

USING OPENQUAKE TO DEFINE SEISMIC RISK AND REAL TIME DAMAGE SCENARIO IN ITALY

Marta FARAVELLI¹, Barbara BORZI², Marco PAGANO³, Davide QUARONI⁴

ABSTRACT

Web-based GIS tools have been developed in order to calculate seismic risk and real time damage scenario for Italian structures and infrastructures. The goal of seismic risk definition is to guide decision makers in identifying the most critical conditions and to manage fund flows to plan mitigation interventions. On the other hand, the target of the definition of real time damage scenario is to provide decision makers with specific tools to plan/handle emergencies in case of an earthquake. The GIS tools described in this paper manage data and results for residential units, school buildings and infrastructures such as the road system, harbors and the airports. For real time damage scenario, the tools also adopt OpenQuake as calculation engine. OpenQuake comes also handy to define seismic risk maps of residential buildings. The implementation and the use of OpenQuake were extremely user friendly for decision makers. The writing of input files, the management of the messages and the output are all automatized through dialog windows. Finally, the implementation has also been tested in terms of damage scenario by means of comparison with observation damage data.

Keywords: Seismic risk, Damage scenario, GIS application, OpenQuake

1. INTRODUCTION

The creation of risk maps and tools for the development of real time damage scenarios in a non-emergency period are becoming increasingly important in recent years for Civil Protection purposes.

The risk maps are an important element for the seismic risk mitigation. They allow: identifying of high-risk geographic areas in which retrofitting of the building stock is a priority, to plan appropriate and cost effective earthquake mitigation measures on large-scale and an appropriate evaluation for insurance purposes. Recent earthquakes occurred in Italy like L'Aquila 2009 or Central Italy 2016, had a significant impact in terms of loss of human lives and costs. Prevention in terms of reduction of structural vulnerability of the building stock is therefore of fundamental importance.

In addition to risk maps, the use of tools that provide almost real time damage scenarios in regions affected by seismic events is increasingly widespread. After a seismic event, it is particularly helpful for Civil Protection to have a set of smart tools for a quick estimation of the expected damages and losses in order to identify operators and facilities to start the emergency procedures. Based on these observations and in order to respond to an explicit request from the Italian Department of Civil Protection, Eucentre has developed three WebGIS platforms (i.e. Geographic Information System published on web). They are able to run real time damage scenarios and seismic risk maps for residential buildings, school buildings and infrastructures using tools developed in house. During 2017 in WebGIS platforms the possibility to use OpenQuake-engine to define seismic risk maps of residential buildings and real time damage scenario for all the structures and infrastructures considered

¹Researcher, Eucentre, Via Ferrata 1, Pavia, Italy, marta.faravelli@eucentre.it

²PhD, Eucentre, Via Ferrata 1, Pavia, Italy, barbara.borzi@eucentre.it

³BSc, Eucentre, Via Ferrata 1, Pavia, Italy, marco.pagano@eucentre.it

⁴Mr, Eucentre, Via Ferrata 1, Pavia, Italy, davide.quaroni@eucentre.it

has been added, as described in the next pages.

1.1 Tools for estimation of earthquake losses

During the years, several research groups around the world have developed tools to maximize earthquake rapid response systems in order to estimate earthquake losses in quasi real time after a seismic event. Erdik et al. (2014) shows a review of many existing earthquake rapid response systems and methodologies that serve to plot earthquake loss information (building damages, casualties and economic losses) immediately after an earthquake. In latter paper the available near real time loss estimation tools were classified in two main categories depending on the size of area they cover: Global/Regional Systems and Local Systems.

The first group lists: GDACS (2014), WAPMERR (2013), PAGER (2004), ELER (2010), SELINA (2010); the second: Taiwan Earthquake Rapid Reporting System, Realtime Earthquake Assessment Disaster System in Yokohama, Real Time Earthquake Disaster Mitigation System of the Tokyo Gas Co., Istanbul Earthquake Rapid Response System.

Spence et al. (2008) compares three methods to evaluate real time damage scenario in Europe, developed within the LESSLOSS SP10 project: KoeriLossV2, AUTHloss e LNECloss. The three tools were tested on 3 different cities (Istanbul, Lisbon and Thessaloniki) considering approximately 50-year and 500-year earthquake scenarios using methods, software and GIS mapping tools which were developed by separate research teams for each of these cities. The individual city studies have been reported in Spence (2007). The approaches used for the three cities had many elements in common, but there were also important differences:

- The three tools model the soil profile differently;
- KoeriLossV2 and LNECloss use the capacity spectrum method to process the fragility curves;
- AUTHloss uses fragility curves developed using a combination of analysis and statistical data like the hybrid method;
- The damage levels used in the three tools are different;
- Each tool estimates the number of victims in a different way.

1.2 OpenQuake

OpenQuake is a recent tool to estimate earthquake loss developed as part of the Global Earthquake Model (GEM) (<http://www.globalquakemodel.org>). OpenQuake is a web-based risk assessment platform, which offers an integrated environment for modelling, viewing, exploring and managing earthquake risk (Silva et al. 2014). The risk component of the OpenQuake-engine can compute both scenario-based and probabilistic seismic damage and risk using various approaches. The following types of analysis are currently supported (GEM 2017): Scenario Damage Assessment, Scenario Risk Assessment, Classical Probabilistic Seismic Damage Analysis, Classical Probabilistic Seismic Risk Analysis, Stochastic Event Based Probabilistic Seismic Risk Analysis, Retrofit Benefit-Cost Ratio Analysis.

In the WebGIS platform described in this paper the Scenario Damage Assessment has been integrated to assess the real time damage scenario and the conditioned risk (the seismic risk related to an event with a certain return period T_r , e.g. $T_r=475$ years). Furthermore, the Classical Probabilistic Seismic Damage Analysis has been integrated in order to evaluate the unconditional seismic risk for a specific time window. The Scenario Damage Assessment calculator computes damage distribution statistics for all assets in a given exposure model for a single specified earthquake rupture. This calculator requires the definition of a finite rupture model, an exposure model and a fragility model, along with the selected GMPE (Ground Motion Prediction Equation). The Classical Probabilistic Seismic Damage Analysis calculator integrates the fragility functions for an asset with the seismic hazard curve at the location of the asset, to give the expected damage distribution for the asset within a specified time period. The calculator requires the definition of an exposure model, a fragility model with fragility functions for each taxonomy represented in the exposure model, and hazard curves calculated in the

region of interest (GEM 2017).

2. INTEGRATION OF OPENQUAKE IN THE WEBGIS PLATFORMS

Eucentre has developed three WebGIS platforms to assess risk maps and damage scenarios. The first focuses on residential buildings and the minimum unit of definition is the municipality (Faravelli et al. 2017). The second relates to school buildings identified with a single point (Faravelli et al. 2017) and the third provides the risk of the infrastructure located in the road system (Onida et al. 2001). Recently, the possibility to use OQ-engine to process the real time damage scenarios was integrated in the three WebGIS. Furthermore, only in the residential buildings WebGIS platform risk maps (for different time windows or return periods) with OQ-engine can be produced. All calculations with OQ-engine work jointly but do not replace those carried out with Eucentre tools.

2.1 OpenQuake for residential buildings

In the WebGIS platform for residential buildings you'll find the tab "Custom curve" (Figure 1) in which the user can insert new fragility curves or use the default set of curves to elaborate seismic risk maps using OQ-engine. In particular, the OQ tool "Scenario Damage Assessment" has been implemented to calculate conditional risk for different return periods (30, 50, 72, 100, 140, 200, 475, 1000, 2500 years) and the OQ tool "Classical Probabilistic Seismic Damage Analysis" for the unconditional risk in different time windows (1, 10 or 50 years). The user can download the shapefile of the map or an excel file that summarizes the results. In this WebGIS, like in the other two, using the tab "Scenario OpenQuake" it's possible to run the real time damage scenario using the tool "Scenario Damage Assessment" of OQ-engine (Figure 2). To define the hazard data the user can:

- Insert only the minimum data like magnitude, longitude and latitude of the epicentre, depth of the hypocenter;
- Define the dimensions and the features of the fault;
- Insert the ID of the shakemap produced by the INGV (Nation Institute of Geophysics and Volcanology).

For the first two cases, the radius describing the evaluated area around the epicentre and the GMPE from a list (Boore and Atkinson 2008, Akkar and Bommer 2010, Bindi et al. 2011, Cauzzi and Faccioli 2008) must also be indicated. Regardless of the user's choice, the output is a shapefile with the map and an excel file with the results.

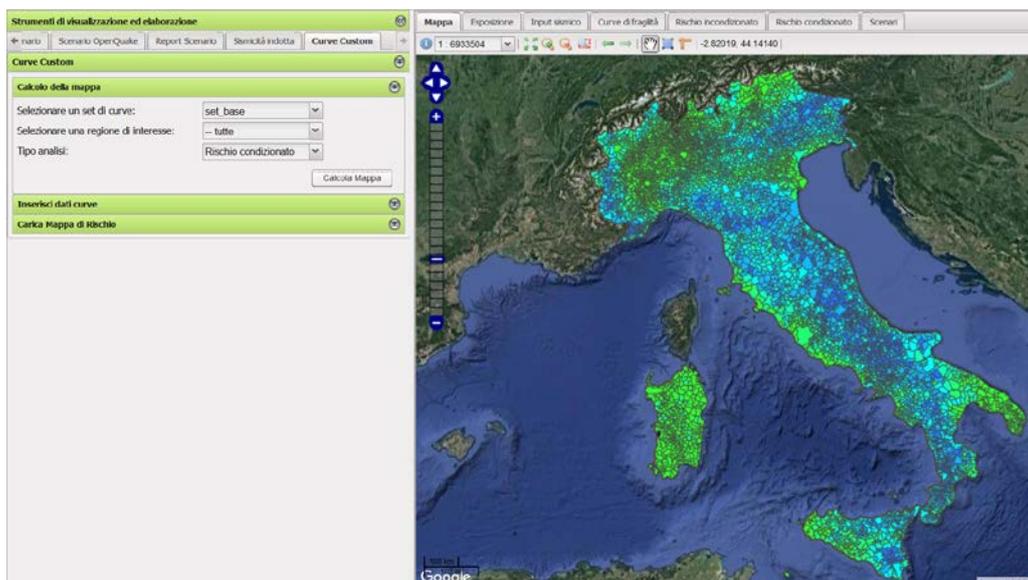


Figure 1. Tool to produce risk maps with OQ-engine for residential buildings

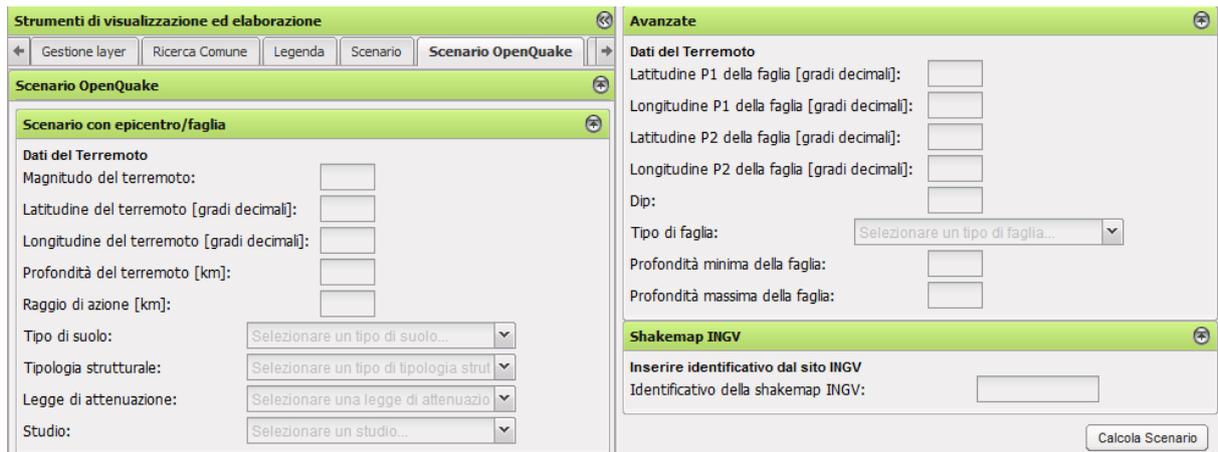


Figure 2. Tool to elaborate real time damage scenarios with OQ-engine for residential buildings

2.2 OpenQuake for school buildings

The tool “Scenario Damage Assessment” of OQ-engine has been implemented in the school buildings WebGIS platform, too. The input data that the users have to select in order to define the hazard for the real time damage scenario are the same as the previous ones. Figure 3 shows the tab “Scenario OpenQuake” for this platform. Also in this case the export files are the shapefiles and the excel files.

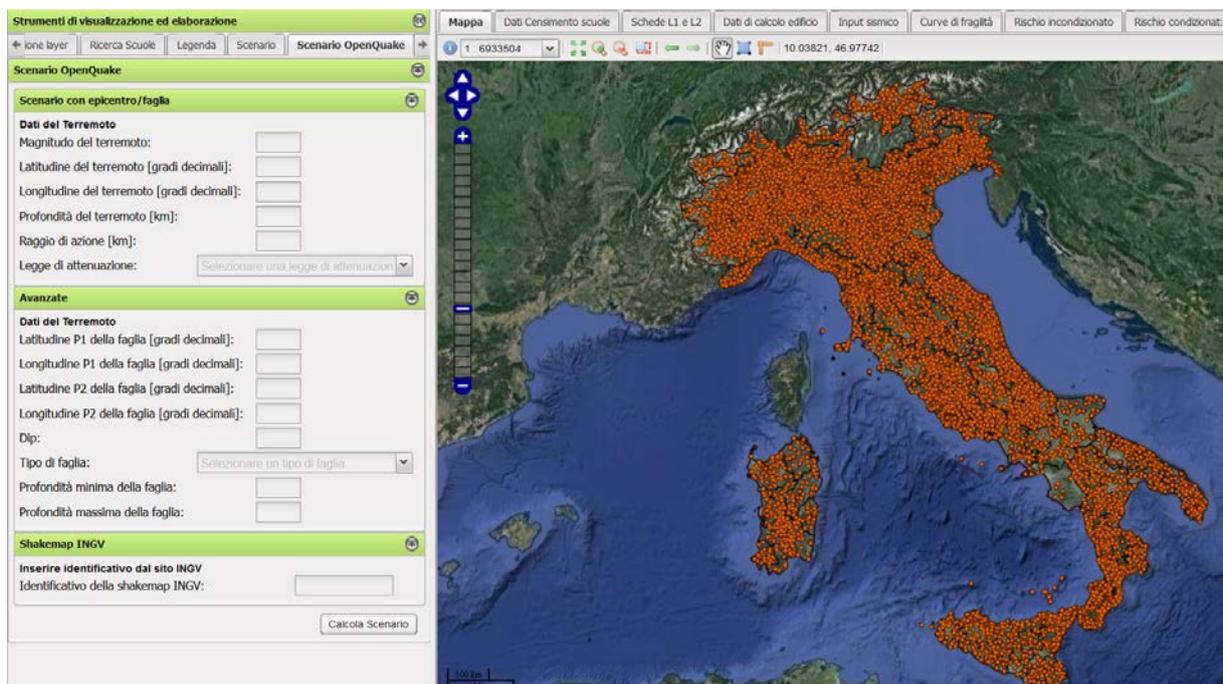


Figure 3. Tool to elaborate real time damage scenarios with OQ-engine for school buildings

2.3 OpenQuake for infrastructures in the road network

The last platform in which OQ-engine has been implemented relates to the road network. Using this WebGIS platform the user will be able to produce seismic risk and damage scenario maps for many typologies of infrastructures which affect the road system. The infrastructures examined are: bridges, retaining walls, tunnels, ports and airports. The tool “Scenario OpenQuake” is like the previous two, but the user can select one or more infrastructures interested in the scenario calculation. Figure 4 shows the WebGIS platform for the road network and this specific tool.

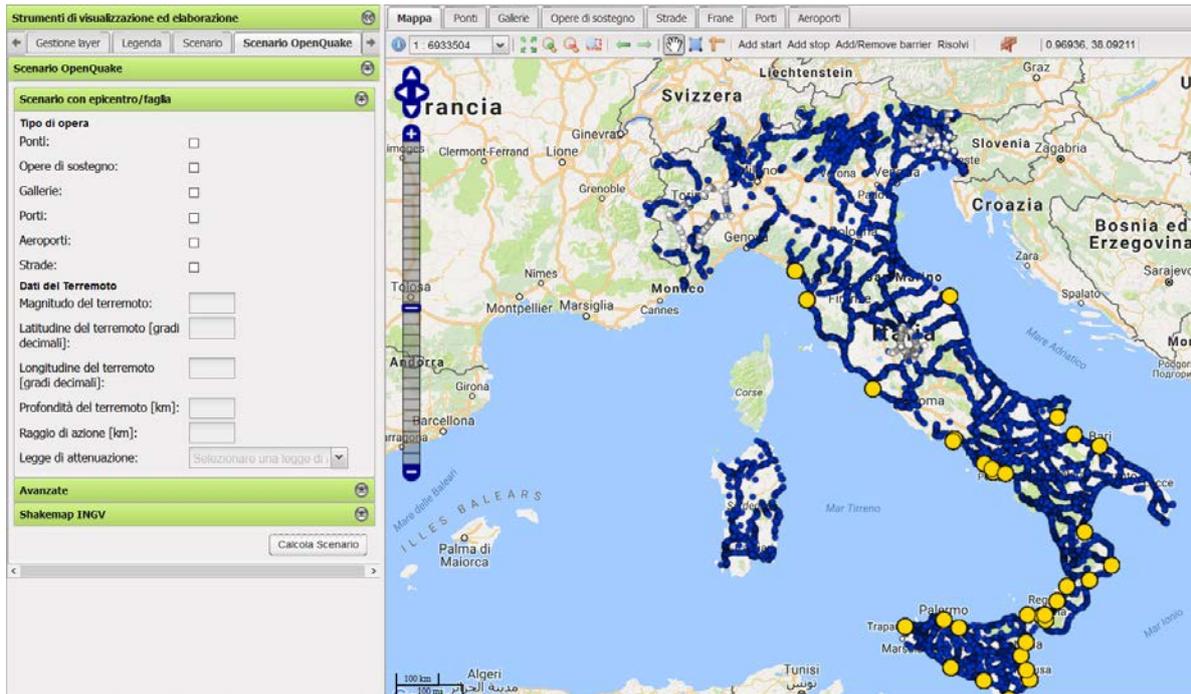


Figure 4. Tool to elaborate real time damage scenarios with OQ-engine for infrastructures on the road system

3. IMPLEMENTATION OF WEBGIS / OPENQUAKE INTERFACE

3.1 Required input files

OpenQuake requires several input files in order to perform its calculations:

- Configuration file: text file with the typology of analysis (Scenario Damage Assessment or Classical Probabilistic Seismic Damage Analysis), short description of the analysis, name of the fragility and exposure files, identification of the interested area for the analysis (for example coordinates of the polygon that encloses the area);
- Fragility model: XML file listing the kind of the fragility curve (in this case it's a lognormal curve), the input data in the x-axis (in this case pga), the fragility values (mean and standard deviation) for the different taxonomies used in the calculation. Every taxonomy is associated with a fragility curve for each damage level;
- Rupture model: XML file with the hazard parameters (the required parameters change depending on the type of analysis performed);
- Exposure model: XML file listing the exposure to consider in the calculation. Each asset in the list contains an id, the taxonomy, the number of buildings/bridges/etc. and their position.

The number of damage levels listed in the fragility file is different for each structure: there are five damage levels (from D1 to D5 derived from the EMS scale [Grunthal 1998]) for residential and school buildings, two for bridges (moderate and severe), three for ports, airports and tunnels (light, moderate and severe) and one for retaining walls (moderate). There's an additional damage level that refers to the absence of damage for buildings, named D0.

3.2 Input file creation for the various calculations

While the creation of the configuration file is straightforward, fragility, rupture model and exposure files creation may be different for each calculation type, as described below.

3.2.1 Real time damage scenario

This calculation uses the Scenario Damage Assessment analysis of OpenQuake. The creation of the fragility file is different for each of the three platforms used: the residential buildings platform uses a static file with different taxonomies, while the other two are derived from a query performed in the database where the fragility for the different structures (school buildings, bridges, etc.) is stored. In the rupture file there are parameters of the earthquake event, i.e. its magnitude, position, depth. The exposure file is simply a list of buildings/bridges/etc. within the radius chosen for the scenario calculation.

3.2.2 Conditional risk

This calculation was exclusively developed for residential buildings and uses OpenQuake's Scenario Damage Assessment analysis. Since the WebGIS platform runs custom fragility curves, the fragility file is based on the values stored in the database for the chosen curve sets. The rupture file is represented by a "gmf" (ground motion field) file: for every point in the map (latitude and longitude) the pga value is reported, in relation to the return period selected. Since the calculation is performed on the whole territory, the exposure file is a static file with the exposure of the Italian municipalities.

3.2.3 Unconditional risk

This calculation also was developed only for residential buildings. It is based on the Classical Probabilistic Seismic Damage Analysis of OpenQuake and the fragility file is based on the custom set of curve like in the conditional risk. The rupture file is represented by a hazard curve file for each of the three time windows considered (1, 10, 50 years). These are static files read from File System. The exposure file is the same used in the conditional risk calculation.

3.3 Running the Calculation Engine

Once the input files are correctly created, the instructions to run the OQ-engine are executed from the Java Server application in charge to create a new thread for each step and to monitor the activity of OpenQuake, interpreting the console output and parsing the output files as soon as they are ready. Figure 5 shows the implementation scheme of OQ-engine in the WebGIS platforms.

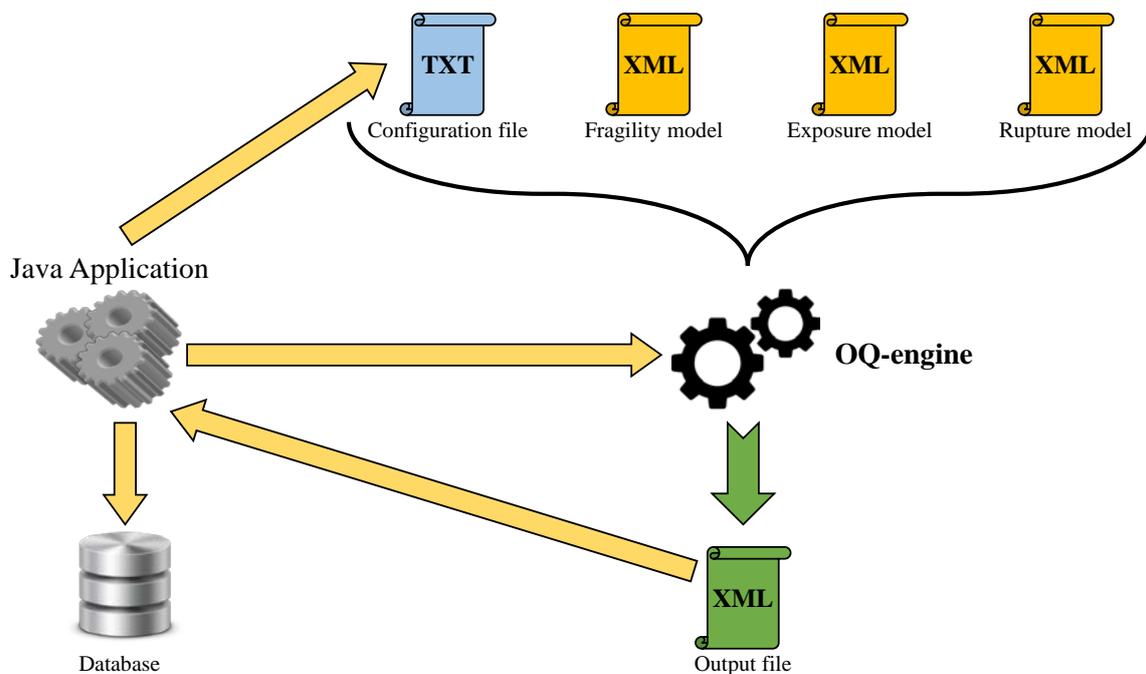


Figure 5. OpenQuake integration scheme

3.4 Results

OpenQuake results are stored in its internal database and can be exported as an XML file. Java application parses such file, calculates additional computations as percentages, and stores them in a dedicated table inside the WebGIS database. In the web application, a layer is dynamically created, using GeoServer, and displayed on the map.

4. SEISMIC RISK MAPS AND DAMAGE SCENARIOS DERIVED FROM DIFFERENT METHODOLOGIES

In order to verify the correct implementation of OQ in the WebGIS platforms described in the previous chapters, the risk maps for residential buildings obtained with the OQ-engine from the WebGIS and those obtained with Eucentre tools were compared in §4.1. Then, §4.2 shows a comparison between the damage scenario for L'Aquila 2009 earthquake obtained with OQ-engine from the WebGIS, those obtained with Eucentre tools and the damage data observed in field collected with the Aedes forms.

4.1 Comparison of seismic risk maps

Seismic risk maps have been generated for different return periods and time windows using two different calculation tools (OQ-engine and Eucentre), using the same input data: the buildings fragility is described by a single set of fragility curves for all Italian municipalities, the hazard is deriving from the NTC08 (D.M. 14.01.2008) and the exposure derives from the ISTAT 2001 database. Figure 6 shows the maps for a return period of 475 years and damage level D2, while Figure 7 shows the maps for a time window of 50 years and damage level D3 in terms of % of buildings.

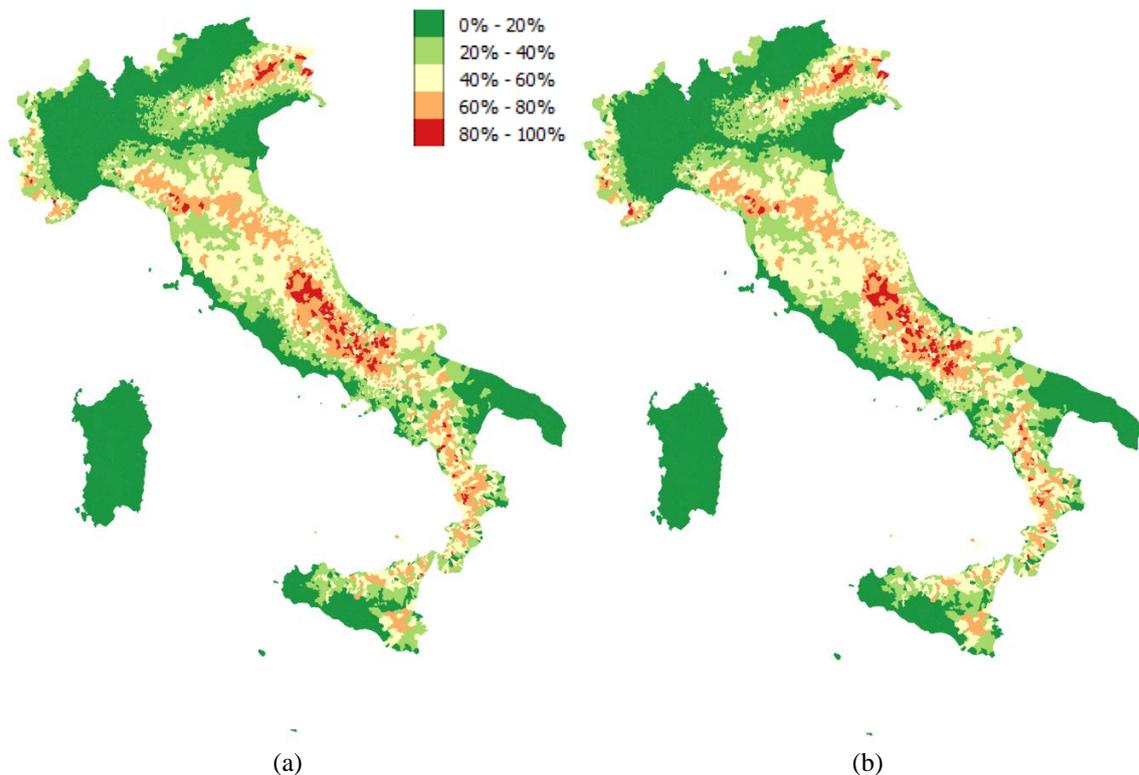


Figure 6. Seismic risk maps for a return period of 475 years in terms of % of buildings that reach the damage level D2 elaborated with (a) OQ-engine and (b) Eucentre tool

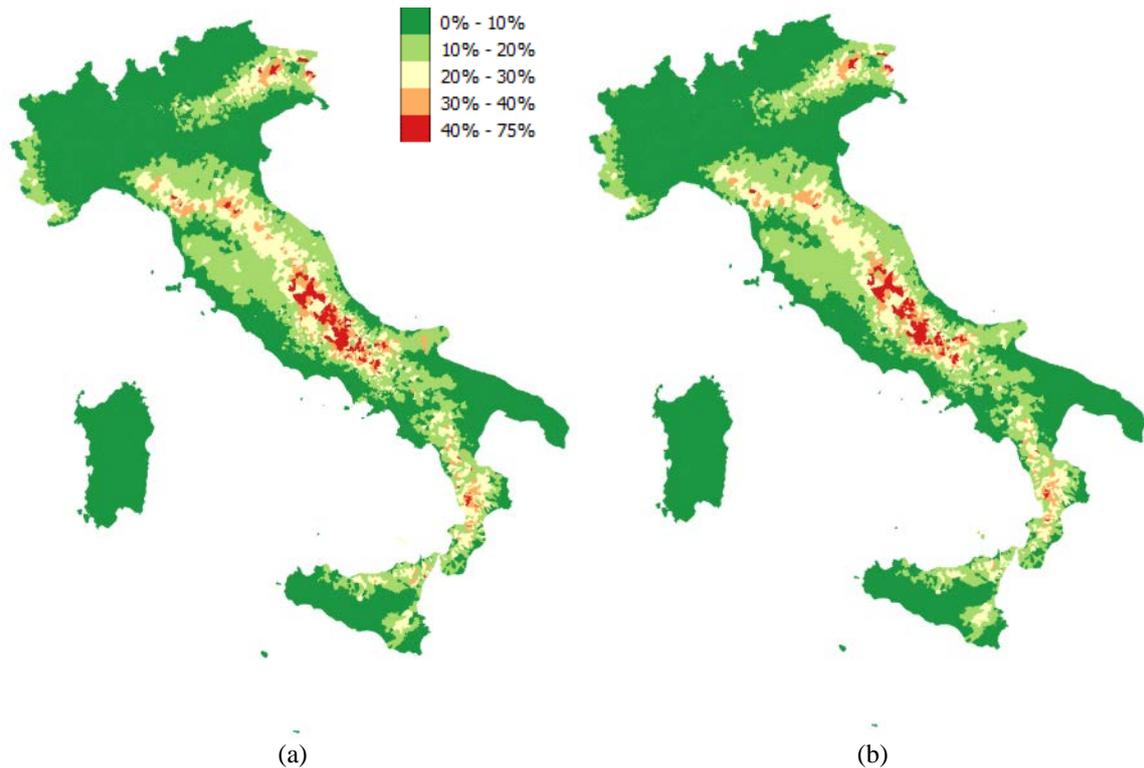


Figure 7. Seismic risk maps for a time window of 50 years in terms of % of buildings that reach the damage level D3 elaborated with (a) OQ-engine and (b) Eucentre tool

The good agreement between the maps shown in Figure 6 and 7 proves that OQ-engine “Classical Probabilistic Seismic Damage Analysis” has been properly integrated into the WebGIS platform.

4.2 Comparison for the scenario damage of L’Aquila 2009

Using the WebGIS platform developed for residential buildings, the damage scenario for L’Aquila 2009 earthquake with OQ-engine and the Eucentre tool was generated. The results were compared with the observed data. Figure 8 shows the comparison in terms of usability criteria obtained with different GMPEs (Boore and Atkinson 2008, Akkar and Bommer 2010, Bindi et al. 2011). In order to correlate the damage levels and the usability criteria, the formulation elaborated by Sabetta et al. (2013) and reported below was used:

- Usable buildings: $D0+0.6\cdot D1$
- Damaged buildings: $0.4\cdot D1+0.2\cdot (D2+D3)$
- Unusable buildings: $0.8\cdot (D2+D3)+D4$
- Collapsed buildings: $D5$

Figure 9 shows the mean values obtained from the three GMPEs in terms of damage levels. The mean values attenuate the differences reported in Figure 8 showing a good agreement between the scenarios obtained with OQ-engine and those derived from the Eucentre tool. The integration of OQ-engine “Damage Assessment Scenario” in the WebGIS platform can be considered validated. The comparison with the observed data generally shows an overestimation of the damage, especially for D3 and D4. The differences are, however, limited, reaching at most 24% for D0, and therefore fall within the range of acceptability for large scale scenarios.

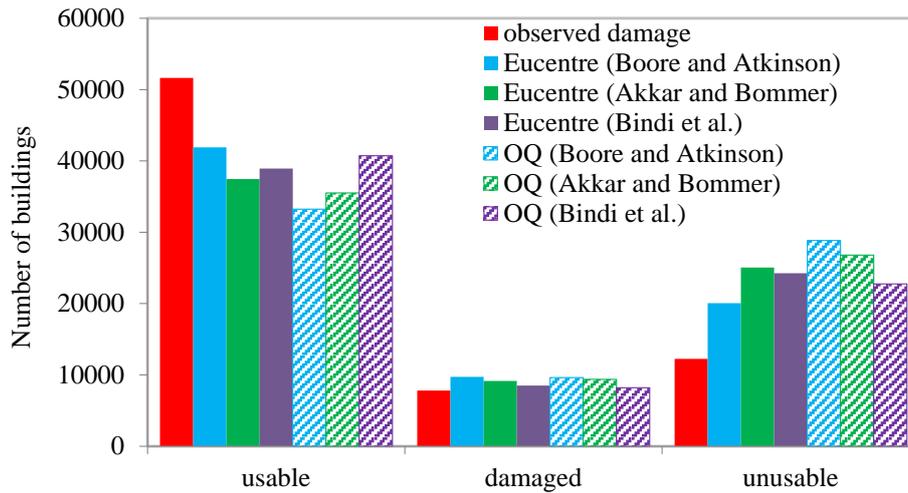


Figure 8. Damage scenario in terms of usability criteria with three GMPEs

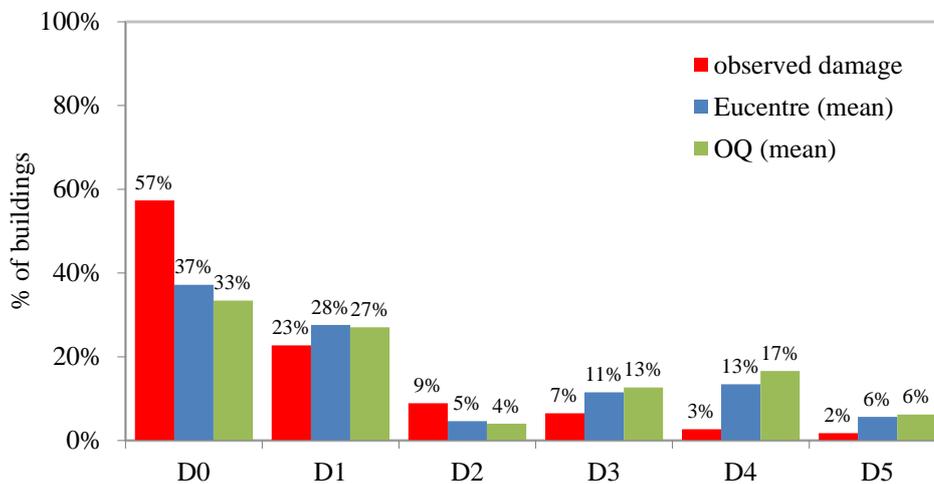


Figure 9. Mean damage scenario in terms of damage levels

It is worth explaining the differences between OpenQuake and Eucentre. Although in the calculation with OpenQuake SP-BELA fragility curves are used (Borzi et al. 2008a, 2008b), the differences are due to the fact that Eucentre routines, using SP-BELA as well as a fragility methodology, do not consider fragility curves, but a comparison between building capacity and demand imposed by the earthquake. Therefore, in Eucentre routine the scenario is a point of a fragility curve calculated for the spectral shape corresponding to the GMPEs. OpenQuake, on the other hand, extracts the point of the fragility curve that corresponds to the PGA value defined according to the GMPE. Furthermore, the SP-BELA fragility curves have been calculated assuming a frequency content of the earthquake, which does match with the GMPE spectral shape.

5. CONCLUSIONS

This paper describes the integration of OQ-engine in the WebGIS platforms developed by Eucentre. The work carried out has shown the versatility of the two components: the platforms and the calculation engine. By creating a special graphical interface and custom written Java applications that feed the computing engine, send input files and then rework outputs, you can connect other computing hardware besides the one shown here. Similarly, OQ-engine has shown that its integration into a platform does not imply great difficulties, so it could easily be integrated into several risk management

platforms. The work here presented makes the adoption of OQ-engine, basically used by command line, very user friendly and leaves to an ad hoc graphical interface the difficulties related with the definition of input and interpretation of output.

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