (EU) 2019/420)). Some countries have not yet developed some or all of the components of a national seismic risk model to the same level of maturity as ESRM20, and so these models can provide a baseline upon which further, more detailed, local developments can be built. Furthermore, the model can help and encourage the harmonised modelling of the cross-border impact of earthquakes.

4.3 Academics, Researchers, Students

The current models could be used by different types of researchers in various research applications. Some examples include the following:

- A national PSHA modeller might replace the ESHM20 hazard model with a national hazard model, and use this together with the exposure and vulnerability models from ESRM20 in order to investigate the impact of changes in the hazard in terms of risk metrics.
- Likewise, an engineering seismologist developing a new ground motion model might use the scenario repository to easily investigate the impact of their model on the damage and losses for different scenarios.
- A geologist developing a database of faults might wish to understand the proximity of the faults to population and buildings, and use this to prioritise the field work required to improve the database.
- A geotechnical engineer working on seismic microzonation of a given city might use the components of the ESRM20 together with their own site response model, and thus undertake more detailed risk calculations.
- A PhD student working on seismic risk assessment of a given region might re-run ESRM20 for that region, and investigate in more detail the model and its possible outputs. For example, they might run the calculations with longer stochastic catalogues, a larger number of logic tree branches, or with spatial correlation included. They might wish to calculate additional risk metrics, such as loss exceedance curves for each administrative region per occupancy class.

During the development of ESRM20, a large number of areas of future research were identified. Whilst we, the core team of ESRM20, are keen to continue researching these topics, we encourage other researchers to also investigate these topics, potentially also in collaboration with us. A brief summary of these future research areas is listed below:

- The impact of the correlation of epistemic uncertainties within the hazard logic tree on the risk results requires further investigation, and methods to trim the branches for more computationally efficient models are required.
- The exposure models will need to be continuously updated, as more recent housing census data or socio-economic information becomes available.
- The modelling of occupants within the buildings during different times of the day, week and season, accounting also for the migration of people from their place of residence to place of work, or for tourism, could be improved, using datasets such as those from the ENACT project[11].

[11] https://ghsl.jrc.ec.europa.eu/enact.php.

- Fragility and vulnerability models using a simulated-design approach could be developed for more building classes (beyond reinforced concrete frame buildings).
- Separate fragility models could be provided for structural, non-structural and contents (which is not currently the case), and these could be combined with appropriate damage-loss models to produce vulnerability models that account for the loss to each component separately.
- Data on demand surge could be collected and its effects included in the risk model to account for larger losses in the more damaging events.
- The vulnerability models could be expanded to include other consequences, for example: injuries, homelessness, and downtime.
- The inputs for a larger number of past scenarios and future 'what if' scenarios could be prepared. These might include, for example, past historical earthquakes such as the 1356 Basel earthquake in Switzerland or the 1756 Düren earthquake in Germany, or hypothetical events close to major cities in Europe.
- Now that the risk model is available, it should be possible to quantify the extent to which good microzonations for a city can help to reduce or refine the estimates of losses for a country. This can help make the case for investing resources in microzonation to help reduce the uncertainty in site response.

5 Conclusions

This Chapter has presented a succinct summary of the 2020 European Seismic Risk Model (ESRM20) which was recently openly released to the scientific community. This model estimates that the average annual economic loss in Europe is around 7 Billion EUR, with almost 70% of this loss occurring in Italy, Turkey and Greece. The average annual loss of life is estimated to be around 900 fatalities, with over 75% of those fatalities in Italy and Turkey, alone. Mid-rise reinforced concrete frames with infill panels designed to outdated seismic design codes, together with low-rise unreinforced masonry buildings, are the two building classes that contribute most to both economic losses and loss of life in Europe. The outputs of the model have been tested using a number of empirical loss databases and the initial outcomes are encouraging and provide a sufficient level of confidence in this first version of the model. Nevertheless, continued improvements to the model are expected following this open release, as more feedback and additional testing is provided by the scientific community.

We hope that, in addition to providing a first view of the seismic risk to which the European population is exposed, ESRM20 can support the research of a large variety of researchers through the many datasets, scripts and models that have been released as part of its development (all available via http://risk.efehr.org), along the lines of some of the initial examples and suggestions that have been provided herein.

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