Deliverable

D8.4 Report on the Description of Standards for Dynamic Risk Services

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Summary

This deliverable summarizes the data formats and standards adopted by the main services and data products developed within RISE Project. Standardized procedures and reporting practices ensure consistency and transparency, which is essential for risk assessment and management.

Access to real-time or near real-time dynamic risk services can provide crucial information for efficient assessment of earthquake-related risks. These services offer main datasets, inputs, and results, which can aid in making timely and effective decisions in the event of an earthquake. The use of data exchange standards enables rapid analysis and communication of results, as well as providing access to critical information. Earthquake-related services can vary from seismology monitoring to structural monitoring and seismic risk assessment, all of which can benefit greatly from the availability of real-time data and dynamic risk services.

Overall, standardization and data exchange protocols will be critical components for the wide-spread adoption and use of dynamic risk services. We can enable the development of innovative and useful applications that benefit a wide range of stakeholders by defining and implementing these standards.

1. Introduction

Dynamic and operational earthquake risk services are essential for assessing and mitigating earthquake risks as data, models and computing resources increase. At the same time, web-based earthquake risk platforms such as the web-platform of the European Facilities of the Earthquake Hazard and Risk (www.efehr.org) and their service standards are valuable tools for the community. The web-platform of European Mediterranean Seismological Centre (EMSC) provides real-time earthquake data, products, and services to scientists, civil protection authorities, and the public. Furthermore, ORFEUS (Observatories & Research Facilities for European Seismology) promotes and coordinates European-Mediterranean monitoring and distribution of earthquake recordings. EIDA (European Integrated Data Archive infrastructure) is part of ORFEUS and provides seismic waveform data from European archives for research and development. EFEHR, EMSC and ORFEUS are forming the Seismology Thematic Core Services EPOS, and actively contribute with data, data products and services to its platform.

Standardization is crucial. Comparisons between models and tools are difficult without data standards and or standardized web-services. Standardized procedures and reporting practices ensure consistency and transparency, which is essential for research and development, for decision makers but also for the general public.

QuakeML, ShakeMap, and NRML (Natural Risk Markup Language) are classified here as dynamic earthquake related standards. These standards describe data collection, models, computational aspects, outputs and reporting.

QuakeML is an XML (Extensible Markup Language) format developed and maintained by ETH Zurich, and it was designed to standardize the exchange of seismological data. QuakeML has a modular design (Schorlemmer et al. 2004). In June 2011, the International Federation of Digital Seismograph Networks (www.fdsn.org) adopted QuakeML as the standard for earthquake event description. A general schema specifies the root elements, with children defined in distinct packages, each with its own theme. The package provides a basic explanation of seismic event data and explains how to unequivocally identify resources. It contains information about the source, the source's uncertainty, the picks, amplitudes, magnitudes, and focal mechanisms. Standard seismic inventory and resource metadata documents must be added to the so-called Basic Event Description (BED) package. QuakeML BED describes the properties of seismic events hierarchically, using a posteriori knowledge of the relationships between elements (such as the association of origins with events). This information may not be available when dealing with real-time processing of seismic data. Consequently, an alternative version of BED (BED-RT) with flatter hierarchies has been developed in the recent version of QuakeML (v2, https://quake.ethz.ch/quakeml/Recent-Changes).

ShakeMap®, a product of the U.S. Geological Survey (USGS), facilitates the dissemination of earthquake information beyond magnitude and location. ShakeMap (Worden et al 2020) illustrates the distribution and severity of shaking by rapidly mapping earthquake ground motions.

ShakeMap is primarily designed as a geographic product, providing a visual representation of the potentially intricate shaking patterns associated with an earthquake. Given the complex nature of these events, a variety of maps are generated, each tailored to specific uses or audiences. Thus, ShakeMap products is a collection of various input and output formats including: binary files (HDF5, containing the input parameters and data, metadata and the output spatial grids); text file containing parameters for processing and constraints, input data, output parameters, timestamps, and versioning; GeoJSON station file that contains seismic stations, observations, predictions, and parameters that have been converted (e.g., intensity to acceleration); static maps and diagrams (JPEG and PDF images); GeoJSON representation (if any) of the finite rupture geometry; XML grid of ground motion and their uncertainty; GIS Shapefiles and ESRI Raster Grid Files compressed in a zip file; Google Earth KMZ file containing multiple ground-motion layers, station data, and additional parameters; and finally contour files in GeoJSON format. A comprehensive description of these formats is available online: https://usgs.github.io/shakemap/manual4_0/ug_products.html#sec-products-4.

NRML is a data interchange format, developed and maintained by Global Earthquake Model Foundation. This format makes use of existing standards such as the Geography Markup Language (GML) and QuakeML, which is a seismology data model. The OpenQuake hazard and risk engine primarily uses NRML as an input and output format. Seismic source parameters and rupture geometries, as well as hazard curves and ground motion fields, are addressed in the seismic hazard module. Loss and ratio loss curves, exposure portfolios, and vulnerability curves are included in the seismic risk module. The format is documented and available online at https://docs.openquake.org/oq-engine/1.2/schema.html#documentation.

Web-based platforms such as the hazard and risk services of EFEHR have defined standards too. *OpenCMS* is one web content management system that is currently in use for various applications. This system provides templates and tools to format and style content consistently, improving the usability and accessibility of web-based services depicting the earthquake related services, as implemented for various web-applications in RISE project (i.e., web-platform to distribute the seismic hazard models).

Furthermore, having lightweight, scalable and maintainable webservices built on HTTP (Hypertext Transfer Protocol) standards and following REST (Representational State Transfer) design conventions as well as adopting OGC standards helps create discoverable, interoperable, and reusable web services. OGC (Open Geospatial Consortium), WMS (Web Map Service) and WFS(Web Feature Service), standards for geospatial data access and sharing, provide a standard interface.

Earthquake risk services should meet these standards when possible. "Simple" ad-hoc solutions can be used when standardized services are unavailable. RESTful web services are described in machine-readable WADL (Web Application Description Language) or Open-API (Application Programming Interfaces). WADL and OpenAPI generate client code and document RESTful web services. HTML extraction can create human-readable RESTful web service documentation.

However, several limitations have to be listed here mainly due to few factors, the goal of a uniform standard from seismic network to the building instrumentation was partially fulfilled. First, the Internet of Things (IoT) has not advanced far enough to allow for the creation of a customized standard for dynamic risk management services. IoT is still in its infancy and rapidly evolving, making the development of a stable and comprehensive standard difficult. Secondly, the some of the sensors used for structural monitoring have embedded data formats thus difficult to be modified. We can ensure that different systems communicate effectively by adhering to existing standards, resulting in greater interoperability and seamless integration of different devices and services.

To summarize, developing a customized standard for Internet of Things may not be the suitable approach, and we should instead focus on adhering to existing standards and protocols.

Here are some of the most frequently used data formats by most of the dynamic risk services that are operational at the European level, as defined in the RISE Project:

JSON (JavaScript Object Notation) is a lightweight data format that humans and machines can read and write with ease. It is frequently employed for data storage and exchange in web applications and IoT devices. JSON can be used to store sensor data including temperature, humidity, and motion as well as SHM data including vibration measurements and strain gauges.

CSV (Comma Separated Values) is a common format for storing and exchanging tabular data, such as sensor time series data. Spreadsheet applications, such as Microsoft Excel and Google Sheets, can easily open and analyze CSV files.

ESRI Shape Files: a common geospatial vector data format for storing geographic features, boundaries, and landmarks. A set of shapefiles describes and represents a location's geographic features. These files include a feature geometry file and indexing and metadata files. Shapefiles can be used with many GIS programs and shared easily

XML (Extensible Markup Language) is a data format commonly used to exchange data between various systems and applications. XML is highly configurable and can be used to store a variety of data types, such as sensor data and SHM data. Here we have the QuakeML, ShakMaps, NRML.

SQL databases: MySQL, PostgreSQL, and Microsoft SQL Server are frequently used to store and query sensor data and SHM data. SQL databases offer a dependable and scalable method for storing large amounts of data, and they can be easily integrated with other systems and applications.

Binary formats: Binary formats, such as HDF5 and NetCDF, are frequently used for compact and efficient storage of large amounts of sensor data and SHM data. These formats can be read and processed with ease using specialized software libraries, and they can be integrated with other data analysis tools and platforms.

In the next section, we will discuss the existing data formats and data standards as used to describe the data, data products and services for the operational hazard and risk services as part of the RISE project.

2. European Seismic Hazard and Risk Services

The web-platform of the EFEHR Consortium (European Facilities for Earthquake Hazard and Risk) is a major web-platform and infrastructure, providing data, products and services to scientists, engineers, stakeholders, decision-makers, and the general public. It complements the other European major earthquake related web-platforms and infrastructures such as EMSC and ORFEUS.

The web-platform recently updated the European Seismic Hazard Model (Danciu et al. 2021). This updated model provides information and access to the recent seismic hazard in Europe. Furthermore, the EFEHR Consortium's web-platform also hosts the first openly available earthquake risk model for Europe (Crowley et al. in 2021). The two EFEHR's web-platforms are hazard.efehr.org and risk.efehr.org. Additionally, a GitLab repository (https://gitlab.seismo.ethz.ch/efehr) provides access to various datasets of the two models.

It is important to note that the availability of these two models on the web-platform, from input datasets to results, is a significant milestone for the RISE Project, as many of these components have been updated and/or directly used in the research and development of the dynamic risk products in RISE Project. Consequently, it will contribute to the effective and sustainable management of seismic risk in Europe.

2.1 European Seismic Hazard Services

The portal is comprised of web-services that connect to the principal hazard outputs (i.e., seismic hazard maps, seismic hazard curves and uniform hazard spectra). The EFEHR web-portal provides a centralized location for accessing data, models, and results. There is no authorization requirement. The EFEHR web-portal provides the following seismic hazard models:

- The Global Hazard Map for 1999 produced by the Global Seismic Hazard Assessment Program (GSHAP, Giardini 1999)
- The 2013 European Seismic Hazard Model (ESHM13, Wossner et al., 2015);
- The Middle East Earthquake Model for 2014 (EMME14, Giardini 2018)
- The Swiss Hazard Model for 2015 (SuiHaz15, Wiemer et al 2015)
- The European Seismic Hazard Model for 2020 (ESHM20, Danciu et al 2021)

All datasets are provided by standardized data formats: Natural hazards' Risk Markup Language (NRML), OGC Web Map Services (WMS) response, geospatial vector shape file, open standard to represent seismological data (QuakeML, https://quake.ethz.ch/quakeml/) and tabular ASCII data. Also provided are the OpenQuake (Pagani et al 2014) input files required to reproduce the hazard calculation.

The EFEHR hazard web-portal consists of several components summarized hereinafter. The key components are:

- Database server – with Postgresql 9.3 (https://www.postgresql.org), postgis extensions and daily backup
- Java/Tomcat/OpenCMS (http://www.opencms.org/en/development/installation/server.html) based web content management system
- Standalone interactive data viewers in html/javascript libraries (Ext Js, GeoExt, OpenLayers – see http://presentations.opengeo.org/2012_javascript/javascript/concepts.html)
- Map server (https://live.osgeo.org/archive/6.5/it/overview/mapserver_overview.html) implementing the OGC web map service standard.
- A HTTP based web service implemented in Java (https://docs.oracle.com/javaee/6/tutorial/doc/gijqy.html)

2.2 European Seismic Risk Services

The first openly available data on earthquake risk for Europe is distributed via the risk web-platform risk.efehr.org, hosted at Eucentre, Pavia, Italy. The main input datasets use the Natural hazards' Risk Markup Language (NRML) and OGC Web Map Services (WMS), geospatial vector shape file and tabular ASCII data). European risk calculations use OpenQuake-engine and can directly use NRML hazard input models. NRML-formatted exposure, fragility, and vulnerability models are risk input models (as well as csv).

WMS and WFS web services will provide exposure data for a region of interest. GeoNetwork, OCG-CSW, and/or OAI-PMH are being investigated to expose the vulnerability database, which can include documentation. GeoNetwork is an open-source geospatial metadata catalog that allows users to search, discover, and share geospatial metadata. OGC-CSW (Catalog Service for the Web) is an OGC standard for publishing and discovering geospatial data, services, and applications' metadata. It specifies a protocol for retrieving metadata from distributed catalogs via querying; whereas OAI-PMH (Open Archives Initiative Protocol for Metadata Harvesting) is a protocol used to harvest metadata from digital repositories. It enables the discovery of metadata pertaining to geospatial data, services, and applications from dispersed repositories.

3. European Rapid Loss Assessment (RLA) System

In the context of Rapid Loss Assessment, several standards are proposed to ensure interoperability and consistency in data sharing and analysis.

The FDSN (Federation of Digital Seismograph Networks) standard, for example, defines a set of web services for accessing and sharing earthquake data, including seismic waveforms and station metadata.

Another standard is the EIDA (European Integrated Data Archive) standard, which provides standardized and open access to seismic waveform data in European archives. EIDA is a member of the ORFEUS (Observatories and Research Facilities for European Seismology) foundation, which coordinates and promotes digital, broadband seismology in the European-Mediterranean region.

There are also standards for earthquake early warning systems, such as the ShakeAlert system in the United States, which provides real-time notifications of earthquake shaking intensity to people and automated systems, allowing for timely response and mitigation.

3.1 European ShakeMap System

The European ShakeMap service prototype had also been developed by ETH Zurich and the National Institute for Geophysics and Volcanology in Italy, leveraging the most recent version of ShakeMap (v4), Worden et al 2020 and adopting ShakeMap (v4) web portal development. Using web services developed by EMSC and ORFEUS, the service automatically registers earthquakes in Europe with a magnitude greater than 3.50 and receives any recorded strong motion data.

The European ShakeMap system is fully compatible with the data and modelling protocols used by the national services for Italy, Greece, and Switzerland (and could therefore serve as a backup for these national installations), and there are plans to extend this standardisation to other European countries.

The European ShakeMap input and output files are described by the online documentation of the ShakeMap (http://www.seismo.ethz.ch/static/shakemap/shake/KP201202280901/about_formats.html). In summary, the following input files are required: stationlist.xml, *_fault.txt files, grid.xml, and info.xml, which contain seismic station data, intensity data, the Vs30 grid, the fault file format, configuration, and processing parameters. The file stationlist.xml contains earthquake source specifications and input data from all of the original processing centre's input files. Fault files are named <something> fault.txt and are listed in info.xml. ShakeMap's input directory may contain zero or more fault files.

The European ShakeMap output files and products include runtime information, metadata, static maps and plots such as macroseismic intensity, peak ground acceleration, velocity, and pseudo-spectral acceleration, uncertainty maps, regression plots, station lists, interactive maps, and grids of interpolated ground shaking such as an XML grid of ground motions, an XML grid of ground motions on "rock", an XML grid of ground-motion uncertainty, and a grid (deprecated). In addition, standard formats like contour files and Shapefiles, ESRI Raster Grid Files, Google Earth KML files, and ESRI Raster Grid Files are available.

3.2 European Vulnerability and Exposure

Within the framework of the Horizon 2020's SERA and RISE projects, the first Euro-Mediterranean exposure and vulnerability models, were developed. These models are now openly available to the community and public via risk services of EFEHR (European Facilities for Earthquake Hazard and Risk: http://risk.efehr.org, Haslinger et al 2022).

The exposure models used in 2020 European Seismic Risk Model (ESRM20, Crowley et al, 2021) have now been disaggregated to a 30 arcsecond grid using WorldPop[1], using openly available tools developed in the RISE project in collaboration with the GEM Foundation[2] (Dabbeek et al., 2021).

The exposure and the vulnerability models have been distributed via the EFEHR's gitlab repository: https://gitlab.seismo.ethz.ch/efehr. Additionally, the vulnerability models updated to include injuries for four different severity levels (as defined in HAZUS – FEMA, 2003, and given in Deliverable D6.1) are now included in the European vulnerability repository: https://gitlab.seismo.ethz.ch/efehr/esrm20_vulnerability.

Fig. 1 Example of the XML – formal depicting the input file for structural exposure model for Albania

[1] https://www.worldpop.org/

[2] https://github.com/GEMScienceTools/spatial-disaggregation

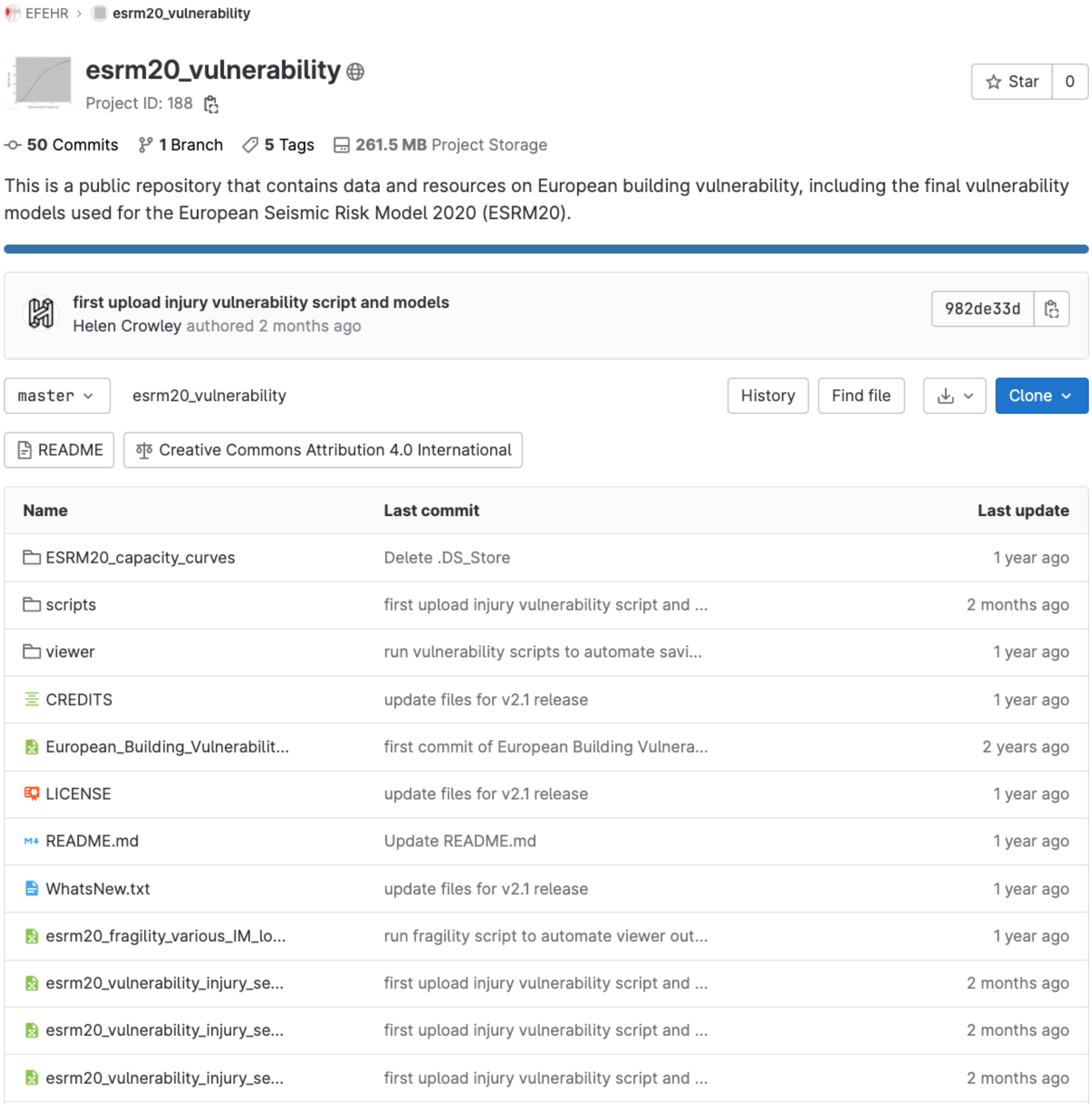

Fig. 2 Example of the vulnerability repository

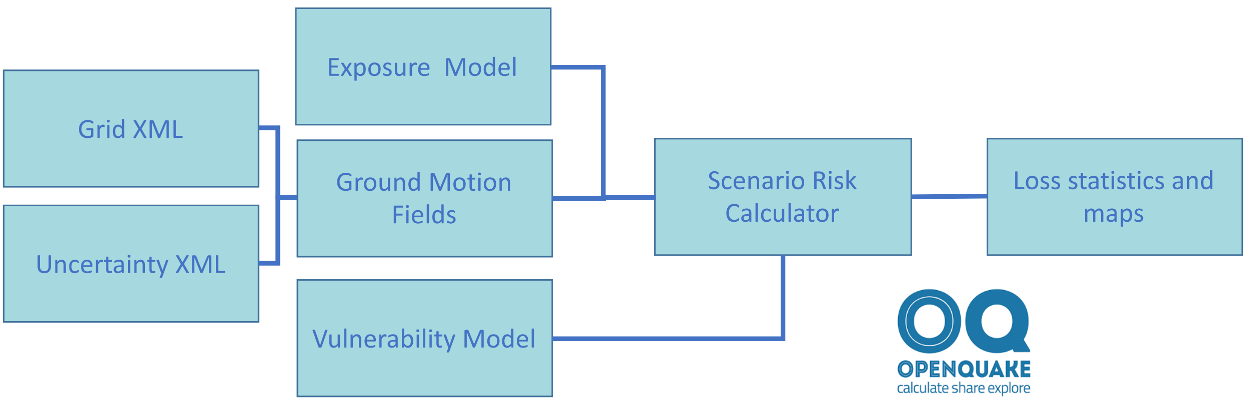

Fig. 2 Scenario from ShakeMap workflow of the OpenQuake engine (Pagani et al 2014, and deliverable D6.5)

3.3 European Rapid Earthquake Loss Assessment Software

The earthquake rapid loss assessment is built upon the OpenQuake (Pagani et al 2014) scenario risk calculator and the ShakeMap data. The OpenQuake-engine is an open-source software tool for assessing seismic hazard and risk.

The European exposure and vulnerability models which were used to develop a Rapid earthquake Loss Assessment (ReLA) service, are open to access and publicly available on GitLab: https://gitlab.seismo.ethz.ch/efehr/esrm20_exposure, https://gitlab.seismo.ethz.ch/efehr/esrm20_vulnerability.

The exposure and vulnerability models have been formatted as input files for this software, and can be used in conjunction with ShakeMap data (i.e., grid and uncertainty xml files) obtained from the European ShakeMap service via available webservices. The workflow depicted in Figure 3 can then be used to generate damage and loss statistics as well as maps.

This demonstration service uses web services to download ShakeMaps from the European Shake-Map system and then launches the OpenQuake-engine to calculate scenario damage and risk.

The service's output contains earthquake loss distributions in terms of completely damaged buildings, economic loss, and fatalities, which can be extracted using the impact scale proposed by Wald et al. for PAGER (2010).

asset_id	taxonomy	lon	lat	structural~no_damage	structural~DG1	structural~DG2	structural~DG3	structural~DG4	structural~DG5
COM2746	M5_L	7.74729	47.51982	2.58E-01	3.88E-01	2.51E-01	8.64E-02	1.59E-02	1.23E-03
COM2746	RCW_L	7.74729	47.51982	1.19E+00	6.41E-01	1.53E-01	1.99E-02	1.41E-03	2.08E-05
IND15427	Ind	7.74729	47.51982	1.19E+00	6.41E-01	1.53E-01	1.99E-02	1.41E-03	2.08E-05
AGR26783	M3_L	7.74729	47.51982	5.15E-01	7.77E-01	5.01E-01	1.73E-01	3.17E-02	2.46E-03
AGR26784	M5_L	7.74729	47.51982	2.58E-01	3.88E-01	2.51E-01	8.64E-02	1.59E-02	1.23E-03
AGR26785	M5_L	7.74729	47.51982	5.15E-01	7.77E-01	5.01E-01	1.73E-01	3.17E-02	2.46E-03
AGR26786	M6_L	7.74729	47.51982	5.71E-01	3.32E-01	8.45E-02	1.18E-02	8.92E-04	1.94E-05
RES48717	M3_L	7.74734	47.52881	3.07E-01	3.98E-01	2.20E-01	6.46E-02	1.00E-02	6.48E-04
RES48718	M3_L	7.74734	47.52881	1.84E+00	2.39E+00	1.32E+00	3.88E-01	6.00E-02	3.89E-03
RES48719	M6_L	7.74734	47.52881	6.27E+00	3.02E+00	6.37E-01	7.30E-02	4.54E-03	3.30E-05
RES48720	RCW_L	7.74734	47.52881	1.17E+01	5.21E+00	1.02E+00	1.10E-01	6.16E-03	1.11E-05
RES48721	RCW_M	7.74734	47.52881	1.03E+00	7.19E-01	2.12E-01	3.33E-02	2.75E-03	6.77E-05
COM2746	M5_L	7.74734	47.52881	3.07E-01	3.98E-01	2.20E-01	6.46E-02	1.00E-02	6.48E-04
COM2746	RCW_L	7.74734	47.52881	6.47E-01	2.89E-01	5.69E-02	6.09E-03	3.42E-04	6.18E-07
IND15421	Ind	7.74734	47.52881	6.47E-01	2.89E-01	5.69E-02	6.09E-03	3.42E-04	6.18E-07
IND15422	Ind	7.74734	47.52881	6.47E-01	2.89E-01	5.69E-02	6.09E-03	3.42E-04	6.18E-07
IND15423	Ind	7.74734	47.52881	4.53E+00	2.03E+00	3.98E-01	4.26E-02	2.40E-03	4.33E-06
IND15424	M6_L	7.74734	47.52881	6.27E-01	3.02E-01	6.37E-02	7.30E-03	4.54E-04	3.30E-06
IND15425	M6_L	7.74734	47.52881	6.27E-01	3.02E-01	6.37E-02	7.30E-03	4.54E-04	3.30E-06
IND15426	RCW_L	7.74734	47.52881	1.94E+00	8.68E-01	1.71E-01	1.83E-02	1.03E-03	1.85E-06
AGR26782	M3_L	7.74734	47.52881	3.07E-01	3.98E-01	2.20E-01	6.46E-02	1.00E-02	6.48E-04
COM2745	M3_L	7.7474	47.53781	2.14E-01	3.73E-01	2.78E-01	1.10E-01	2.30E-02	2.02E-03

Fig. 3 Example 'csv' output of OpenQuake scenario damage calculation

4. European Operational Earthquake Forecasting (OEF)

The goal of operational earthquake forecasting (OEF) is to provide timely and reliable information about the likelihood and impact of earthquakes in a given region, firstly to efficiently communicate and secondly to reduce the impact of the earthquakes on communities.

A forecasting model for Switzerland and Italy was developed and tested as part of the RISE project, and a similar model is being developed for Europe.

To calculate time-dependent earthquake rates, the model uses long-term seismicity rates and short-term clustering patterns. For time-dependent earthquake forecasting, the Epidemic-Type Aftershock

Sequence (ETAS, Ogata, 1988) model is widely used. The proposed ETAS model is calibrated using the European earthquake catalogue, which was assembled through the efforts of ESHM20 (Danciu et al 2021, 2022).

The Operational Earthquake Forecast (OEF) service plays a crucial role in enhancing the accuracy and timeliness of earthquake risk analysis. It leverages standard earthquake catalogs and uses FDSN webservices, which are accessible over HTTP, to obtain these catalogs. These catalogs can contain all the essential information of an earthquake in QuakeML, including magnitude, location, date and time. The European OEF uses an ETAS type model to analyze this information and generate forecasts. The forecasts are then provided in a common format, typically in the form of a csv file, containing essential information that stakeholders can use to inform decision-making for emergency response and risk mitigation.

To ensure effective integration of the OEF forecasts with other systems and applications, users can access these forecasts in QuakeML or a csv representation. This approach allows for seamless communication and analysis of earthquake risks and helps ensure that critical information is available to all stakeholders in a consistent and efficient manner. By facilitating timely decision-making and risk mitigation efforts, the OEF forecasts can play an essential role in improving public safety and disaster response.

4.1 A European OEF Model – Earthquake Ruptures and Ground Motion Modelling

To generate a set of stochastic earthquake catalogues over a given time interval, operational earthquake forecast (OEF) systems typically use point processes such as the ETAS model. These catalogues provide information on earthquake recurrence rates, but additional attributes are needed for seismic hazard and risk analysis.

As a result, the stochastically generated earthquakes must be transformed into three-dimensional finite ruptures containing additional information such as *hypocentral* depth and earthquake rupture parameters such as strike, rake, and dip. These finite ruptures are used to calculate source-to-site distances as well as other variables needed for ground motion prediction modelling.

#									trts=['Alpine Deep Crust', 'Alpine Shallow Crust', 'Foreland Deep Crust', 'Foreland Shallow Crust']	
seed	mag	rake	lon	lat	dep	multiplicity	trt	kind	mesh	extra
1	4	0	7.41407	46.34305	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4192, 7.4089, 7.4192, 7.4089]], [[46.3473, 46.3388, 46.3473, 46.3388]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
2	4	0	7.3889	46.34214	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.3941, 7.3837, 7.3941, 7.3837]], [[46.3464, 46.3379, 46.3464, 46.3379]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
3	4.5	0	7.39334	46.35454	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.402, 7.3847, 7.402, 7.3847]], [[46.3617, 46.3474, 46.3617, 46.3474]], [[6.9673, 6.9673, 9.0327, 9.0327]]]]	{"occurrence_rate" : 0.0}
4	4	0	7.37922	46.34947	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.3844, 7.3741, 7.3844, 7.3741]], [[46.3537, 46.3452, 46.3537, 46.3452]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
5	4	0	7.4006	46.35079	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4057, 7.3954, 7.4057, 7.3954]], [[46.355, 46.3466, 46.355, 46.3466]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
6	4.3	0	7.35427	46.3851	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.3613, 7.3472, 7.3613, 7.3472]], [[46.3909, 46.3793, 46.3909, 46.3793]], [[7.1606, 7.1606, 8.8394, 8.8394]]]]	{"occurrence_rate" : 0.0}
7	4	0	7.40601	46.33969	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4112, 7.4009, 7.4112, 7.4009]], [[46.3439, 46.3354, 46.3439, 46.3354]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
8	4.6	0	7.39878	46.3557	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4084, 7.3892, 7.4084, 7.3892]], [[46.3636, 46.3478, 46.3636, 46.3478]], [[6.8546, 6.8546, 9.1454, 9.1454]]]]	{"occurrence_rate" : 0.0}
9	4.1	0	7.39937	46.35211	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4051, 7.3937, 7.4051, 7.3937]], [[46.3568, 46.3474, 46.3568, 46.3474]], [[7.3177, 7.3177, 8.6823, 8.6823]]]]	{"occurrence_rate" : 0.0}
10	5.1	0	7.40394	46.34812	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.42, 7.3878, 7.42, 7.3878]], [[46.3614, 46.3349, 46.3614, 46.3349]], [[6.077, 6.077, 9.923, 9.923]]]]	{"occurrence_rate" : 0.0}
11	4	0	7.47707	46.39361	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4822, 7.4719, 7.4822, 7.4719]], [[46.3978, 46.3894, 46.3978, 46.3894]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
12	4.2	0	7.41229	46.34297	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4186, 7.406, 7.4186, 7.406]], [[46.3482, 46.3378, 46.3482, 46.3378]], [[7.2432, 7.2432, 8.7568, 8.7568]]]]	{"occurrence_rate" : 0.0}
13	5.9	0	7.43231	46.34682	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4692, 7.3954, 7.4692, 7.3954]], [[46.3772, 46.3165, 46.3772, 46.3165]], [[3.5948, 3.5948, 12.4052, 12.4052]]]]	{"occurrence_rate" : 0.0}
14	4.2	0	7.41118	46.36122	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4175, 7.4048, 7.4175, 7.4048]], [[46.3664, 46.356, 46.3664, 46.356]], [[7.2432, 7.2432, 8.7568, 8.7568]]]]	{"occurrence_rate" : 0.0}
15	4	0	7.40243	46.35239	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4076, 7.3973, 7.4076, 7.3973]], [[46.3566, 46.3482, 46.3566, 46.3482]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
16	4	0	7.39088	46.35199	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.396, 7.3857, 7.396, 7.3857]], [[46.3562, 46.3478, 46.3562, 46.3478]], [[7.3849, 7.3849, 8.6151, 8.6151]]]]	{"occurrence_rate" : 0.0}
17	4	0	7.41512	46.36747	8	1	Alpine Shallow Crust	ParametricProbabilisticRupture PlanarSurface	[[[[7.4203, 7.41, 7.4203, 7.41]], [[46.3717, 46.3632, 46.3717,	{"occurrence_rate"

Fig. 4 Example stochastic catalogue in 'csv' format compatible with OpenQuake

It is necessary to have a regional distribution of rupture property distributions across Europe, which can be obtained from one of the seismogenic sources of ESHM20. To generate ground motion fields for OEF, a ground motion model (GMM) must be chosen, as well as a spatial and inter-period ground motion residual correlation model, and a site model to characterize soil conditions.

4.2 A European OEF Model – Damage and Loss Assessment

The ongoing developments described in the previous sections will determine the feasibility of European-scale Operational Earthquake Loss Forecasting (OELF). Thus, this is not yet a RISE project service, but Deliverables 4.3 and 6.2 have demonstrated OELF systems at the national scale through Italy's MANTIS-K and MANTIS v2.0 systems.

Once a system can generate OEF rates and estimate ruptures and ground shaking for any location in Europe, it will be straightforward to assess earthquake losses in a European OELF system with the exposure and vulnerability models described for the European Rapid earthquake Loss Assessment (ReLA) tool (Crowley et al 2021). Again, describing Vulnerability, Exposure and Fragility, the NRML standard is being used as shown before. Expressing dynamic exposure processes and damage dependent fragility- and vulnerability functions, new standards will have to be defined or probably even better, existing ones extended.

5. Conclusions and Outlook

The importance of technical standards and protocols for automated data exchange in order to provide dynamic web-services is undeniably growing in today's dynamic digital world.

Data standardization permits the harmonization of seismic hazard and risk across international borders in a consistent and compatible manner. Extension of the XML standard, the Natural Hazard Markup Language (NRML) is a standard format for transferring seismic hazard and risk models. In addition, it contains metadata fields for documenting the model, its input data sources, and its development procedures.

The Eartqhuake Rapid Loss Assessment (ReLA) provides information regarding the regional damage and loss assessment following an earthquake. The system utilizes ShakeMap output formats, i.e. XML and geo-referenced grid files, as well as input files depicting exposure and vulnerability models, in order to rapidly assess regional losses.

Operational Earthquake Forecast relies on the background earthquake catalogue (documented csv file) and the event information (QuakeML) to initiate the computation of the time-dependent earthquake forecast.

In recent decades, European-founded projects such as NERA, SHARE, SERA, and RISE have made significant progress in proposing data standards and products that can be widely adopted and used by a diverse community, from earth scientists, engineers and decision makers.

Furthermore, standardized data formats not only facilitate the development of web services, but also ensure interoperability, data integration, and information exchange among various stakeholders. This is especially important in earthquake-related services, where timely communication and collaboration among stakeholders can mean the difference in preventing loss of life and property.

The use of standard data formats ensures that all stakeholders, regardless of location or organization, have consistent and efficient access to and analysis of earthquake data. In the long term, community-specific data and data products, such as the European Plate Observing System (EPOS) data portal (https://www.ics-c.epos-eu.org/) are of vital importance. This newly released webportal represents the next step in the evolution of a unified, pan-European, distributed, and sustainable infrastructure for solid Earth science, thereby enhancing earthquake knowledge, preparedness, and mitigation.

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