Deliverable 6.3

Report on Iceland demonstration site: Rapid Loss Assessment

Deliverable information	
Work package	WP6. Demonstration: Pilot and Demonstration sites for RISE technologies and methods
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Summary

This deliverable describes the activities that have been carried out during the RISE project to revive the ShakeMap system in Iceland, and to connect it to the exposure and vulnerability models developed in WP4 (Deliverable 4.1 and 4.2) and the software developed in WP6 (Deliverable D6.5) for Rapid Loss Assessment. During the project two earthquakes with magnitude greater than 5 have occurred, and they have been used to demonstrate the RLA capabilities in Iceland.

1. Modification of Original Deliverable

D6.3 was originally planned to be a description of all demonstration activities in Iceland, led by IMO. However due to a lack of personal resources of IMO, who did not provide the necessary catalogue data for OEF (which was to be carried out in collaboration with ETH), it has been prepared with a focus only on demonstrating Rapid Earthquake Loss Assessment in Iceland. Some of the activities presented herein have been undertaken by IMO, but they have not contributed to the writing of this deliverable, which has been prepared solely by EUCENTRE.

2. ShakeMaps and Rapid Loss Assessment System for Iceland

2.1 ShakeMap System in Iceland

2.1.1 Icelandic ShakeMap Systems and Improvements in RISE

An older system based on ShakeMap v3.5 was run by the Icelandic Met Office (IMO) from 2008 to 2014, following development and installation in the SAFER project. This system did not run from 2014 to 2020, mainly due to a lack of human resources to maintain the system. The automatic Mw calculation (in under 3- minutes) and ShakeMap generation was reawakened at IMO in the summer of 2020, funded by a student innovation grant from RANNÍS (the Icelandic Research fund) and partially supported by RISE. This new ShakeMap system was based on ShakeMap v4. The list of events M>=3 is accessible at http://hraun.vedur.is/ja/Mpgv/ where they are organised in directories for each year. ShakeMaps are generated for events of Mw>=3.5.

The Icelandic ShakeMap system uses the attenuation model of Petursson and Vogfjord (2009) to calculate the PGA and the PGV. These are then converted to MMI using the conversion equations included in the ShakeMap system. Maps in jpg are output showing Intensity-, PGV- and PGA-contours. The contour files for the 0.3, 1.0 and 3.0 sec spectral acceleration are not included.

During 2020, the system was found, however, not able to determine fast reliable Mw for events of ~Mw4 and greater, and so it was important to revive and improve the process. This process was very valuable during the intense seismicity period leading up to the eruption at Fagradalsfjall. At the beginning of the intense seismicity triggered by the dyke intrusion on Reykjanes Peninsula in February 24 2021, some of the events following the first Mw5.64 event at 10:05 were missed because of high background noise from the first event on most nearby stations. The process also was found not to do so well with events offshore to the North and South of the country. Furthermore, during most of 2020 and 2021, the process missed some of the events in Bárdarbunga volcano (64.7 -17.5) (very long source time function), but this has now been improved and the system is catching these events now.

During 2021, modifications were made to the system, thanks to collaboration with the team developing the European ShakeMap system (see Deliverable D6.5), to ensure that the 'grid.xml' and 'uncertainty.xml' were produced and stored for each event above magnitude 5. These input files are required for the rapid loss assessment calculations.

2.1.2 Differences between Icelandic and European ShakeMap Systems

On 31st July 2022, an earthquake of Mw 5.3 with a depth of 2.7 km (IMO) occurred on Reykjanes peninsula, close to the town of Grindavík which caused some minor damage. Although the event was ~35 km from Reykjavík, it was widely felt in the city, but without any damage. Figure 1 below presents the ShakeMaps from IMO and European ShakeMap systems. Both ShakeMaps show very close characteristics in terms of location and magnitude but the depth of the event is reported as 2.1 and 10 km in IMO and European ShakeMaps, respectively. Another difference to be noted is the ground motion model (GMM) in two systems. IMO ShakeMaps are based on Petursson and Vogfjord (2009) while European ShakeMaps are based on ESHM13 (Woessner et al., 2015) (and plan to be updated to those from ESHM0: Danciu et al., 2021). The maximum PGA values are quite similar, 0.211g and 0.219g for IMO and European ShakeMaps, respectively. However, as can be seen from Figure 2, the attenuation of PGA is very different in the two systems.

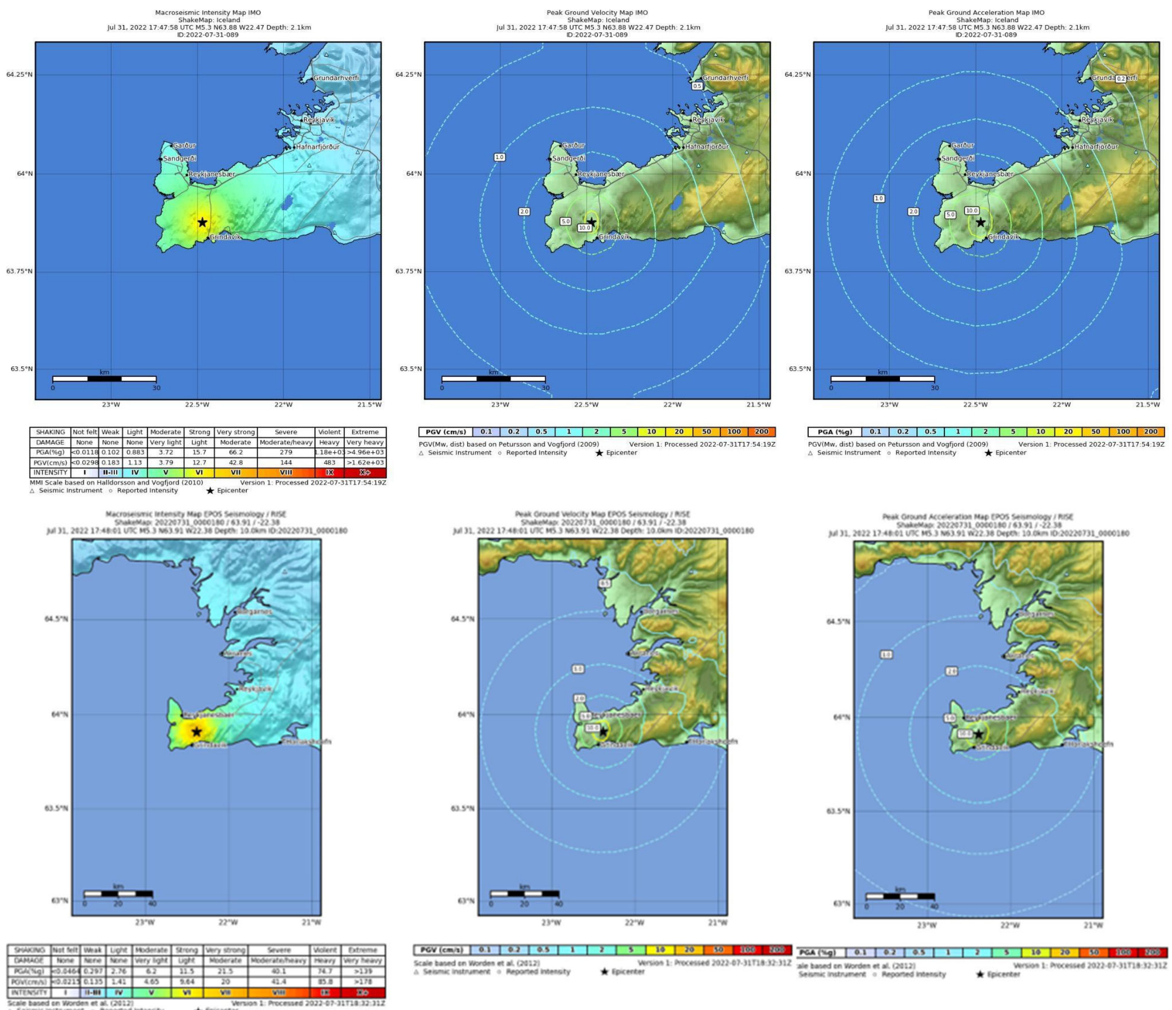
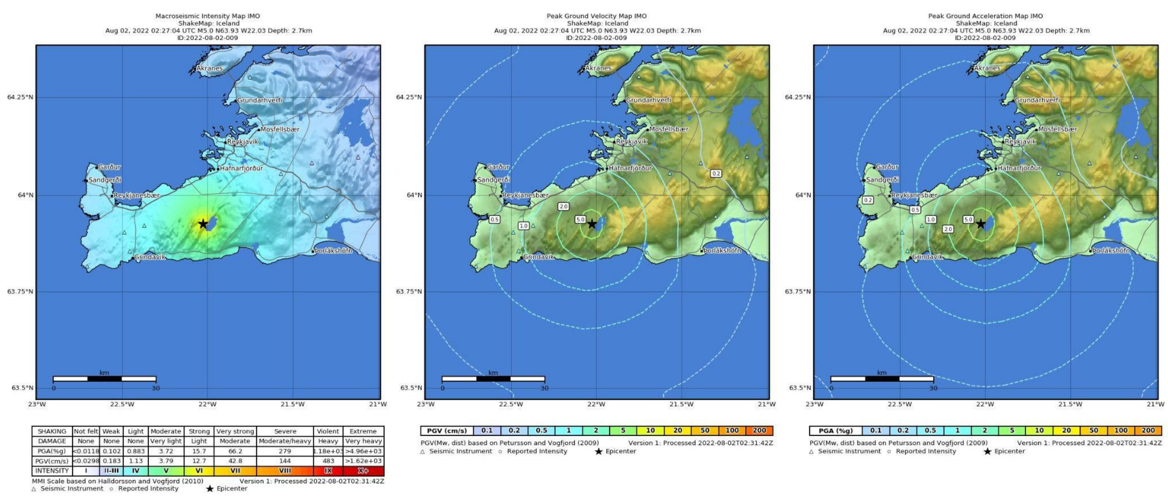


Fig. 1 Comparison of ShakeMaps from the IMO system (top) and the European ShakeMap system, http://shakemapeu.ingv.it/ (bottom) for the M5.3 earthquake on 31st July 2022

Fig. 2 Attenuation of PGA values from the IMO (left) and the European ShakeMap system (right) for the earthquake on 31st July 2022

On 2nd August, another earthquake of Mw 5.0 occurred with a depth of 3.9 km, farther east on the peninsula, ~15 km away from Reykjavík, where it was felt. Figure 3 below presents the ShakeMaps from IMO and European ShakeMap systems. For this event, some differences are observed between the Shakemaps in terms of epicentre and the magnitude, as well as the depth of the event. According to IMO ShakeMap, the M5.0 event occurs at a depth of 2.7 km, slightly to more south as compared to the epicentre of the M5.1 event with a depth of 10km in European ShakeMap. Due to these differences along with the GMM, the maximum PGA values are also quite different, 0.145g and 0.291g for IMO and European ShakeMaps, respectively. A very significant difference in the attenuation is also observed (Figure 4).



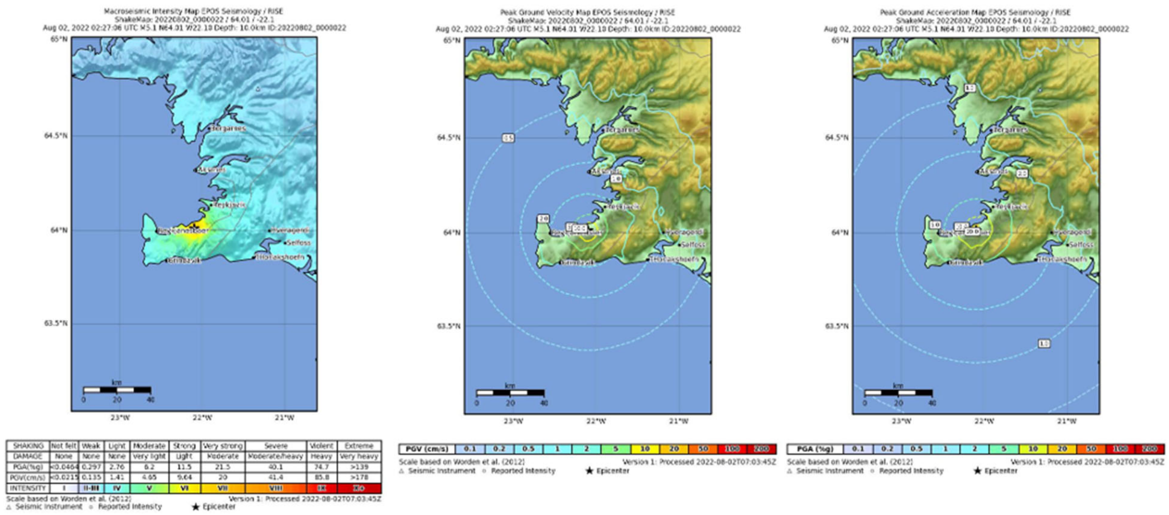


Fig. 3 Comparison of ShakeMaps from the IMO system (top) and the European ShakeMap system, http://shakemapeu.ingv.it/ (bottom) for the M5.1 earthquake on 2nd August 2022

Fig. 4 Distribution of PGA values from the IMO (left) and the European ShakeMap system (right) for the earthquake on 2nd August 2022

The differences between the two ShakeMap systems illustrated above highlight the need to update the configuration of the European ShakeMap system for Iceland. Such activity will hopefully be achieved in upcoming projects, including the GeoINQUIRE project (where a workshop with ShakeMap operators, including Iceland, is planned for May 2023).

2.2 Rapid Loss Assessment (RLA) for Iceland

2.2.1 Explanation of Repository and Software

This section describes a GitLab repository that we have been setting up for RLA in Iceland (https://gitlab.seismo.ethz.ch/hcrowley/RISE_Iceland_scenarios). This repository has exposure (disaggregated to 30 arc second) and vulnerability models needed for RLA and the results of the two IMO ShakeMaps described in the previous section have already been included in this repository, the results of which are described in the following section.

The scenario-based seismic risk and damage calculations after an earthquake can be calculated using OpenQuake engine, an open-source software developed by GEM Foundation for seismic hazard and risk analyses (Silva et al., 2014; Pagani et al., 2014). The ShakeMap calculator of the engine uses grid and uncertainty xml files from ShakeMaps to generate a set of ground motion fields (GMFs) and then a scenario risk calculation will be performed using these GMFs along with the risk models (exposure and vulnerability) for the region covered by the extent of the ShakeMap. More information is included in RISE Deliverable 6.5.

The RLA procedure is based on a set of Python scripts and can easily be run using the main script (main.py) along with the data from the following folders:

- python scripts to run the software located in ***ReLA*** folder,
- exposure and vulnerability models for Iceland in ***data/Exposure_30arcsec*** and ***data/vulnerability***,
- the ShakeMaps (grid and uncertainty xml) from Icelandic events located in ***data/ShakeMaps-IMO*** folder under specific event folders,
- pre-defined templates of job files (the "preparation" file and the "run" file) to be used for OpenQuake located in ***templates*** folder.

The "preparation" file contains the exposure and the vulnerability models with related descriptions as follows:

```
[general]
description = Preparation file for economic losses and fatalities, Scenario from ShakeMap Calculation - 2022-07-31-089
calculation_mode = scenario

[vulnerability]
structural_vulnerability_file = ../../../esrm20/vulnerability/vulnerability_total-repl-cost_ESRM20_PGA.xml
occupants_vulnerability_file = ../../../esrm20/vulnerability/vulnerability_loss-of-life_ESRM20_PGA_day.xml
taxonomy_mapping_csv = ../../../esrm20/vulnerability/esrm20_exposure_vulnerability_mapping.csv

[exposure]
region_grid_spacing = 5
time_event = day
exposure_file =
 OQ_Exposure_30arcsec_Input_Iceland.xml
```

Fig. 5 Preparation job file for a scenario-risk calculation

For the scenario-risk calculations, the two vulnerability files, the structural (total replacement cost) and the occupants (loss of life), are characterised by the given intensity measure type existing in ShakeMap service (MMI, PGV, PGA, SA(0.3), SA(1.0), and SA(3.0)). In the case of ShakeMaps provided by the Icelandic Meteorological Office (IMO), the ground motion is identified by MMI, PGA and PGV, therefore the vulnerability models based on PGA from ESRM20 are used (Romão et al., 2021). The vulnerability models also include the variability applied as a coefficient of variation. Similarly, for the scenario-damage calculations the fragility model given in PGA is defined in the preparation file.

The parameter, *region_grid_spacing* (in km) is defined to create an envelope of the exposure sites and builds a grid of hazard sites, associating the site parameters from the closest site in the site model and discarding sites in the region where there are no assets.

The *time_event* parameter is obtained automatically from the grid.xml through Python scripts, hence not required to be defined by the user.

The exposure files of the countries affected by the event are also automatically obtained and processed through Python scripts using the extent of given ShakeMaps.

The run file contains the ShakeMap files with related descriptions as follows:

```
[general]
description = Scenario losses for event 2022-07-31-089 with Icelandic ShakeMap
taxonomy_mapping_csv = ../../../esrm20/vulnerability/esrm20_exposure_vulnerability_mapping.csv
calculation_mode = scenario_risk
ses_seed = 45
spatial_correlation = no
cross_correlation = no
ignore_master_seed = true

number_of_ground_motion_fields = 200
shakemap_uri = {
        "kind": "usgs_xml",
        "grid_url": "grid_2022-07-31-089.xml",
        "uncertainty_url": "uncertainty_2022-07-31-089.xml"
        }
```

Fig. 6 Run job file for a scenario-risk calculation

In the run file, some parameters related to OpenQuake engine such as *calculation_mode* (scenario_risk or scenario_damage), *ses_seed* (seed to control the sampling of ground motion), *ignore_master_seed* (improving the calculation performance) are pre-defined. The *number_of_ground_motion_fields* (number of different possible simulations of ground motion) can be chosen by the user.

Once again, the Python scripts automatically locate the path of the ShakeMap products.

The OpenQuake Engine also allows to compute both the spatial correlation and the cross correlation between different intensity measure types (except for MMI). The choice of correlations can be done in nine combinations where *yes* for using the correlation matrix of the Silva-Horspool paper; *no* for using no correlation; yes for correlation; *full* for using an all-ones correlation matrix.

```
- spatial_correlation = yes, cross_correlation = yes  # the default
- spatial_correlation = no, cross_correlation = no   # disable everything
- spatial_correlation = yes, cross_correlation = no
- spatial_correlation = no, cross_correlation = yes
- spatial_correlation = full, cross_correlation = full
- spatial_correlation = yes, cross_correlation = full
- spatial_correlation = no, cross_correlation = full
- spatial_correlation = full, cross_correlation = no
- spatial_correlation = full, cross_correlation = yes
```

Fig. 7 Use of different correlations for a scenario calculation

The Icelandic events evaluated here do not include any of these correlations for the time-being, but these settings can be changed by the user.

The steps to be followed to run the software are:

1. The repository 'RISE_Iceland_scenarios' (https://gitlab.seismo.ethz.ch/hcrowley/RISE_Iceland_scenarios) should be downloaded or cloned in the same directory.
2. The OpenQuake engine (v3.16) is to be installed (https://github.com/gem/oq-engine/blob/engine-3.16/doc/installing/universal.md).
3. With the OpenQuake virtual environment activated following the instructions in the installing process, the dependencies should be installed using *pip* with the command: *pip install -r requirements.txt*
4. Before running the software, a modification is necessary (below) within an OQ script (oq-engine\openquake\hazardlib\shakemap\parsers.py) as the Icelandic shakemaps hold different intensity measure types from the default ones in OQ.

```
US_GOV = 'https://earthquake.usgs.gov'
SHAKEMAP_URL = US_GOV + '/fdsnws/event/1/query?eventid={}&format=geojson'
F32 = numpy.float32
SHAKEMAP_FIELDS = set(
    'LON LAT SVEL MMI PGA PSA03 PSA10 PSA30 '
    'STDMMI STDPGA STDPSA03 STDPSA10 STDPSA30'
    .split())
FIELDMAP = {
    'LON': 'lon',
    'LAT': 'lat',
    'SVEL': 'vs30',
    'MMI': ('val', 'MMI'),
    'PGA': ('val', 'PGA'),
    'PSA03': ('val', 'SA(0.3)'),
    'PSA10': ('val', 'SA(1.0)'),
    'PSA30': ('val', 'SA(3.0)'),
    'STDMMI': ('std', 'MMI'),
    'STDPGA': ('std', 'PGA'),
    'STDPSA03': ('std', 'SA(0.3)'),
    'STDPSA10': ('std', 'SA(1.0)'),
    'STDPSA30': ('std', 'SA(3.0)'),
}
# REQUIRED_IMTS = {'PGA', 'PSA03', 'PSA10'}
REQUIRED_IMTS = {'PGA'}
```

5. Lastly, by navigating the ReLA folder in 'RISE_Iceland_scenarios' repository, the software can be run with the command: *python main.py*

After running the software, three folders will be produced (inside a results folder):

- `inputs`: this includes a directory with the name of the ShakeMap unique ID, inside which you will find the downloaded ShakeMap grid and uncertainty files, a reduced ShakeMap (with intensity values greater than or equal to III), the 30 arc second exposure models that have been cut to the size of the reduced ShakeMap, as well as the log files of the OpenQuake engine calculations (all of these are useful for results checking and debugging).
- `outputs`: this includes a directory with the name of the ShakeMap unique ID, inside which you will find a summary of the mean losses/damage as well as loss/damage distribution plots.
- `outputs_oq`: this includes a directory with the name of the ShakeMap unique ID, inside which you will find all of the OpenQuake engine outputs for the calculation (this provides access to additional outputs, and can be used for further checking and debugging).

2.2.2 Results of RLA using IMO ShakeMaps

The RLA procedure is performed to evaluate the loss and damage calculations of the two events that occurred in Iceland during the RISE project.

Upon completing the RLA procedure, the histogram plots of estimated economic losses (in millions, Euro) and fatalities are produced by characterising different colour-coded alert levels depending on the threshold values as in the Table 1. The probability of each bin is expressed in median values of estimated loss in the logarithmic domain.

For the event on 31.07.2022, the likelihood of 40% of having losses exceeding 1 M EUR while for the life of loss the probability of having less than 1 casualty is 100%. Similarly, in terms of number of damaged buildings (Figure 9), this event shows 80% of likelihood that <1 building will have extensive or complete damage and a median value of between 10-100 buildings in slight damage, and 1-10 buildings moderately damaged.

Table. 1 Color-coded alert levels and corresponding loss values (adapted from PAGER earthquake impact scale, Wald et al., 2010)

Alert Level and Color	Estimated Fatalities	Estimated Economic Losses(in millions, Euro)	Estimated Number of Damages (for complete damage)
Red	1000+	1000+	1000+
Orange	100 - 999	100 - 999	100 - 999
Yellow	1 - 99	1 - 99	1 - 99
Green	0	< 1	< 1

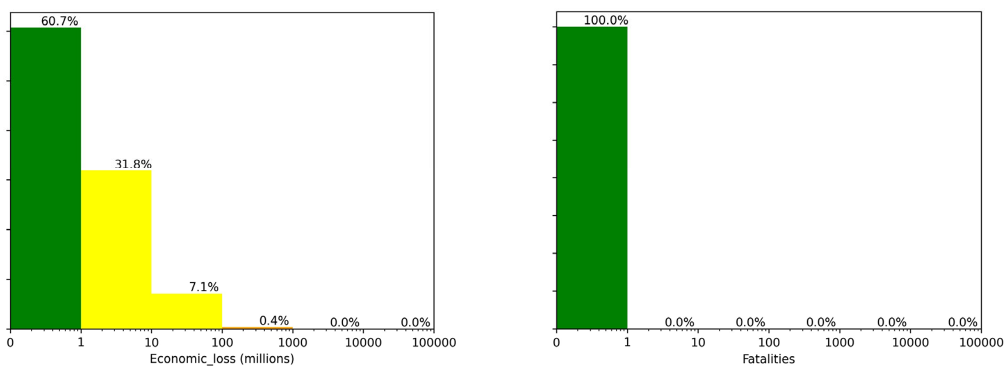


Fig. 8 Histogram of Estimated Economic losses and Fatalities for the event on 31.07.2022

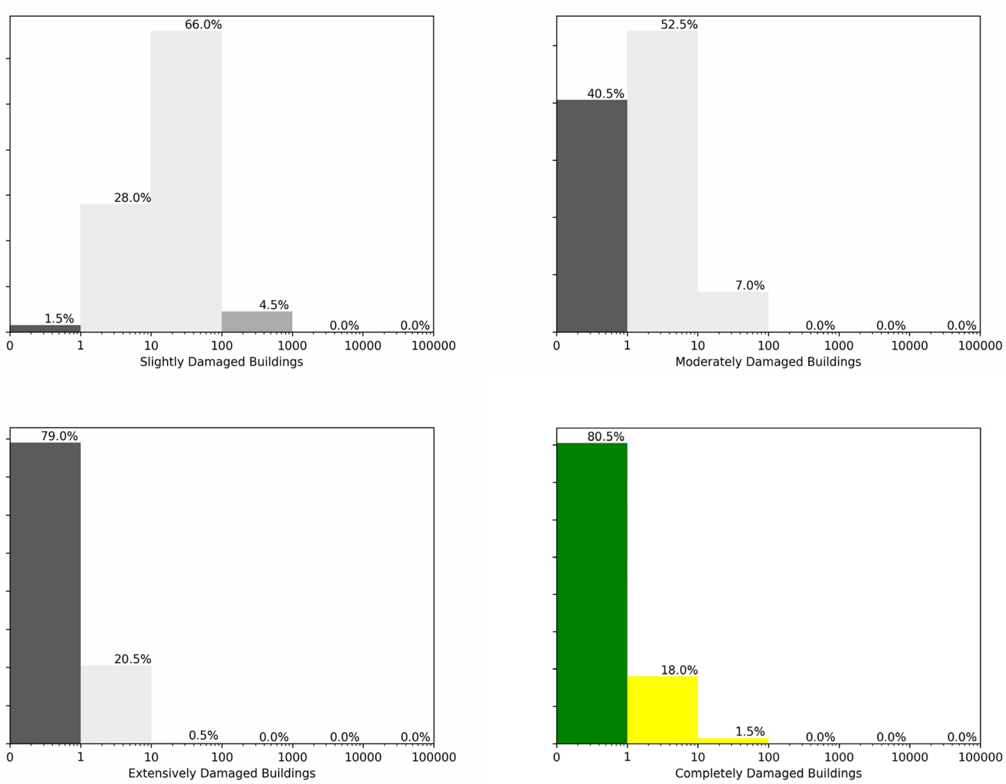


Fig. 9 Histogram of damaged buildings in different damage states for the event on 31.07.2022. Note that only the complete damage is presented with the alert colour scale (and the others are shown with a greyscale) as this is the damage state which will drive the need for emergency response

For the event on 02.08.2022, the likelihood of having up to one million of economic loss is 99% while for the life of loss the probability of having no casualties is 100%. Similarly, in terms of number of damaged buildings (Figure 11), this event shows 98% of likelihood <1 building with damage exceeding moderate damage, and a median value of 1-10 buildings with slight damage.

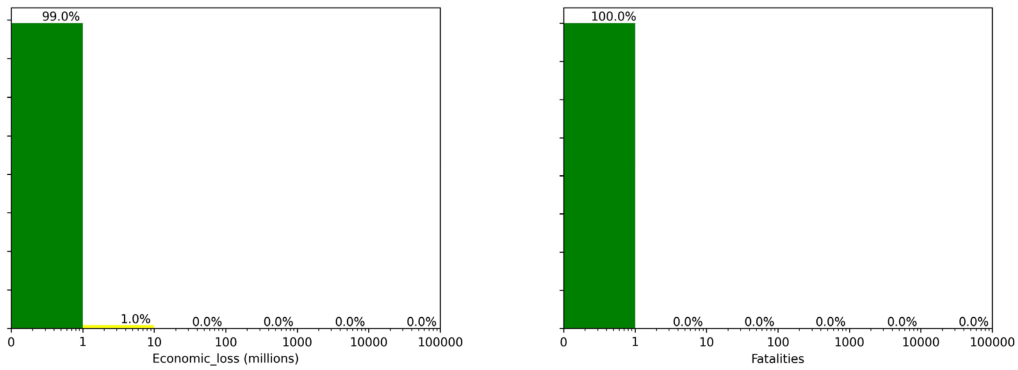


Fig. 10 Histogram of Economic losses and Fatalities for the event on 02.08.2022

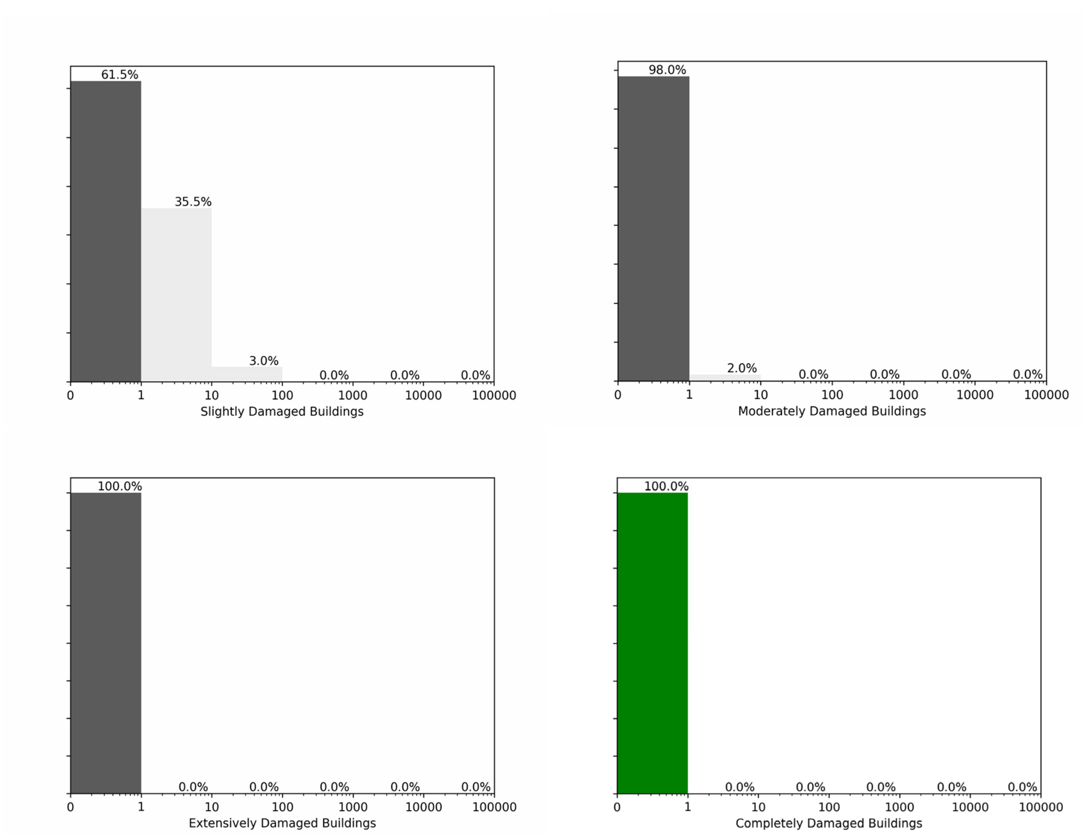


Fig. 11 Histogram of damaged buildings in different damage states for the event on 02.08.2022. Note that only the complete damage is presented with the alert colour scale (and the others are shown with a greyscale) as this is the damage state which will drive the need for emergency response

A final reminder is made that although this tool is effective and essential to evaluate the impact of an event rapidly, the procedure includes different sources of uncertainties from the ground shaking to exposure and vulnerability models, and is thus best placed to provide an indication of the range of losses that could be expected.

3. Conclusions

Despite the difficulties engaging with the IMO partner during the RISE project, a successful demonstration of the updated ShakeMap system and the rapid loss assessment for two earthquakes in Iceland has been achieved. This RLA system is openly available on a public repository and can be used by IMO in the future to run a rapid assessment of the impacts of any future earthquake, based on the downloaded grid.xml and uncertainty.xml files. Instructions on how to undertake the analyses have been provided herein, as a 'user manual' to support these efforts.

References

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RISE Deliverable 4.1 "Exposure and vulnerability models for RLA service for Europe (Demonstrator)"

RISE Deliverable 4.2 "Exposure and vulnerability models for RLA service for Europe (Report)"

RISE Deliverable 6.5 "Report on the Development of RLA, EEW and OEF at European Scale"

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Woessner, Jochen, et al. "The 2013 European seismic hazard model: key components and results." Bulletin of Earthquake Engineering 13 (2015): 3553-3596. https://doi.org/10.1007/s10518-015-9795-1