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# DELIVERABLE

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# D25.7 ESHM20: Hazard Products for Risk Applications

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# Summary

As discussed in Deliverable D25.1 (Engineering and risk modelling output requirements for natural and anthropogenic earthquake hazard), the European Seismic Hazard Model 2020 (ESHM20) needs to provide a number of outputs for European structural engineers and risk modellers. The engineering community requirements were defined at the time by the needs arising from the ongoing revisions to Eurocode 8, whereas the risk modelling needs were identified by participants of the SERA work-package JRA4 (Risk Modelling Framework for Europe). This initial deliverable was used to guide the work of JRA3, whereas now that the ESHM20 is close to being finalised, this deliverable summarises the final set of outputs that will be made available with the official release of ESHM20.

# 1 Hazard Products for Earthquake Engineers

Following the workshop that took place in EUCENTRE (Pavia, Italy) on Monday 14th October 2019, an agreement on the products that SERA JRA3 would produce for CEN/TC250/SC8 was made and documented in Deliverable D2.14 (Stakeholders workshop M30). In summary, it was agreed that the two main products that will be produced (and that would be subject to a final vote by the national delegates of EC8 on whether to include them as an informative annex of Eurocode 8, Part 1) are as follows:

- European map of the median elastic spectral acceleration of the plateau[1]* of the response spectrum on reference rock with a Vs30 of 800 m/s.
- European map of the median elastic spectral acceleration at 1 second on reference rock with a Vs30 of 800 m/s.

However, in addition to the above two main products, a number of other results will be released on the EFEHR (European Facilities for Earthquake Hazard and Risk) platform (www.efehr.org/hazard-data-access):

- European maps of the median elastic spectral acceleration of the response spectrum on reference rock with a Vs30 of 800 m/s for the following periods of vibration: 0.01, 0.1, 0.15, 0.2, 0.25, 0.3, 0.5, 0.75, 1, 2, 3, 4 (s)
- Hazard curves across Europe on reference rock with a Vs30 of 800 m/s for the following periods of vibration: 0.01, 0.1, 0.15, 0.2, 0.25, 0.3, 0.5, 0.75, 1, 2, 3, 4 (s)
- UHS across Europe on reference rock with a Vs30 of 800 m/s for the following return periods: 73, 102, 475, 975, 2475, 4975 (years)
- Disaggregation at a number of sites across Europe for each spectral ordinate and return period described above.

# 2 Hazard Products for Risk Modellers

Unlike the CEN/TC250/SC8 that requires specific predefined outputs of the ESHM20 as described in the previous section, the European Seismic Risk Model 2020 (ESRM20) requires the input models to the hazard calculations, as well as intermediate results such as stochastic event sets, and additional functionalities of the software, such as spatial and cross correlation models, and functionality for various intensity measures.

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[1] The definition of the plateau of the spectrum is being provided by a working group of CEN/TC250/SC8.

The following input models will be made available for the European Seismic Risk Model 2020 (ESRM20):

- ESHM20 source model logic tree (see Deliverable D25.3)
- ESHM20 ground-motion prediction equation (GMPE) logic tree (see Deliverable D25.4)
- European site model (with definition of slope, geology and Vs30 at each site in the European risk model) (see Deliverable D26.4)

The framework for calculating seismic risk at the European scale is discussed in Deliverable D26.7. A number of samples of the source model and GMPE logic trees branches are first made to reduce the computational intensity of the risk calculations. The sampled source model logic tree is used to calculate, using the OpenQuake-engine (Silva et al., 2014; Pagani et al., 2014), an earthquake rupture forecast (which is a list of all potential ruptures and annual probabilities of occurrence) from which a large number (at least 10k) stochastic event sets (SES), each of one year, are randomly sampled (see Figure 1). Ground motion fields are then produced for each event in the SES using one or multiple ground motion prediction equation(s) and amplified to the surface using the geology/topography-based site model. These ground motion fields are combined with the European vulnerability and exposure models to calculate the losses for each event to produce event loss tables from which loss exceedance curves, average annual losses, probable maximum losses and other statistics are derived.

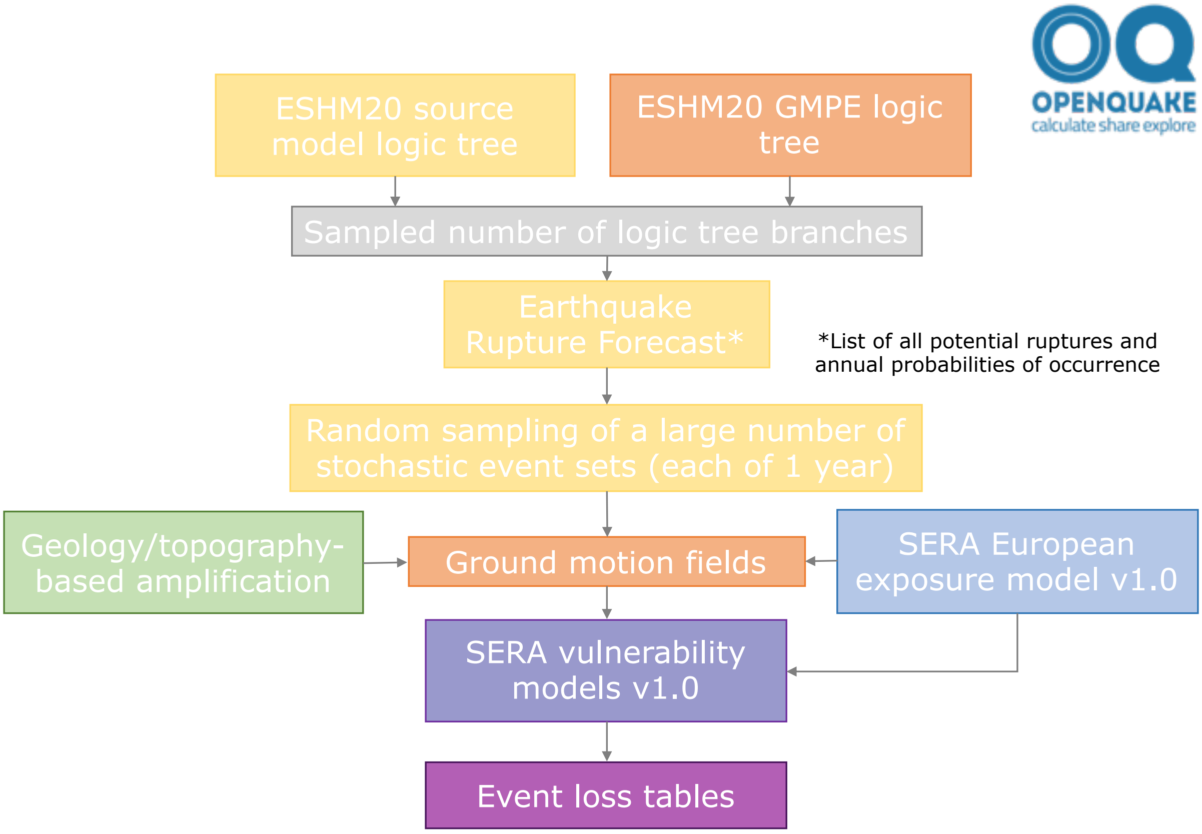

Figure 1: Workflow for European Seismic Risk Model 2020 (ESRM20) calculations

The intensity measure (IM) being used for the ESRM20 is average spectral acceleration, AvgSa, defined as the geometric mean of the spectral ordinates over a range of periods of vibration (Bianchini et al. 2009). In order to use this IM, the functionality to calculate AvgSa using existing ground motion models for a user-defined range of periods considering inter-period correlation has been added to the OpenQuake-engine, which is discussed in further detail in Section 2.2.

Readers are referred to Deliverables D25.3 and D25.4 for a full description of the source model logic tree and ground motion logic tree. Instead, some examples of the products generated with these models and used in the risk calculations are provided in the following sections.

## 2.1 Stochastic event sets

As described above, the risk calculations use stochastic event sets that are sampled from the earthquake rupture forecast that is calculated using the source model logic tree and the OpenQuake-engine. Figure 2 shows an example of the 10,000 SES that have been sampled for a risk assessment in Greece.

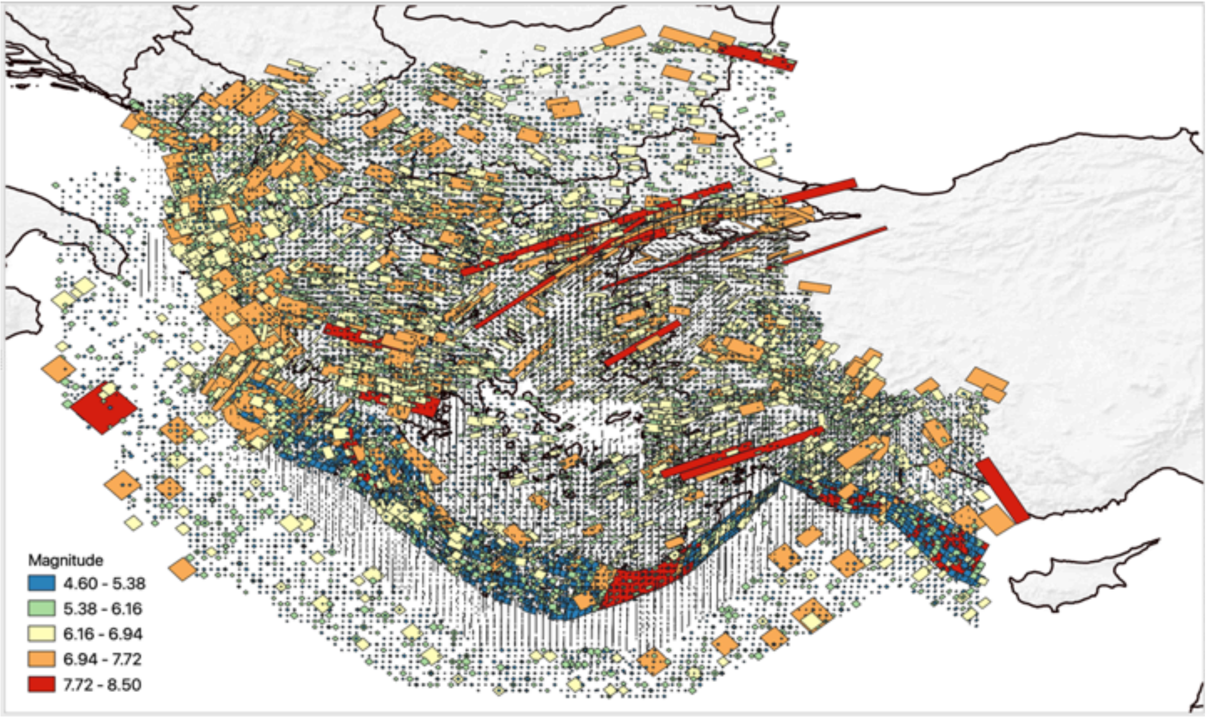

Figure 2: Stochastic event sets (10,000) considered for the risk assessment in Greece

The earthquake rupture forecast, from which the stochastic event sets are sampled, is available as a .csv from the OpenQuake-engine and has the following output fields:

**rup_id**: a unique id given to the rupture

**multiplicity**: the number of times this rupture is sampled from the ERF

**mag**: moment magnitude of the rupture

**centroid_lon**: centroid of the rupture, longitude coordinate in decimal degrees

**centroid_lat**: centroid of the rupture, latitude coordinate in decimal degrees

**centroid_depth**: depth in km

**trt**: tectonic region

**strike**: of the rupture in degrees

**dip**: of the rupture in degrees

**rake**: of the rupture in degrees

**boundary**: geographical description of the rupture boundary using Well-Known Text (WKT) format

The final event loss table includes the rupture ids that are sampled from this earthquake rupture forecast to produce the SES. Modifications to the rupture output are currently being undertaken to also include the date and time of the event.

## 2.2 Ground motion fields for AvgSa with spatial correlation

Ground motions are calculated for each event in the stochastic event set using the sampled branch of the ground motion logic tree. The OpenQuake-engine can now calculate AvgSa for a user-defined set of periods of vibrations using any ground motion model. AvgSa is defined as the geometric mean of spectra acceleration (Sa) across a range of n periods, T:

$$\ln AvgSa(T) = \frac{1}{n}\sum_{i=1}^{n} \ln Sa(T_i)$$

In many cases the range of periods is defined such that the $AvgSa(T_0)$ is the geometric mean between $a \cdot T_0$ and $b \cdot T_0$, with $a$ commonly taken as 0.2 and $b$ in the range 1.5 to 3.0. For the prediction of $AvgSa(T_0)$ the *indirect* calculation approach is adopted (Kohrangi et al., 2018) in which the expectation ($\mu_{\ln AvgSa|T,m,r}$) and variance ($\sigma_{\ln AvgSa|T,m,r}$) are determined from the median and variance of existing ground motion models (as opposed to adopting a ground motion model specifically for $AvgSa(T)$, otherwise known as the *direct* approach), such that:

$$\mu_{\ln AvgSa(T)|m,r} = \frac{1}{n} \cdot \sum_{i=1}^{n} \mu_{\ln Sa(T_i)|m,r}$$

$$\sigma_{\ln AvgSa(T)|m,r} = \left(\frac{1}{n}\right)^2 \cdot \sum_{i=1}^{n}\sum_{j=1}^{n} \rho_{\ln Sa(T_i), \ln Sa(T_j)} \cdot \sigma_{\ln Sa(T_i)|m,r} \cdot \sigma_{\ln Sa(T_j)|m,r}$$

Where $\mu_{\ln Sa(T)|m,r}$ and $\sigma_{\ln Sa(T)|m,r}$ are the median and variance of the spectral acceleration at period T as given by the ground motion model, and $\rho_{\ln Sa(T_i), \ln Sa(T_j)}$ the cross-correlation coefficient between the logarithm of the acceleration at spectral periods $T_i$ and $T_j$ respectively. The indirect approach is preferred for this purpose in favour of the direct approach, owing to the diversity of ground motion models and tectonic region types considered within the ESHM20. Whilst some ground motion models do exist for $AvgSa(T)$ (e.g. Kohrangi et al., 2018), these are limited exclusively to regions of shallow crustal seismicity and not necessarily explicitly transferable to other regions such as stable craton or subduction environments, where regional variability in terms of the source spectrum and travel path are expected to alter the characteristics of the response spectrum at short periods. The adoption of the *indirect* approach, however, does require the selection of a spectral cross-correlation model. For the current purposes the model of Akkar et al., (2014) is selected. Ideally, each ground motion model should be adopted with its corresponding cross-correlation matrix; however, a comparison of several published general cross-correlation models has found the estimates of $AvgSa(T)$ to be largely insensitive to the choice of cross-correlation model.

The introduction of the indirect $AvgSa(T)$ functionality into the OpenQuake-engine permits its usage both for classical PSHA and for the generation of ground motion fields that are integral to the event-based risk approach. At the time of completion of the ESHM20 and ESRM20, the capability to generate spatially correlated fields of $AvgSa(T)$, in the same manner as is possible for $Sa(T)$, was not yet available. A prototype is currently under development following the methodology proposed by Stafford (P. Stafford, personal communication, 4th December 2019), and it is hoped that this enhancement will become available for subsequent applications. An example ground motion field for PGA with spatial correlation, estimated with the OpenQuake-engine, is shown in Figure 3.

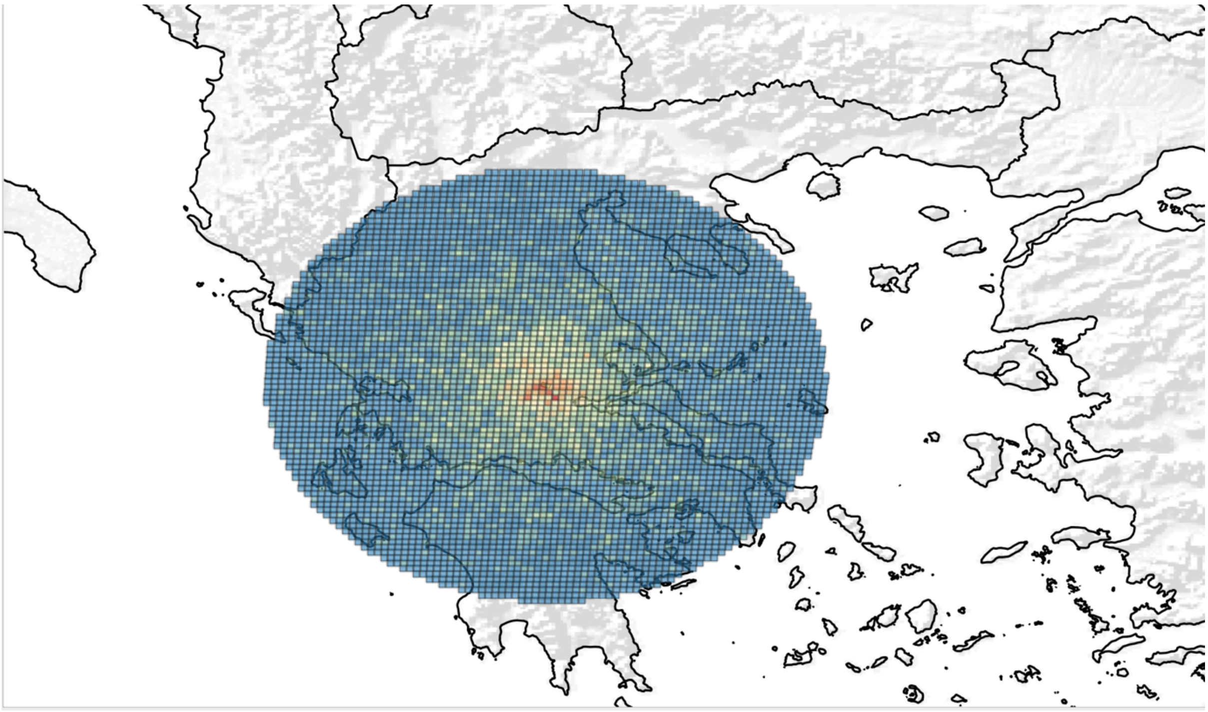

Figure 3: Example ground motion field for PGA with spatial correlation for one of the events in the SES

## 2.3 Adaptable Site Models for Different Exposure Resolutions

The development of the European site amplification model for application to the ESHM20 is based on a new approach that calibrates the specific site amplification factors for a location according to the local slope and geological condition at the site, as detailed in SERA Deliverable 26.4. This approach is not only compatible with the proposed ground motion model logic tree (SERA Deliverable 25.4), it also adjusts the ground motion uncertainty appropriately to take into account the simple but generalisable parameterisation of the ground motion needed for comprehensive pan-European application. The European site amplification model provides a means of characterising the site condition in ground motion for every location on a 30 arc-second grid across Europe. In the seismic risk calculations, however, the exposure model may be defined in terms of: i) a regularly spaced grid, ii) a set of political administrative districts, or iii) a set of individual locations. Options i) and ii) are commonly encountered for residential and commercial exposure, whilst iii) may be encountered in the case of industrial exposure. As the resolution of the exposure model may differ and is, in the majority of cases, based on a coarser spatial resolution than that at which the site model is defined, there emerges the issue of how to define an appropriate site property/properties for the location(s) at which the ground motion is input for the seismic risk.

In previous applications, the site property has been taken from that reported at the centroid of the cell or polygon for which the exposure is defined. Depending on the resolution at which the exposure is aggregated, however, the properties at the location of the geographical centroid (or any particular location within the cell/polygon) may not necessarily be the most representative of the sites in the polygon, nor the most relevant for the risk application. An illustrative example of a potential misclassification might be that of a town/village in an upland valley, with the majority of the actual buildings exposed are likely to be found on the flat valley floor, characterised by low slope and predominantly Quaternary alluvial geology, rather than on the steeper hillside. If the geographical centroid or simply the mid-point of a regular cell is used then the site property taken for application to the cell may be that of the hillside rather than the valley bottom, which is less representative of the site condition affecting the exposure and likely associated to lower site amplification factors.

To attempt to improve on current practices, and to ensure that the site model inputs for the OpenQuake-engine can be built in a manner that is most appropriate to the exposure model and to the type of calculation the user wishes to run, a specific site model builder tool has been developed. This site model builder tool is an open source Python module, which can be run from the command line or called as a Python module in environments such as a Jupyter Notebook. The tool (*exposure_to_site.py*) allows the user to configure the type of exposure model they wish to generate, from either a grid (defined by a bounding box and a resolution, a set of administrative regions (as a shapefile) or a set of site locations or a set of point locations. Where the exposure is intended to represent an aggregated property over a geographical region (i.e. for the grid and polygon options) the user can define the site property as an average across the region. The average can, however, be weighted by the distribution of urban density using the high resolution Global Human Settlement (GHS) layer (https://ghsl.jrc.ec.europa.eu/data.php, Corbane et al. 2018). The use of the GHS layer to develop exposure models is demonstrated in Dabbeek and Silva (2019). The addition of the weighting means that the site properties for a given cell or polygon may be skewed toward those affecting the highest density of buildings/population, rather than the geometric centres of the regions. Once the site properties have been defined and the site model constructed, the *exposure_to_site.py* tool can export the output to both the site model formats supported by the OpenQuake-engine (i.e. xml and csv) or to a shapefile for visualisation in GIS platforms.

The sensitivity of the seismic risk calculations to the different site model configurations is currently being explored and preliminary results are included in Deliverable D26.8. The tool itself will be released publicly via the EFEHR GitLab (see below) at the end of the project.

# 3 Next Steps

Once the ESHM20 is finalised, all of the pre-computed products described herein will be made available through the EFEHR hazard platform (http://www.efehr.org/en/hazard-data-access/Intro/). A GitLab repository has also been set up that will store all of the OpenQuake-engine input files, intermediate products and tools used in the risk calculations of ESRM20 (https://gitlab.seismo.ethz.ch/efehr/).

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