16TH EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING
THESSALONIKI 18 - 21 JUNE 2018

# TOWARDS A UNIFORM EARTHQUAKE RISK MODEL FOR EUROPE

Helen CROWLEY[1], Daniela RODRIGUES[2], Vitor SILVA[3], Venetia DESPOTAKI[4], Xavier ROMÃO[5], José Miguel CASTRO[6], Sinan AKKAR[7], Ufuk HANCILAR[8], Kyriazis PITILAKIS[9], Dimitris PITILAKIS[10], Myriam BELVAUX[11], Stefan WIEMER[12], Laurentiu DANCIU[13], António A. CORREIA[14], Oreste Salvatore BURSI[15], Moritz WENZEL[16]

## ABSTRACT

Seismic risk has been the focus of a number of European projects in recent years, but there has never been a concerted effort amongst the research community to produce a uniform European risk model. The H2020 SERA project has a work package that is dedicated to that objective, with the aim being to produce an exposure model, a set of fragility/vulnerability functions, and socio-economic indicators in order to assess probabilistic seismic risk at a European scale. The partners of the project are working together with the wider seismic risk community through web tools, questionnaires, workshops, and meetings. All of the products of the project will be openly shared with the community on both the OpenQuake platform of the Global Earthquake Model (GEM) and the web platform of the European Facilities for Earthquake Hazard and Risk (EFEHR).

*Keywords: Seismic risk; Exposure model; Fragility model; Socio-economic vulnerability; European risk*

## 1. INTRODUCTION

The recognition of the significant seismic risk in Southern Europe has propelled several large-scale European projects over recent years, which have covered seismic hazard (SHARE - www.share-eu.org, Giardini et al. 2013), structural fragility/vulnerability (Syner-G - www.vce.at/SYNER-G) and building exposure (NERA - www.nera-eu.org). However, none of these projects had the goal to generate a uniform seismic risk model across the European territory. This paper describes the development of the various components of the seismic risk work package (so-called WP26 or JRA4: http://www.sera-eu.org/en/activities/joint-research/) of the H2020 SERA project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe), which will generate a number of risk metrics (average annualised losses, probable maximum losses, risk maps), critical for the development of seismic risk reduction strategies. Amongst the many outcomes of the SERA project,

---

[1] Affiliated researcher, EUCENTRE, Pavia, Italy, helen.crowley@eucentre.it
[2] Affiliated researcher, EUCENTRE, Pavia, Italy, daniela.rodrigues@eucentre.it
[3] Seismic Risk Coordinator, GEM Foundation, Pavia, Italy, vitor.silva@globalquakemodel.org
[4] Physical Risk Engineer, GEM Foundation, Pavia, Italy, venetia.despotaki@globalquakemodel.org
[5] Assistant Professor, CONSTRUCT-LESE, University of Porto, Porto, Portugal, xnr@fe.up.pt
[6] Assistant Professor, CONSTRUCT-LESE, University of Porto, Porto, Portugal, miguel.castro@fe.up.pt
[7] Professor, Bogazici University, Istanbul, Turkey sinan.akkar@boun.edu.tr
[8] Associate Professor, Bogazici University, Istanbul, Turkey, hancilar@boun.edu.tr
[9] Professor, Aristotle University of Thessaloniki, Thessaloniki, Greece kpitilak@civil.auth.gr
[10] Assistant Professor, Aristotle University of Thessaloniki, Thessaloniki, Greece, dpitilakis@civil.auth.gr
[11] Seismic Project Lead, BRGM, Paris, France, m.belvaux@brgm.fr
[12] Professor, ETH, Zurich, Switzerland, stefan.wiemer@sed.ethz.ch
[13] Researcher, ETH, Zurich, Switzerland, laurentiu.danciu@sed.ethz.ch
[14] Assistant Researcher, LNEC, Lisbon, Portugal aacorreia@lnec.pt
[15] Professor, University of Trento, Trento, Italy, oreste.bursi@unitn.it
[16] PhD Student, University of Trento, Trento, Italy, moritz.wenzel@unitn.it

this paper presents the activities towards the development of an exposure model, a set of fragility/vulnerability functions, socio-economic indicators and the calculation of probabilistic seismic risk.

The quantitative risk assessment will be performed by combining the exposure and vulnerability models with a new probabilistic seismic hazard analysis (PSHA) model for Europe, within the OpenQuake-engine, the open-source software for seismic hazard and risk analysis (Silva et al. 2014; Pagani et al. 2014) supported by the Global Earthquake Model (GEM, www.globalquakemodel.org). In this process, both classical PSHA-based and event-based approaches will be employed to simulate thousands of years of seismicity and associated ground motion across the European territory. Then, economic and human losses will be derived for each simulated event/ground-motion. This set of losses will be used to calculate the average annualised loss per country, probable maximum losses and, for the first time, a uniform European risk map that will be released in 2020. The main outcome of this work package will be an open and dynamic risk model, which is expected to be collaboratively updated and improved throughout the years.

## 2. COMPONENTS OF THE EUROPEAN RISK MODEL

A probabilistic seismic risk assessment (PSRA) involves the estimation of the probability of damage and losses resulting from potential future earthquakes. This damage and loss might occur to buildings, infrastructure, people or even the environment. Within the European risk framework that is being developed within SERA, the focus is being placed on estimating damage and loss for residential, commercial and industrial buildings (and their occupants) and the main components of critical infrastructures (primarily pipelines and storage tanks in industrial plants).

In simple terms, a PSRA involves the calculation and convolution of seismic hazards (which might be strong ground shaking or ground failure due to liquefaction and landslides), fragility/vulnerability functions for each element at risk, and exposure models, describing primarily the location, building classes and value of all elements at risk (Equation 1).

SEISMIC RISK = SEISMIC HAZARD * VULNERABILITY * EXPOSURE (1)

### *2.1 Seismic Hazard Model*

The SERA project will also propose, in another work package (i.e. Joint Research Activities – JRA3), an update of the 2013 European Seismic Hazard Model (i.e. ESHM13, Woessner et al. 2015), and this will include estimates of surface ground shaking, as required for the risk assessment.

One of the first activities of the European seismic risk model development has thus been to ensure that the seismic hazard data necessary to calculate seismic risk will be produced in this update to the ESHM13 (Crowley et al. 2017a). Although the ESHM13 model is often acknowledged by the reference PGA map (Figure 1), spectral ordinates at a wide range of periods were also produced, and these are typically sufficient for state-of-the-art risk assessment. However, there is a new intensity measure that is being increasingly used in risk assessments and which will thus be included in the update to the ESHM13 model. This measure is the average spectral acceleration, *AvgSa*, defined as the mean of the log spectral accelerations at a set of periods of interest (Kohranghi et al. 2017). Other intensity measures that will be considered include peak ground velocity (PGV), Arias Intensity, and duration of strong ground shaking.

### *2.2 Site Amplification*

For the purposes of a Europe-wide risk assessment it is necessary to obtain seismic hazard inputs that are representative of the ground motions at the ground surface, and appropriate methods for amplifying the hazard obtained for the reference rock for this purpose should be considered. An approach for application on a regional scale is the adoption of topographically derived estimates of $V_{S,30}$ to account for variation in site condition (Wald and Allen, 2007). While this approach has received criticism in the past (e.g. Lemoine et al. 2012), opportunities to improve upon it in a manner that can better represent the spatial variation in site amplification across Europe, and its corresponding uncertainty, will be explored within SERA. For example, the use of additional proxy parameters, such as surface lithology from OneGeologyEurope (Figure 2), will be investigated.

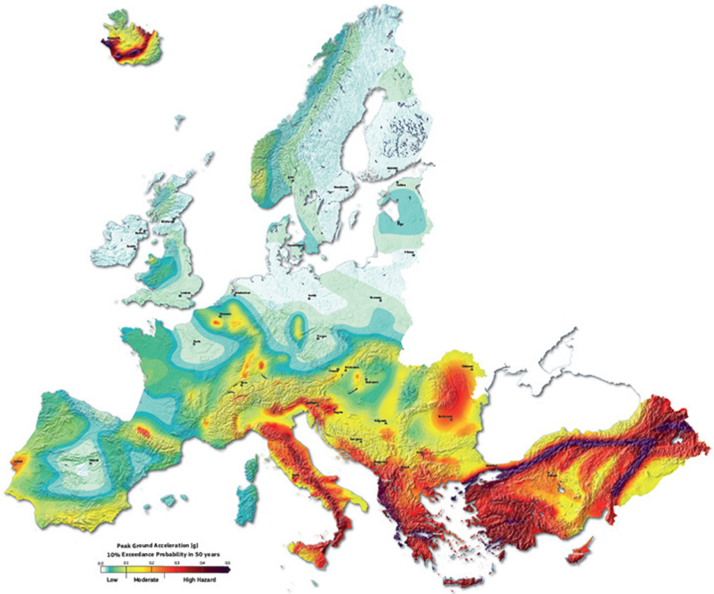


Figure 1. European seismic hazard model (ESHM13) results of peak ground acceleration (PGA) for a 475 year return period and a reference rock condition of Eurocode 8 type A (Vs30 = 800m/s)

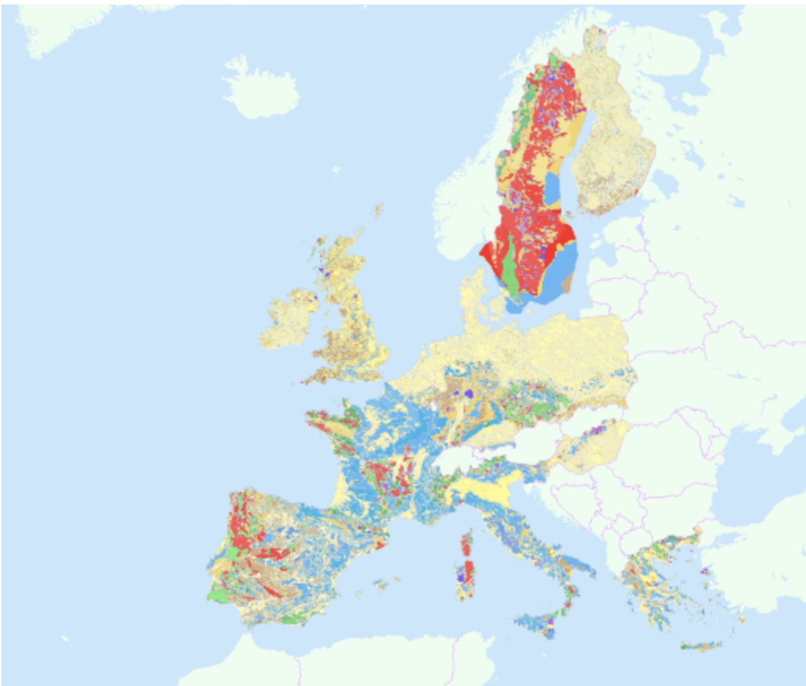

Figure 2. Surface lithology from OneGeologyEurope (http://www.europe-geology.eu/onshore-geology/geological-map/onegeologyeurope/)

*2.3 Exposure Data and Model*

A common classification scheme (i.e. taxonomy) will be used for buildings and other elements at risk within the European risk framework (Crowley et al. 2017b). By using a single classification scheme, it is possible to ensure that fragility/vulnerability models for specific elements at risk are compatible with the exposure models (that provide the location and value of those elements at risk) that may be developed by different parts of the engineering community. The building taxonomy is based on an international standard (the GEM Building Taxonomy: Brzev et al. 2013) and will allow buildings to be classified according to a number of structural attributes (e.g. main construction material, lateral load resisting system, number of storeys, age of construction, seismic design level). A new taxonomy for pipelines and storage tanks has also been developed within the SERA project, based on the experience gained in the European projects SYNER-G, STREST and INDUSE-2-SAFETY.

The European residential building exposure model will build upon previous efforts in the European projects NERIES and NERA (e.g. Figure 3). Further efforts to update underlying national housing census data in each country in Europe is undergoing (Figure 4 and Despotaki and Silva, 2018), and inference rules (that map the available data on the buildings – such as function, age, height and outer façade material – to structural systems for which fragility and vulnerability models are available) are being updated with the input of structural engineers across Europe (see Section 3.1). The SERA project will also develop exposure models for residential and commercial buildings, making use of socio-economic indicators (e.g. labour force, population per economic sector) available in national census data, together with European land cover datasets such as the CORINE Land Cover project (CORINE 2006), which allows industrial and commercial areas to be identified (see Figure 5). The final exposure model will estimate, at a given administrative level, the number of buildings, built-up area, replacement cost and occupants at different times of the day.

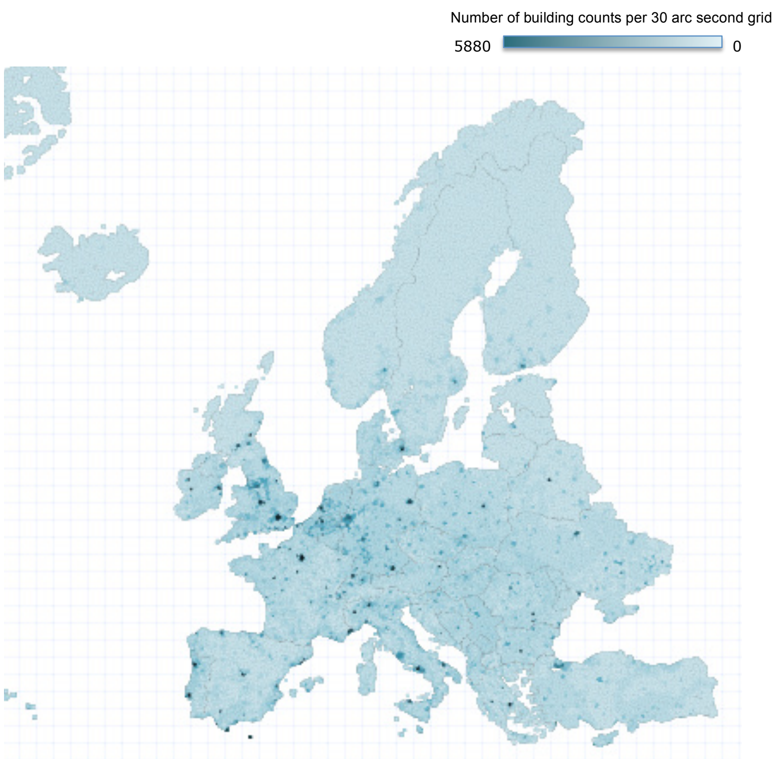


Figure 3. Number of residential buildings on a 30 arc second grid across Europe, developed within the NERA project (Ozcebe et al. 2014)

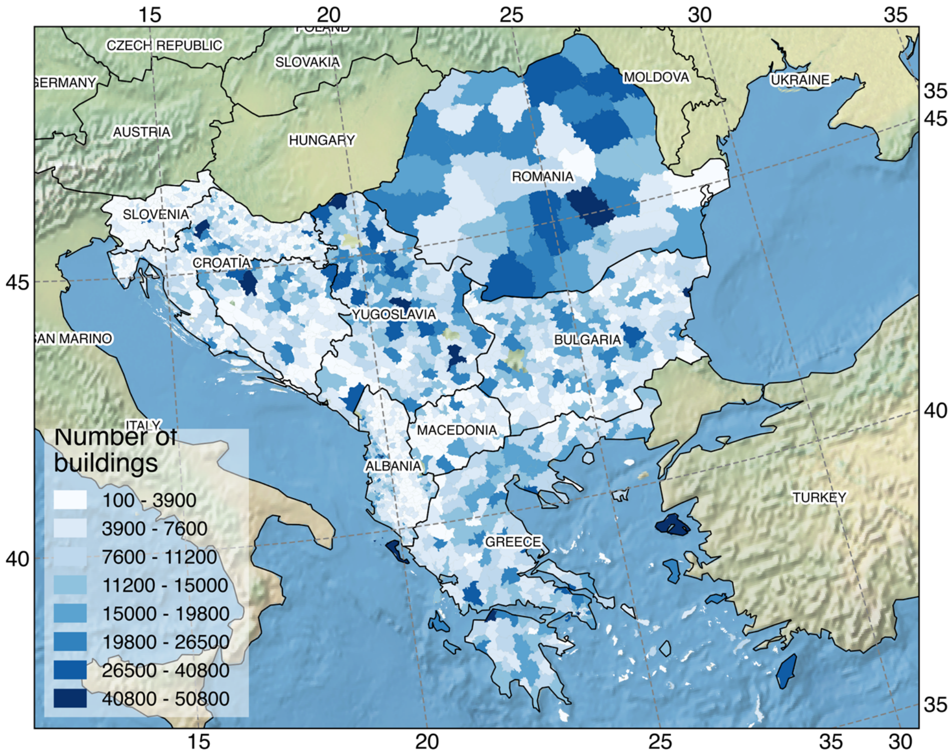


Figure 4. Number of residential buildings obtained from processing of the latest national census data for Eastern Europe

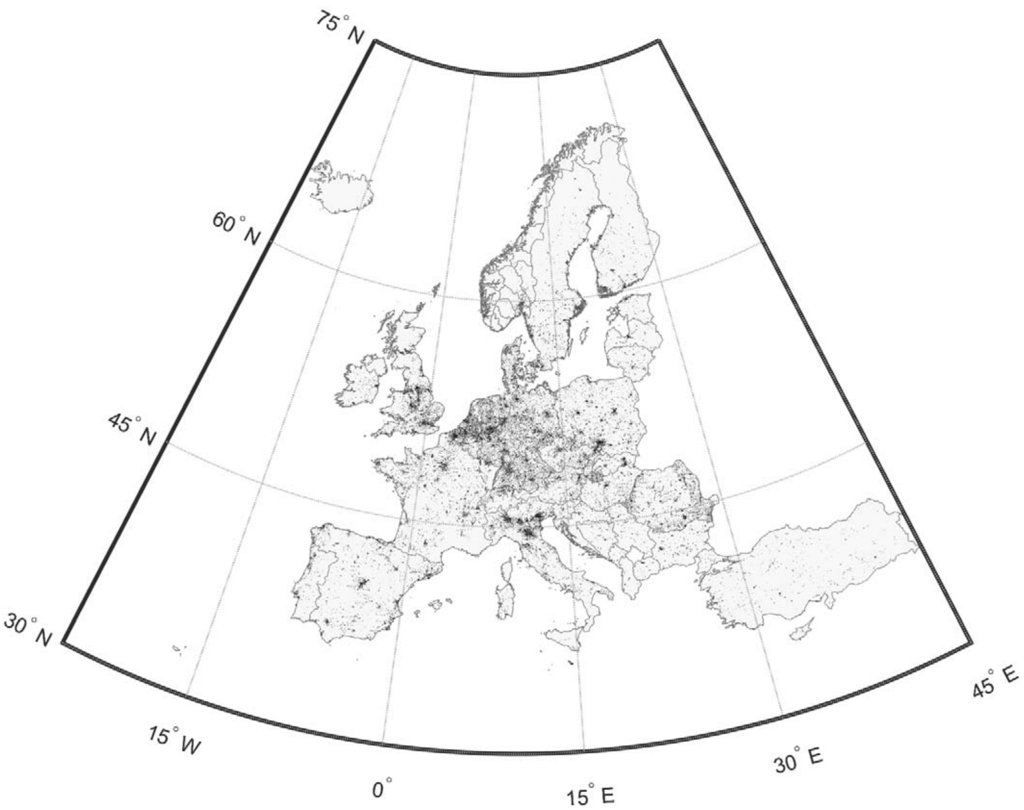


Figure 5. Georeferenced database of non-residential areas (black) provided by the CORINE Land Cover project (CORINE 2006) for 36 European countries (Sousa et al. 2017)

### *2.4 Structural Fragility/Vulnerability Data and Model*

A number of past European projects have developed and/or identified appropriate fragility and vulnerability functions for European buildings and components of critical infrastructure (e.g. RISK-UE, LESSLOSS, SYNER-G, STREST), and there is an abundance of literature on this subject. As part of the SERA project, these European functions are being collected and stored within GEM's Global Vulnerability Database (https://platform.openquake.org/vulnerability/list). By the end of the project this database will house a wide range of capacity curves, fragility functions, damage-to-loss models, and vulnerability functions for European buildings, pipelines, and storage tanks, including also in some cases the influence of soil-structure interaction. It should be noted that most of these existing functions have not been employed in probabilistic seismic risk analysis, and thus have never been validated in a practical use case. One objective of the European risk framework will also therefore be to promote a set of standard verification tests, which can be used to validate these models. Also, in connection with ongoing and past experimental tests within the SERA community, whose results will be available in an open access distributed database developed in the SERIES European project (http://www.dap.series.upatras.gr), the fragility models will be compared and enriched with test data.

Where fragility models are lacking, or the reliability/accuracy of existing ones are not sufficient, new models will be derived based on an analytical methodology that is available within GEM's Risk Modellers' Toolkit (Silva et al. 2015). This process to generate new fragility functions will involve the development of a set of representative single-degree-of-freedom (SDOF) oscillators – that are representative of MDOF buildings – for which nonlinear dynamic analyses will be run using a large number of ground motion records from the European Strong Motion Database (http://esm.mi.ingv.it/). These records are also being used in other working packages of SERA, which will ensure a certain level of consistency The response of the SDOF oscillators will be compared with a damage criterion to allocate each model in a damage state per ground motion record. The damage distribution per intensity measure level will be used to fit a cumulative lognormal function using the maximum likelihood method. These fragility models are then converted to vulnerability models through the means of damage-to-loss models, which establish the relation between loss ratio (either economic loss due to repair costs or loss of life) and a set of damage states. A similar methodology is currently being followed for the creation of a global vulnerability database for 200 building classes (Martins et al. 2017), and was recently employed in the development of a regional vulnerability model for South America (Villar et al. 2016). A workshop to review this methodology and associated models will be undertaken (see Section 3.1), to allow experts from the field of seismic fragility to evaluate the appropriateness of these models for the European risk model.

### *2.5 Socio-economic Vulnerability Data and Model*

The effects of a damaging earthquake could have a long-lasting impact on people's lives and, unfortunately, recent disasters have demonstrated that vulnerable communities (poor, children, elderly, minorities, etc.) suffer the largest burden. For example, poorer or disabled residents of earthquake-stricken areas may not have the resources or the capability to promptly evacuate following a damaging event. The pace of response and recovery depends not only on the extent of the physical damage, but also on the socio-economic conditions of the community (Burton 2015; Despotaki et al. 2017). Therefore, it is equally important, similar to the procedure of assessing the physical risk, to further measure the social exposure and vulnerability and finally evaluate the earthquake risk from a holistic point of view.

Social scientists have well documented and identified variables that can be used to represent the level of social vulnerability or resilience of a community (e.g., Cutter et al. 2010). Commonly, these variables are mathematically combined to create indices that describe the level of vulnerability of particular sectors, such as the economic sector of a region. In the European risk model, specific sets of variables will be combined to create indices (fatalities index, livelihood index and recovery index) that reflect social dimensions, and at the same time can be directly compared with the most commonly used estimates of a physical risk assessment using the OpenQuake-engine (i.e., night time casualties, average annual economic losses and average annual number of collapses). The variables that are used to populate each index (fatalities, livelihood and recovery) have been selected based on an extensive literature review and previous experience on social vulnerability, resilience and recovery (e.g. Power et al. 2015). The national population statistics of each country of interest constitute the primary source of information. Afterwards, maps can be created in order to illustrate the spatial distribution of the above indices. These indices can then be combined with the aforementioned risk estimates (as depicted in the flowchart in Figure 6) and "Impact maps" are generated, namely: Human Impact, Economic Impact and Recovery. The combination of the variables to generate the indices and the integration with the risk estimates will be performed using GEM's OpenQuake Integrated Risk Modelling Toolkit (IRMT) plugin available in QGIS, following the procedure described in https://docs.openquake.org/oq-irmt-qgis/v2.8.1/.

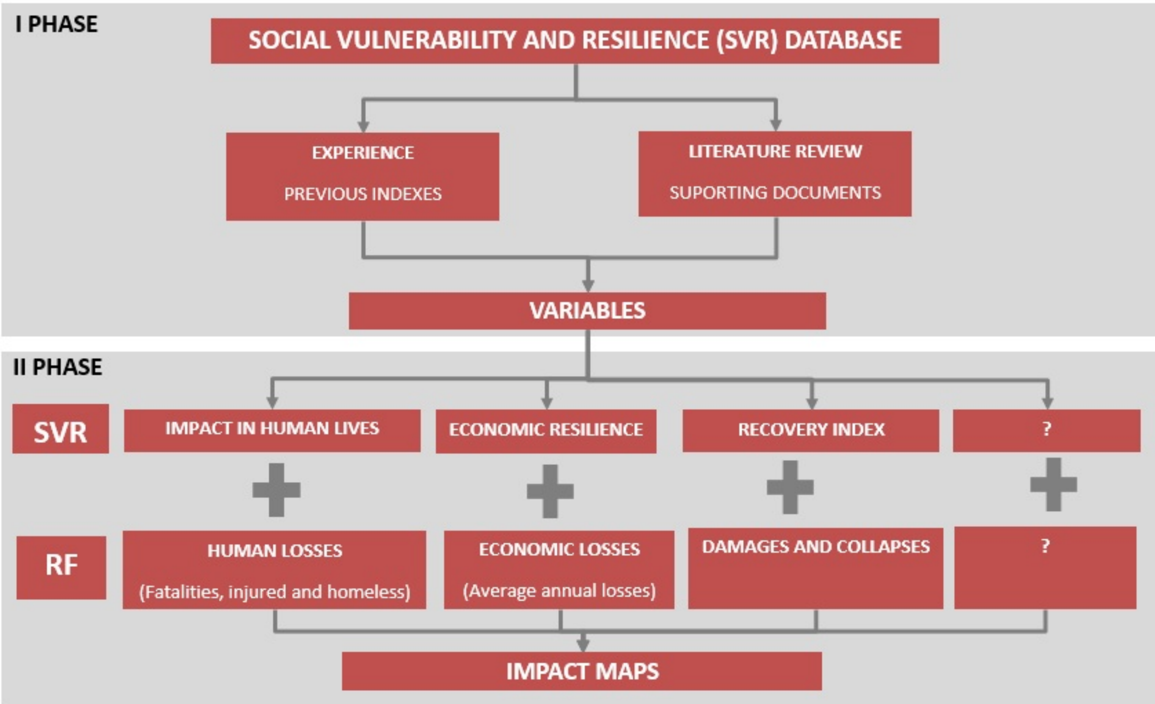


Figure 6. Flowchart of the methodology for integrated risk assessment, and the generation of impact maps

## 3. INVOLVEMENT OF THE WIDER EUROPEAN RISK COMMUNITY

The SERA European risk framework work package includes researchers from a number of European research institutions and universities in Italy, France, Portugal, Turkey, Greece and Switzerland. However, it is clear that there is a larger community of researchers working on seismic risk in Europe and so various mechanisms have been identified in order to include their contributions in the European risk model.

### *3.1 Workshops*

Three workshops will be organized during the project, with the first on European building exposure data and models having taken place in Pavia (Italy) in March 2018 (see Acknowledgements for the names of the external expert participants). A website was set up for this workshop so that all of the contributions of the participants and the outcomes of the workshop could be shared with the community: https://sites.google.com/eucentre.it/sera-exposure-workshop. The second workshop will focus on fragility/vulnerability modelling and will take place in Porto (Portugal) in September 2018. A third workshop will take place in Istanbul, Turkey towards the end of the project and will be an occasion for the community to review the process towards the development of a European risk model, and the preliminary results. A meeting with key members of the European risk community will also be taking place during the 16th European Conference in Earthquake Engineering, in Thessaloniki, Greece.

### *3.2 Webtools and Questionnaires*

The website that has been developed for the European building exposure workshop (see Section 3.1) includes two web tools that have been set up to collect information from the participants and other experts in the field of exposure modelling. The first is the Building Classification Tool (https://platform.openquake.org/building-class/) through which a detailed inventory of the most frequent structural systems (classified using the GEM Building Taxonomy) used for residential, commercial and industrial construction in different countries in Europe. The second is a questionnaire that focuses on secondary information related to buildings, such as the average areas, replacement costs and status of adherence to design codes (https://sites.google.com/eucentre.it/sera-exposure-workshop/questionnaire).

## 4. SHARING OF DATA AND MODELS

All of the data, models and results developed during the project will be assigned a Creative Commons open data license (https://creativecommons.org/licenses/) and will be shared with the community through two different platforms: GEM's OpenQuake platform (Figure 7) and EPOS's European Facilities for Earthquake Hazard and Risk platform (Figure 8). One of main objectives of sharing the data and models is to allow others to test the models, identify gaps in the data, and improve them for future seismic risk models.

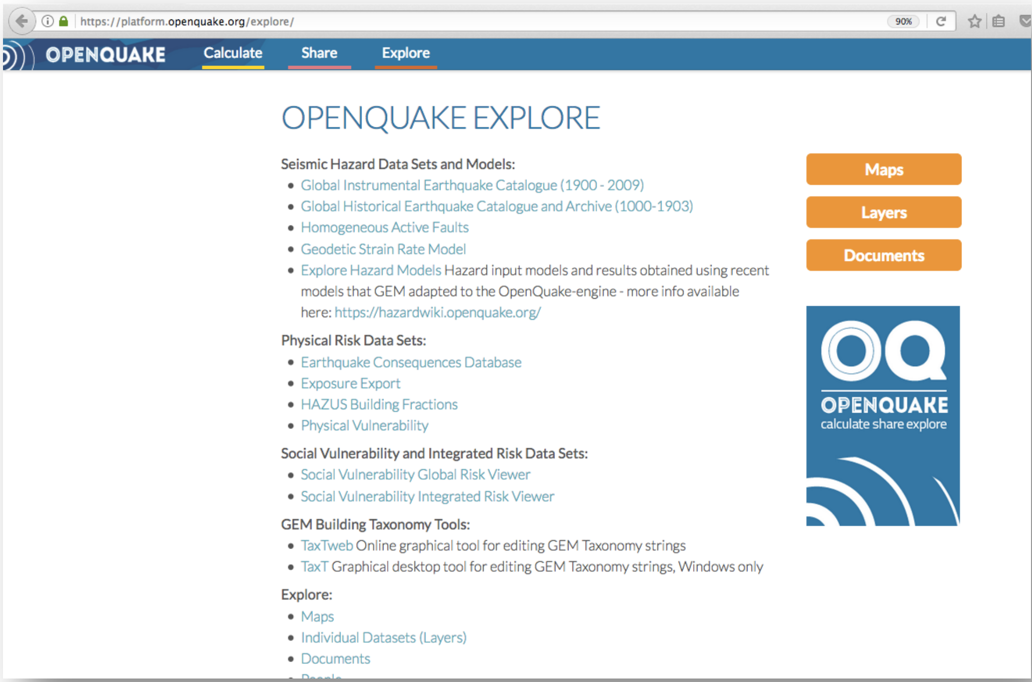


Figure 7. GEM's OpenQuake platform (https://platform.openquake.org/)

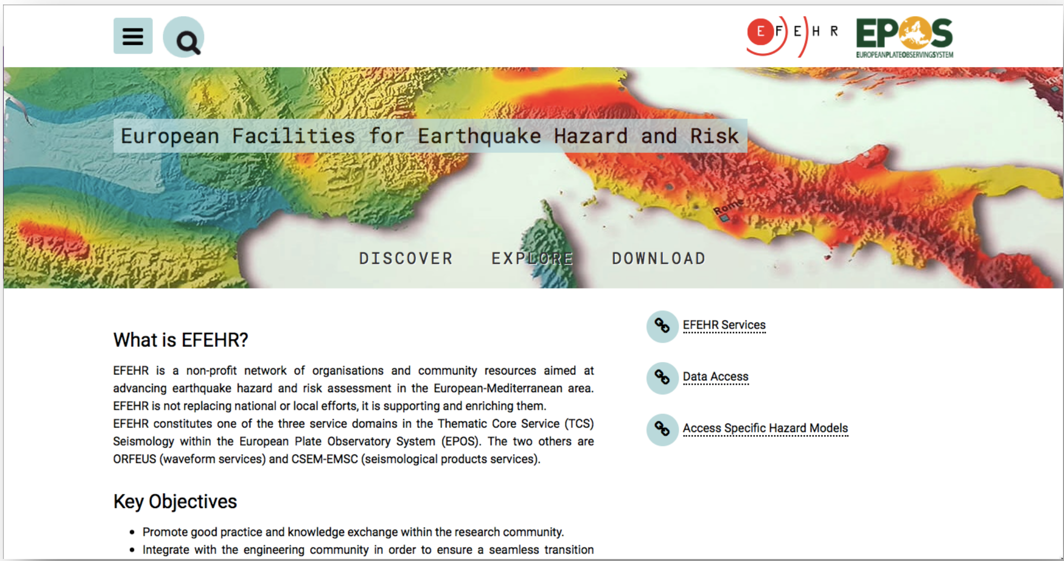


Figure 8. EPOS's European Facilities for Earthquake Hazard and Risk (http://www.efehr.org/en/home/)

## 5. CONCLUDING REMARKS

The H2020 SERA project began in 2017, and work package 26 of this project will develop a seismic risk model for Europe by 2020. This paper has described the main activities in hazard, exposure, and structural/socio-economic vulnerability that will be undertaken over the coming years to develop this model. The key objective will be to involve the European seismic risk community in producing an open and dynamic risk model, which can then be collaboratively updated and improved in the coming years.

## 6. ACKNOWLEDGEMENTS

The partners of SERA JRA4 gratefully acknowledge the contributions of all the external expert participants that attended the first workshop on European exposure data, namely: Manya Deyanova (Bulgaria), Josip Atalic (Croatia), Danai Kazantzidou (Cyrpus and Greece), Philippe Gueguen and Adrien Pothon (France), Antonios Pomonis (Greece), Bjarni Bessason (Iceland), Georgios Tsionis and Luisa Sousa (Italy/Portugal/Europe), Veronika Sendova (Macedonia), Dominik Lang (Norway), Ricardo Monteiro (Portugal), Anže Babič and Jure Žižmond (Slovenia) and Armando Aguilar Melendez (Spain).

This study is funded by the research programme "SERA"—Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No.730900.

## 7. REFERENCES

Burton C (2015). A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study. *Annals of the Association of American Geographers, 105*(1), 67-86.

Brzev S, Scawthorn C, Charleson AW, Allen L, Greene M, Jaiswal K, Silva S (2013). GEM Building Taxonomy Version 2.0. GEM Technical Report 2013-02 V1.0.0, 182 pp., GEM Foundation, Pavia, Italy, DOI: 10.13117/GEM.EXP-MOD.TR2013.02. Available from URL: https://www.globalquakemodel.org/single-post/2017/05/17/GEM-Building-Taxonomy-Version-20

Cutter S, Burton C, Emrich C (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management, 7*(1), 1-22.

CORINE (2006). *Corine Land Cover 2006 seamless vector data*. available at http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-3

Crowley H, Silva V, Correia AA, Pitilakis K (2017a). *D25.1 Engineering and risk modelling output requirements for natural and anthropogenic earthquake hazard*. SERA project deliverable, www.sera-eu.org

Crowley H, Despotaki V, Silva V, Pitilakis D, Pitilakis K, Hancilar U, Bursi O, Wenzel M, di Filippo R, Castro M, (2017b). *D26.1 Taxonomy of European residential, commercial, industrial buildings and industrial plants*. SERA project deliverable, www.sera-eu.org

Despotaki V, Sousa L, Burton C (2017). Using Resilience Indicators in the Prediction of Earthquake Recovery. *Earthquake Spectra In-Press*. doi:https://doi.org/10.1193/071316EQS107M

Despotaki V, Silva V (2018). Probabilistic seismic risk assessment in the Balkan region. Proceedings of 16th European Conference of Earthquake Engineering, Thessaloniki, Greece.

Giardini D et al (2013), Seismic Hazard Harmonization in Europe (SHARE): Online Data Resource, doi: 10.12686/SED-00000001-SHARE, 2013.

Kohranghi M, Bazzurro P, Vamvatsikos D, Spillatura A (2017). Conditional spectrum-based ground motion record selection using average spectral acceleration. *Earthquake Engineering and Structural Dynamics*, DOI: 10.1002/eqe.2876.

Lemoine A, Douglas J, Cotton F (2012). Testing the Applicability of Correlations between Topographic Slope and VS30 for Europe. Bulletin of the Seismological Society of America, 102(6), 2585-2599. doi:https://doi.org/10.1785/0120110240

Martins L, Silva V (2018). A Global Database of Fragility and Vulnerability Models for Seismic Risk Assessment, in 16th European Conference on Earthquake Engineering, Thessaloniki, Greece.

Pagani M, Monelli D, Weatherill G, Danciu L, Crowley H, Silva V, Henshaw P, Butler L, Nastasi M, Panzeri L, Simionato M, Vigano D (2014). OpenQuake Engine: An open hazard (and risk) software for the Global Earthquake Model. *Seismological Research Letters*, 85(3), 692-702.

Power C, Daniell J, Khazai B, Burton C (2015). *Social and Economic Vulnerability Global Indicator Database Handbook.* Socio-economic Vulnerability and Integrated Risk Project. CEDIM. Global Earthquake Model.

Ozcebe S, Crowley H, Baker H, Spence R, Foulser-Piggott R (2014). D7.5 Census data collection and harmonization for Europe. NERA project deliverable, www.nera-eu.org

Silva V, Crowley H, Pagani M, Monelli D, Pinho R (2013). Development of the OpenQuake engine, the global earthquake model's open-source software for seismic risk assessment. *Natural Hazards*, DOI:10.1007/s11069-013-0618-x

Silva V, Casotto C, Rao A, Villar M, Crowley H, Vamvatsikos D (2015). OpenQuake Risk Modeller's Toolkit – User Guide. Global Earthquake Model (GEM). Technical Report 2015-09. DOI: 10.13117/GEM.OPENQUAKE.MAN.RMTK.1.0/02, 97 pages.

Sousa L, Silva V, Bazzurro P (2017). Using Open-Access Data in the Development of Exposure Data Sets of Industrial Buildings for Earthquake Risk Modeling. *Earthquake Spectra* 33(1): 63-84.

Villar-Vega M, Silva V, Crowley H, Yepes C, Tarque N, Acevedo A, Hube M, Santa María H, Coronel G (2016). Development of a Fragility Model for the Residential Building Stock in South America, Earthquake Spectra, 33(2,): 581-604.

Wald DJ, Allen TI (2007). Topographic slope as a proxy for seismic site conditions and amplification. *Bulletin of the Seismological Society of America*. 97(5): 1379–1395. DOI:10.1785/0120060267

Woessner J, Danciu L, Giardini D, Crowley H, Cotton F, Grunthal G, Valensise G, Arvidsson R, Basili R, Demircioglu M, Hiemer S, Meletti C, Musson R, Rovida A, Sesetyan K, Stucchi M (2015). The 2013 European Seismic Hazard Model - Key Components and Results. *Bulletin of Earthquake Engineering*, 13(12): 3553-3596, doi:10.1007/s10518-015-9795-1.