

# A comprehensive review of seismic hazard and loss estimation software

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## ABSTRACT

Over recent years, seismic losses are increasing rapidly, mainly due to the steady increase of population and exposure in earthquake-prone areas. Improved knowledge and accurate predictions of potential seismic risks are needed to plan appropriate emergency response, rescue, and recovery actions. The focus of the research community has therefore concentrated on the development of a various seismic risk assessment software. This paper presents a comprehensive review of the methods and analyses run by available software. First, the common steps in the seismic risk analysis are discussed, namely, seismic hazard, inventory of the exposure and vulnerability models. The following software is considered: HAZUS, EQRM, OpenQuake, CAPRA and ER2-Earthquake. The main advantages and limitations of each software are highlighted.

## RÉSUMÉ

Au cours des dernières années, les pertes sismiques augmentent rapidement, principalement en raison de l'augmentation constante de la population et du milieu bâti dans les zones sujettes aux tremblements de terre. Une meilleure connaissance et des prédictions plus précises des risques sismiques potentiels sont nécessaires pour mieux planifier les interventions d'urgence, de sauvetage et de rétablissement appropriées. La communauté de recherche s'est donc concentrée sur le développement de divers logiciels d'évaluation des risques sismiques. Cet article présente une revue complète des méthodes et des analyses exécutées par les logiciels disponibles. Tout d'abord, les étapes communes de l'analyse du risque sismique sont discutées, à savoir l'aléa sismique, l'inventaire du milieu bâti et les modèles de vulnérabilité. Les logiciels suivants sont pris en compte : HAZUS, EQRM, OpenQuake, CAPRA et ER2-Earthquake. Les principaux avantages et limites de chaque logiciel sont mis en évidence.

## 1 INTRODUCTION

Earthquakes represent a major natural hazard that regularly causes damage to built environment resulting in social and economic losses. Seismic losses in earthquake-prone locations have increased significantly during the past decades ([Guha-Sapir et al. 2017](#)). Beside the overall increase of the exposed population and built environment, the development of super-cities around the Pacific rim and the ever-rising vulnerability of modern societies and sophisticated technologies are important factors to consider ([Kazama and Noda 2012](#); [Smolka et al. 2004](#)). Middle-income countries and particularly those with rapidly growing cities appear the most susceptible to devastating earthquakes ([Tansey et al. 2018](#)). Strong earthquakes, e.g., 2004 M6.7 Northridge, 2004 M9.1 Sumatra, 2011 M6.3 Christchurch, 2011 M9.1 Tohoku, etc., generated significant economic consequences, as well as damage to essential facilities (e.g., hospitals, schools, fire and police stations), lifelines (e.g., potable water supply, gas and oil pipelines), transportation networks (e.g., roads, railways, and bridges), cultural heritage legacy, and the environment ([UNISDR 2015](#)). In many cases, even the buildings

designed to the latest seismic codes sustained damage to a various degree.

Seismic risk assessment is a complex engineering and scientific challenge not only because of the individual structural vulnerability, but also because of the vibrant nexus amongst the city's environment, its residents and many interrelated networks ([Smith 2005](#)). The prediction of seismic risk requires detailed information on the ground shaking intensity (hazard), exposed buildings and infrastructure (exposure) and respective vulnerabilities. Risk assessment results consist of quantification of physical damage and economic and social losses and their likelihood ([UNISDR 2009](#)).

In the last few decades, considerable effort has been made to create an appropriate seismic loss estimation (SLE) software that provides fairly accurate loss estimates, such as Hazard US (HAZUS) ([Kircher et al. 2006](#)) and its versions such as Ergo ([MAE Center 2006](#)), Haz-Taiwan ([Yeh et al. 2006](#)), SELINA ([Molina and Lindholm 2005](#)) and HazCan ([Ulmi et al. 2014](#)), then InaSAFE ([AIFDR 2020](#)), CAPRA ([Reinoso et al. 2018a](#)), DBELA ([Crowley et al. 2004](#)), OpenQuake ([Silva et al. 2014](#)), ER2 web application ([Abo El Ezz et al. 2019](#)), etc. ([Hosseinpour et al. 2021](#)). As it can be seen, certain countries have

developed their own customised versions of SLE software, whereas global projects, such as the Global Earthquake Model (GEM), are developing tools with worldwide capacity (Silva et al. 2014).

This paper provides a comprehensive assessment of the available SLE software. The hazard, exposure, and vulnerability modules of SLE software are covered in depth. The various methods for assessing structural vulnerability are discussed together with important advantages and limitations of each software.

## 2 SEISMIC LOSS ESTIMATION COMPONENTS

Seismic hazard and risk are two fundamentally different concepts. Seismic hazard refers to the intensity of the ground shaking and of other induced hazards generated by an earthquake, whereas seismic risk refers to the negative impacts that may occur to people and built environment and their likelihood. The seismic risk assessment process involves quantification of three major input components, namely, seismic hazard intensity, inventory of assets at risk and respective vulnerability.

### 2.1 Hazard

Seismic hazard is defined by the probability of occurrence a ground motion with a given intensity over a specific period of time at a given location (Bommer 2002). Earthquake hazards can be divided into two main categories, namely, transient ground shaking and permanent ground failures. In the seismic loss analyses, the intensity of ground shaking is the major considered hazard component, whereas identifying and modelling of the secondary hazard parameters of earthquakes is more complex and considerably less reliable (Bird and Bommer 2004). The secondary hazards of earthquake include surface fault rupture, soil liquefaction, settlement, lateral spread, landslide and slope instabilities. They are quantified via the peak ground acceleration (PGA) and permanent ground displacements. Other earthquake induced hazards include tsunamis, seiches, fires, etc. In terms of ground shaking, the 5% damped spectral accelerations at the predominant vibration periods are generally considered as shaking intensity measures (IMs), e.g.,  $S_a(0.3s)$  and  $S_a(1.0s)$ , together with PGA, roof displacement and inter-story drift, defined as the translational displacement between two consecutive floors. There are risk assessment methodologies which are based on the European Macro-seismic Scale or Modified Mercalli Intensity (MMI) (Porter et al. 2008).

The procedures used to assess seismic hazard include two options: Probabilistic seismic hazard analysis (PSHA) and Deterministic seismic hazard assessment (DSHA). PSHA is commonly used for structural analysis and engineering design. This technique considers all probable seismic sources that may affect the studied area. Each seismic source has own magnitude-frequency (Gutenberg-Richter) relationship. The design response spectrum has an annual probability. The total probability theorem determines PSHA (Hosseinpour et al. 2021). DSHA, on the other hand, is compatible to PSHA, but includes a single scenario earthquake with a given magnitude and distance selected

to calculate spatial distribution of the hazard IMs in the study area.

### 2.2 Exposure

The rapid growth of the population requires accurate and up-to-date characterisation of the ever-changing exposure component. The acquisition of building parameters is probably the most time-consuming, tedious and expensive part of each seismic risk assessment (Dunbar et al. 2003). The simplest way to gather building information is to use the one that is already available (e.g., information contained in census questionnaires or municipal tax evaluations). A few global building inventory databases were also created during past research projects. For instance, the US PAGER developed a global building database from a range of national and international sources and experts opinions applying specific procedures to fill in the gaps in the datasets (Porter et al. 2008). Some of the sources included census reports and descriptions from the World Housing Encyclopaedia, the HAZUS database, United Nations (UN) reports, etc. (Wyss et al. 2013). The UN's 2013 Global Assessment Report established an exposure model to evaluate natural hazards losses at the global scale (De Bono and Mora 2014). Population and housing censuses are conducted in most of the countries, and they often contain useful information about the year of construction, load bearing components and roof materials that can be used to infer the type and height of buildings, predominant construction type, etc. (Mansouri et al. 2014).

### 2.3 Vulnerability

The physical vulnerability can be defined as the susceptibility of the exposed buildings to seismic impacts (damage) determined with the likelihood of the occurrence of certain damage level caused by the seismic action. Vulnerability analysis represents a powerful engineering technique at urban and regional scale risk assessments. Central to the vulnerability modelling is the concept of vulnerability curves that link the probability of loss at a given level of seismic motion IM, such as response spectral acceleration for given period and damping ratio. Similarly, fragility (damage) curves represent the likelihood of exceeding different limit states (e.g., physical damage state) given the intensity of the seismic motion. Depending on the specific conditions, vulnerability and fragility curves, either separately or combined, can be assumed as reliable predictors of damage for a respective group of building with similar structural characteristics and dynamic behaviour.

The development of vulnerability functions is based on one of the following fundamental approaches: empirical, analytical, expert opinion or a combination of the three (hybrid methods) (Calvi et al. 2006; Clementi et al. 2016; Porter 2017). Which method will be selected depends on the quality and type of available data, the expert's knowledge, available resources and the scale of the study area.

The empirical approaches use field observations from past earthquakes to predict physical damage or economic losses for similar seismic settings. From the risk management viewpoint, empirically derived vulnerability

functions are generally the most credible since they are entirely derived from the observations of the actual performance of buildings during strong earthquake events. Analytical vulnerability assessment approaches use modelling to examine a structure's dynamic response to seismic loads. While idealising structural models is possible, it always involves major assumptions and simplifications that may lead to variability. Analytical vulnerability modelling can vary in complexity depending on the modelling method, input data, and model parameters ([Hosseinpour et al. 2021](#)).

### 3 LOSS ASSESSMENT SOFTWARE

Various SLE software is currently being used worldwide to provide predictions of the seismic loss estimates. The available software packages can be proprietary, open access or open-source, and most of them are developed for a specific region with own seismotectonic settings and construction practices. Table 1 summarizes the available SLE software inventoried during this study.

floods, hurricanes and tsunamis. The primary modules of HAZUS are shown in **Error! Reference source not found.**

HAZUS is developed by private companies as a closed source software accompanied by comprehensive users and technical guidelines and parameters of the applied damage functions ([Porter 2010](#)). The software uses C++ and Visual Basic algorithms and Microsoft SQL as relational database interfacing with ArcGIS to visualise damage to the building stock, lifelines and high-potential loss facilities ([FEMA 2012](#); [HAZUS 2013](#); [Kircher et al. 2006](#)).

The modernisation of HAZUS is ongoing with the objective to exclude any commercial software needs on the user's side. The current HAZUS v.4.2 SP3, as of May 2022, offers high-resolution shake-maps and an updated module of fire growth following earthquake. Input data with information on the building stock aggregated at census tract level and links to web sites with supplementary information are provided out-of-the-box. The standard building inventory consists of 15 basic categories with respect to the structural type and material, which when multiplied by building height (low: 1-3 stories, medium: 4-7 stories, high: +8 stories) and design level (pre-, low-, medium- and

Table 1. Summary of the seismic risk assessment software packages

| Software      | Institution          | Programming Language       | Applicability   | Open source | Hazard                         | Vulnerability           | Graphical user interface |
|---------------|----------------------|----------------------------|-----------------|-------------|--------------------------------|-------------------------|--------------------------|
| HAZUS-MH      | FEMA                 | VB6, C++                   | U.S.            | No          | Deterministic<br>Probabilistic | Analytical              | Yes                      |
| HAZCan        | NRCAN                | VB6, C++                   | Canada          | No          | Deterministic<br>Probabilistic | Analytical              | Yes                      |
| Ergo (MAEviz) | Illinois U.          | Java (Eclipse Rich Client) | US.             | Yes         | Deterministic<br>Probabilistic | Analytical<br>Empirical | Yes                      |
| OpenQuake     | GEM                  | Python (Web-based), NRLM   | Italy           | Yes         | Deterministic<br>Probabilistic | Analytical<br>Empirical | No                       |
| SELENA        | NORSAR               | MATLAB, C++                | Norway          | Yes         | Deterministic<br>Probabilistic | Analytical              | Yes                      |
| CAPRA         | World Bank           | Visual Basic.NET           | Central America | Yes         | Deterministic<br>Probabilistic | Analytical<br>Empirical | Yes                      |
| ER2           | NRCAN, CSSP          | Java                       | Canada          | No          | Deterministic<br>Probabilistic | Analytical              | Yes                      |
| EQRM          | Geoscience Australia | Python, MATLAB             | Australia       | Yes         | Deterministic<br>Probabilistic | Analytical<br>Empirical | No                       |

#### 3.1 HAZUS

The U.S. Federal Emergency Management Agency (FEMA) started the development of the HAZUS software in the early 1990s for calculation of seismic impacts to buildings and infrastructure, social (e.g., casualties, shelter needs) and economic losses at the census tract, county or state scales. The advanced engineering building module allows for loss assessment at the building level.

Earthquake hazard is considered as transient ground shaking and permanent ground failure ([Kircher et al. 1997](#)). Today, HAZUS is a multi-hazard tool that also includes

high-code), which provides a total of 128 building types.

Beside the building types, HAZUS also includes seven major occupancy categories which impact the building seismic performance parameters, reconstruction costs and resulting social and economic losses: residential, commercial, industrial, agricultural, religious, government, and educational buildings.

The HAZUS vulnerability evaluation included in the module for direct physical damage is based on the capacity spectrum method, CSM, described in ATC-40 ([ATC 1996](#)). In this approach, the performance point of a given building type subjected to specific ground-motion parameters is

determined from the intersection of the seismic demand in the acceleration–displacement domain with the capacity spectrum (pushover curve) that reflects the horizontal displacement of the structure under increased lateral load (Kircher et al. 1997).

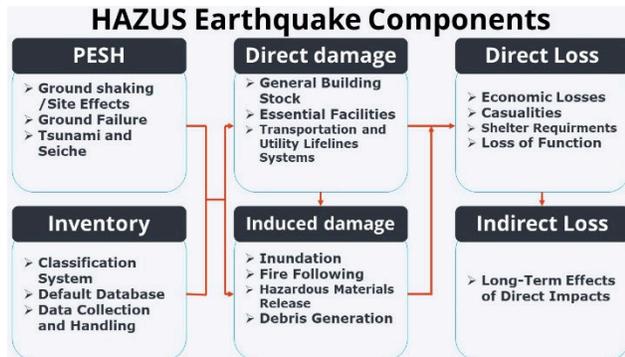


Figure 1. Primary components of HAZUS

### 3.2 EQRМ

EQRМ is an open-source SLE software developed by Geo-Science Australia for Australian seismotectonic conditions and construction practices (Robinson et al. 2007). EQRМ was developed in Python and MATLAB and does not have GUI nor is integrated to a GIS system. EQRМ basically applies the HAZUS methodology for damage assessment with certain differences (Patchett et al. 2005; Robinson et al. 2005):

- CSM implementation: the full structure of the response spectrum and the soil’s amplification across all the vibration periods of interest are considered;
- As opposed to HAZUS, which incorporates the variability of damage state thresholds, capacity curves and the ground shaking, the EQRМ fragility curves considered only the variability of damage state
- Uniform hazard spectra are used instead of demand curves, and MMI scale can also be used.

As well, EQRМ includes PSHA and probabilistic seismic risk analysis using the event-based approach (Dhu et al. 2008). In this way, the ground shaking parameter and respective losses are first computed for each event individually, and then the results are aggregated to obtain probabilistic risk estimates (Robinson et al. 2005). This software can provide various outputs for both the hazard analyses: Seismic hazard maps, hazard exceedance curves and uniform hazard spectra, and for the risk analyses: risk exceedance curves, aggregated and disaggregated annualised losses (Daniell et al. 2014; Robinson et al. 2005).

### 3.3 OpenQuake

The OpenQuake Engine is GEM’s software for seismic hazard and risk assessments at different scales. The current OQ 3.14.0 version is open source coded with the Python programming language. Natural hazard’s risk Markup Language (NRML) is an XML-based language that was developed in parallel with GEM project, and OpenQuake uses this language to read input parameters

and perform loss analyses (GEM 2020). OpenQuake is also very transparent software which is used with GEM or other user-developed models to perform scenario-based or probabilistic risk analyses to generate various hazard and loss outputs. The spatial correlation of the ground motion residuals and correlation of the uncertainty in the vulnerability can also be modelled. The major calculation algorithms include the scenario risk calculator, scenario damage calculator, classic PSHA-based risk, probabilistic event-based (PEB) risk (Figure 2) and retrofitting benefit–cost ratio (GEM 2017; Silva et al. 2014).

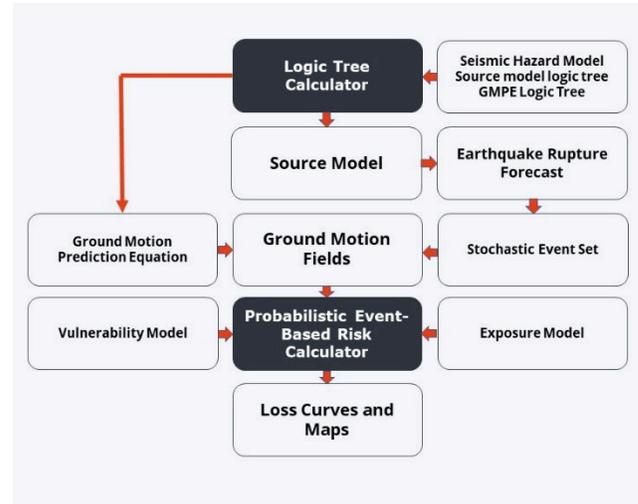


Figure 2. Probabilistic event-based risk assessment process in OpenQuake

When compared to the other SLE software, the PEB calculator is the most innovative module. In PEB, Monte Carlo method is used to generate a stochastic event set (SES), which represents a potential realization of seismicity, with a ground motion field calculated for each event contained in SES. The event-based PSHA calculator takes this large set of ground-motion fields, representative of the potential shake scenarios that the investigated area can experience over a given time period and for each site that computes the corresponding hazard curve. However, the procedure is computationally intensive and is not recommended for large study areas. GEM also developed an evaluation and selection framework of existing fragility curves for new studies (Rossetto et al. 2014). It guides the user to verify the overall quality of the current fragility curves and their relevance, and to reduce inaccuracies by enhancing the selection process. The selection amongst the currently available fragility curves can be very subjective and applying the GEM framework necessitates an in-depth knowledge and data about the structural dynamic response and evaluated fragility curves.

### 3.4 CAPRA-Earthquake

CAPRA is another risk assessment platform released in 2008 with the support of the World Bank (ERN-AI 2020). This platform is an open-source software programmed in Visual Basic language, and its GUI is relatively easy to understand. This software has different modules for risk

assessment: the Strong Motion Analyst deals with processing of strong motion signals and seismological data, Seismic Microzonation Studio focuses on the dynamic soil response in 3D geological environments, and CRISIS 2015 is the PSHA module (Bernal and Cardona 2018; Reinoso et al. 2018b).

The main module is CAPRA-GIS (V 2.4.0), which calculates losses caused by different natural hazards, including earthquakes. CAPRA-GIS performs loss assessment once the required input files (i.e. hazard, exposure and vulnerability files) are imported to this module. The seismic hazard analysis is first conducted by CRISIS 2015 (Aguilar Meléndez et al. 2017), and the results are imported to CAPRA-GIS in \*.ame file format for further loss assessments. The hazard model includes a collection of stochastic scenarios related to specific annual frequency of occurrence, spatial distribution of intensity and variability across the region of interest. A new CAPRA module called CAPRA-EQ is currently being developed and will have the capability to conduct stochastic seismic hazard modelling to be used in risk analyses, reduction and management (ERN-AI 2020).

The damage assessment relies on the vulnerability functions developed for each building type that are provided to the CAPRA-GIS. The development of vulnerability functions is carried out using the CAPRA module ERN-Vulnerabilidad, which is developed by ERN Co. This module considers different methods to generate vulnerability functions and allows the user to define their own functions. The uncertainty in vulnerability functions is considered by adjusting the variance ensuring zero variance for no seismic demand and for infinite demand, considering that the predictable damage is zero for no seismic demand and complete for infinite demand level. The parameters used for adjusting the variance are determined by experts' judgment (Crowley et al. 2010). CAPRA provides the following outputs over a set of buildings or for a single building: loss exceedance curve, probable maximum loss and average annual loss.

### 3.5 ER2-Earthquake

ER2 (Rapid Risk Evaluator) is another HAZUS-based risk assessment software that is currently being developed by Natural Resources Canada (Abo El Ezz et al. 2014; Abo El Ezz et al. 2019). ER2 is the only web-based user-friendly software that can be run by both expert and non-expert users. It has been developed using Java (vulnerability assessment applet) and Python (web-based interface) programming languages. Seismic risk assessment can be carried out for a user defined scenario earthquake or for embedded probabilistic scenarios over a range of return periods between 100 and 10,000 years.

An innovation regarding the standard HAZUS methodology is that ER2 introduces a non-iterative algorithm instead of the standard CSM for the computation of the performance point (Porter 2009). The efficient inverse procedure starts from the performance point (structural response) and then determines the respective seismic scenario that caused it. The performance point is specified with an effective damping ratio and a pair of spectral displacement-spectral acceleration values. This seismic demand is correlated to

the 5% damped input spectrum determined with the IMs, e.g.  $S_a(0.3s)$  and  $S_a(1.0s)$ , from the respective seismic scenario (magnitude, distance, local site conditions, GMPE). For the considered building type, the spectral displacement of the performance point is associated with the set of the respective HAZUS displacement-based fragility functions and the probability of being in each of the five potential damage states is obtained. In the last step, probabilities of the damage states are linked to the IMs of the input spectrum. The procedure commences with low spectral acceleration values yielding elastic response (displacement) on the capacity curve. The spectral acceleration is gradually increased until a reasonably high displacement is attained in a fully plastic state of the capacity curve. The results from numerous scenarios are stored in a database for each building type (Abo El Ezz et al. 2019; Nollet et al. 2018), substituting the tedious iterations for the performance point quantification with simple queries to pick-up rapidly the appropriate pre-computed scenario. The development process for the forward (HAZUS) and backward (ER2) method is presented in Figure 3 **Error! Reference source not found..**

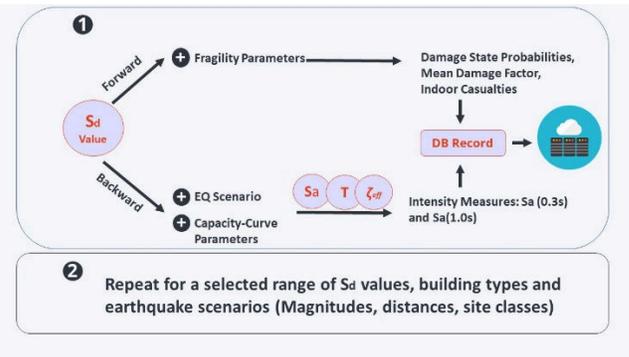


Figure 3. Forward (HAZUS) and backward (ER2) methods for computation of building damage states

A diagrammatic representation of the sequence of operations constituting ER2 is presented in Figure 4. The user should begin by locating the epicenter of the earthquake on the map. Next, the user should choose the type of analysis to perform (either a user-defined scenario or a probabilistic scenario), and then they should click the Run button. The results from software finally are reported in terms of the economic and social losses.

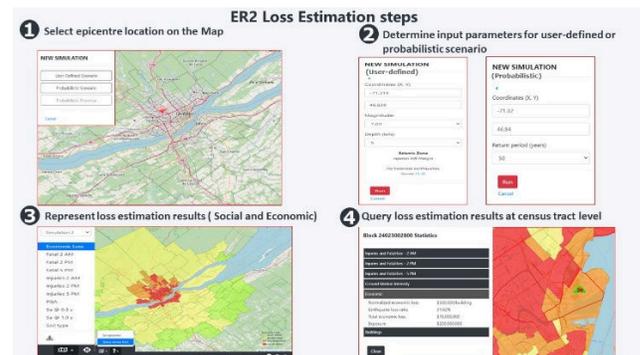


Figure 4. Schematic presentation of the consecutive steps for running ER2

#### 4 DISCUSSION

It has been demonstrated that the analysed SLE software has many positive features. These includes implementation of GUI and the possibility for on-screen visualisation of input and output parameters (e.g., Ergo), open-source codes (e.g., SELENA, EQRM, Ergo, ER2), web-based online software free of any charge for use of commercial software (e.g., OpenQuake, ER2), use of logic tree to model epistemic uncertainty (e.g., SELENA), comprehensive user and technical manuals (e.g., SELENA, HAZUS) and the possibility for users to provide their own input data and determine the type of analysis (e.g., user-defined regions, vulnerability functions and hazard parameters).

Certain limitations have also been observed in terms of the application of the SLE software, including the absence of detailed technical documentation, the need of significant coding, lack of flexibility for user-provided input, wide-range of pre-processing, formatting and input data preparation, lack of GUI, restrictions on the type of analyses and outputs, and most of all the requirement for a high level of expertise for application of majority of the software and the need for licenses to run proprietary software.

Several data acquisition methods have been reviewed in the Exposure section. The most effective method for a given study area can be determined followed by the comparison of the cost of data acquisition against the obtained level accuracy precision of the final datasets, as well as the ability of each of the methods to collect the most important or the 'more useful' data.

Different approaches and methods for seismic vulnerability assessment were highlighted. The input data vary considerably based on the seismic vulnerability assessments method, simplified methods that apply data that mostly affect the seismic vulnerability to more complex ones that requires comprehensive information on the buildings and infrastructures characteristics. Given the assessment of seismic vulnerability of a large study area, attaining the level of detail required by the more complex methods could be an important challenge. Consequently, simplified methods are generally applied. Nonetheless, several methods are focused on specific buildings, infrastructure classes or locations, thereby limiting their wider applicability.

The PSHA can be computationally laborious and its use in regional SLE is potentially less effective. The other more sophisticated option is to represent the seismic hazard with a large number of earthquake scenarios consistent with the regional seismicity in magnitude, location and associated frequency ([Crowley and Bommer 2006](#); [Silva 2018](#)). OpenQuake and EQRM perform event-based PSHA and analyses, and these processes should be applied to other risk assessment software. For convergence in event-based risk assessment for the rate of exceedance above  $10^{-3}$  at a single location, SES with 200,000 years is generated to achieve reliable results ([Silva 2018](#)). PSHA-based loss curves overestimate the losses because the aleatory

variability in the ground-motion prediction at each site is treated as being entirely inter-event variability where in fact a large component of the variability is intra-event ([Crowley and Bommer 2006](#)).

Problems in scenario loss modelling and probabilistic seismic risk assessment, such as the number of simulations needed to obtain reliable results and convergence in probabilistic event-based loss assessment, effects of selection of GMPEs, assessment of aleatory uncertainty in ground motion and vulnerability and consideration of fault geometry, are encountered ([Silva 2018](#)).

HAZUS does not include uncertainty explicitly, partially assuming that the uncertainty propagation from various sources is covered within the sets of damage functions and the probabilities of a building to exceed the predefined damage states. The final results represent expected loss values and do not include the associated uncertainty ranges that would help better understand the results' potential variability. A sensitivity analysis could be used to investigate the model's variability to some extent. Furthermore, in HAZUS, the epistemic uncertainty that results from a lack of information cannot be considered. For the time being, among the HAZUS based software only SELENA applies the logic tree approach to solve this problem ([Molina and Lindholm 2005](#)). Damage states and loss levels of building structural components defined with qualitative variables (e.g., slight damage state) are not accurate enough and generate high uncertainty in the loss assessment process. Ergo does not support probabilistic assessment. Moreover, it only calculates damages caused by earthquakes, but a user can use USGS probabilistic seismic shake maps as input.

#### 5 CONCLUSION

This paper presented a state-of-the-art review of existing SLE software. The foundation and structure of earthquake loss assessment were first explored and briefly described. The review summarises applicable seismic risk methodology and software components, identifying their benefits and limits and providing recommendations for future risk methods and software development.

Various software for seismic loss assessment have been developed and applied worldwide, and most of them have the same or similar methodology as the one employed by HAZUS considered as the world reference in the domain. For example, ER2 was inspired by HAZUS and is used in Canada; SELENA is another HAZUS-based technology that takes epistemic uncertainty and topography effect into account when assessing seismic risk.

Deterministic scenario earthquake and probabilistic seismic hazard are the two types of earthquakes shaking hazards included in all of the considered SLE software. Most of the software perform their own hazard analyses with the exception of Ergo, Insafe and ER2 that rely on importing respective PSHA shake maps. Most of the SLE software have their own embedded inventory datasets. The OpenQuake team aims to provide a rough global coverage for buildings allowing for a first-hand risk assessment worldwide. Analytical, empirical and expert opinion methods are the three common approaches for providing

vulnerability indices and functions used in the analyses. In most SLE software, analytical vulnerability based on capacity spectrum method is used (e.g., HAZUS and its derivatives).

There has been an increase in demand for online seismic risk assessment tools with a graphical user interface that can be accessed via the internet and run by users with only a basic understanding of earthquake engineering and GIS. In the field of online SLE software, OpenQuake and the user-friendly ER2, both applicable in Canada, are pioneers. These tools set a great example for future SLE tools development. Another useful feature in OpenQuake is the ability to use user-supplied data and choose the type of analysis (for example, user-defined regions, vulnerability functions, and hazard parameters). The availability of comprehensive user and technical manuals (e.g., SELENA, HAZUS) that allow users to understand assumptions and simplifications in each step of the loss assessment process is also an important and practical point to consider.

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