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SELENA – An open-source tool for seismic risk and loss assessment using a logic tree computation procedure ☆

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ABSTRACT

The era of earthquake risk and loss estimation basically began with the seminal paper on hazard by Allin Cornell in 1968. Following the 1971 San Fernando earthquake, the first studies placed strong emphasis on the prediction of human losses (number of casualties and injured used to estimate the needs in terms of health care and shelters in the immediate aftermath of a strong event). In contrast to these early risk modeling efforts, later studies have focused on the disruption of the serviceability of roads, telecommunications and other important lifeline systems. In the 1990s, the National Institute of Building Sciences (NIBS) developed a tool (HAZUS®99) for the Federal Emergency Management Agency (FEMA), where the goal was to incorporate the best quantitative methodology in earthquake loss estimates.

Herein, the current version of the open-source risk and loss estimation software SELENA v4.1 is presented. While using the spectral displacement-based approach (capacity spectrum method), this fully self-contained tool analytically computes the degree of damage on specific building typologies as well as the associated economic losses and number of casualties. The earthquake ground shaking estimates for SELENA v4.1 can be calculated or provided in three different ways: deterministic, probabilistic or based on near-real-time data. The main distinguishing feature of SELENA compared to other risk estimation software tools is that it is implemented in a 'logic tree' computation scheme which accounts for uncertainties of any input (e.g., scenario earthquake parameters, ground-motion prediction equations, soil models) or inventory data (e.g., building typology, capacity curves and fragility functions). The data used in the analysis is assigned with a decimal weighting factor defining the weight of the respective branch of the logic tree. The weighting of the input parameters accounts for the epistemic and aleatoric uncertainties that will always follow the necessary parameterization of the different types of input data.

Like previous SELENA versions, SELENA v4.1 is coded in MATLAB which allows for easy dissemination among the scientific-technical community. Furthermore, any user has access to the source code in order to adapt, improve or refine the tool according to his or her particular needs. The handling of SELENA's current version and the provision of input data is customized for an academic environment but which can then support decision-makers of local, state and regional governmental agencies in estimating possible losses from future earthquakes.

1. Introduction

Seismic risk estimation is based on the need to quantify the expectations of ground shaking and the corresponding performance of structures. Based on such investigations and efforts, construction techniques have improved over time, and appropriate counter-measures can be taken. The scientific field of seismic risk and loss assessment is a growing research area which, traditionally, has been either based on macroseismic intensity or peak ground acceleration (PGA). In recent years, different risk assessment methodologies have been developed which are incorporated in a considerable number of different software programs (Crowley et al., 2004; McGuire, 2004; Oliveira et al., 2006).

Unfortunately, it is only the large damaging earthquake which is fully able to verify or refute the estimated seismic scenario, the chosen methodology and the defined assumptions. But still this creates a fruitful situation when we are able to calibrate our models and input parameters against this experience and when

☆ Code available from server at http://www.norsar.no/c-144-SELENA.aspx.

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the results of different risk estimation methods can be compared with each other. In general, nearly all available risk and loss assessment studies define individual scenario earthquakes as a main basis for planning (Davis et al., 1982a, 1982b; Dames and Moore, Inc., 1996; EQE, 1997; FEMA, 1985; Harlan and Lindbergh, 1988; NOAA, 1973; Rojahn et al., 1997; Reichle et al., 1990; Steinbrugge et al., 1987; Toppozada et al., 1988, 1995). All of these studies use existing knowledge of regional geology and seismic activity to generate maps with estimated intensities I or ground motion accelerations a. This, in combination with other types of input data (e.g., building stock, population density), is used to calculate the extent of damage to structures and life-lines as well as the impacts on population. Some of these studies additionally address potential secondary hazards such as fire, flood and release of hazardous materials. Earthquake scenarios of this type have been employed by governmental institutions and public utilities to prepare for and to mitigate the degree of damage from future events. Thus, it appears that the typical loss study has been focused on a single event, applied in the long-term pre-event period, and utilized primarily by those concerned with seismic safety planning and disaster management.

In this respect, the Federal Emergency Management Agency (FEMA 366, 2001, 2008) initiated a study on seismic risk estimation for all regions of the United States using the national loss estimation tool HAZUS®99 and HAZUS®MH, respectively. The study's main task was to analyze and compare the seismic risk across regions in the US which have different hazard levels, characterized by different population density or physical building vulnerability.

The advent of high-speed computing, satellite telemetry and Geographic Information Systems (GIS) made possible to the electronic generation of loss estimates for multiple earthquake scenarios, to provide a nearly unlimited mapping capability, and perhaps most importantly, to develop estimates for a current earthquake event in near real-time given its source parameters, i.e., magnitude and location, are provided.

Currently, a number of different computer tools able to estimate seismic risk using different methodologies are available. Table 1 lists some of them and briefly describes their main principles and outputs.

A very powerful approach, that is particularly attractive from a scientific-technical perspective, is the HAZUS software (HAZUS®97, HAZUS®99, HAZUS®99-SR1, HAZUS®99-SR2, HAZUS®MH, HAZUS®MH MR1, HAZUS®MH MR2 and HAZUS®MH MR3). The software was developed by the National Institute of Building Sciences (NIBS) for the Federal Emergency Management Agency (FEMA, 1997, 1999, 2001, 2002, 2004, 2005a, 2006, 2007). The HAZUS tool is built upon the integrated geographic information system platform ArcGIS (ESRI, 2004) and can be considered as a software extension to ArcGIS. HAZUS is directly integrated with the national and regional databases on building stock and demography data of the United States (FEMA 366, 2008). This enables any larger community in the United States to simulate earthquake risk scenarios with a minimum of efforts since most of the necessary data are already prepared. The basic methodology behind HAZUS represented the starting point for the development of alternative tools (see Table 1) in order to compute seismic risk and loss estimates, and it also initiated numerous application studies

Table 1
Overview of available risk and loss estimation software tools and characterized.

Tool	Type of analysis	Damage estimation based on	Calculation of				GIS
			Damage to buildings	Damage to life-lines	Economic loss	No. of casualties	
ABV (Porter and Kiremidjian, 2001)	Deterministic, probabilistic	Spectral parameters[a]	●	–	●	–	n. a.
EPEDAT (Eguchi et al., 1997)	Deterministic	Spectral parameters[a]	●	●	●	●	MapInfo
HAZUS-MH (FEMA, 2004)	Deterministic, probabilistic	Spectral parameters[a]	●	●	●	●	ESRI ArcGIS
KOERILOSS (Erdik and Aydinoglu, 2002)	Deterministic, probabilistic	Intensity, spectral parameters[a]	●	●	●	●	MapInfo
LNECLOSS (Campos Costa et al., 2006)	Deterministic	Spectral parameters[a]	●	–	●	●	n. a.
MAEViz (MAE; Spencer et al., 2008)	Deterministic, probabilistic	Spectral parameters[a]	●	●	●	●	open GIS
MDLA (Mitrani-Reiser, 2007; Muto et al., 2008)	Deterministic, probabilistic	Intensity, structural response measures (peak transient IDR, peak floor acceleration)	●	–	●	–	n. a.
NHEMATIS (Webb, 1999)	Deterministic	Intensity, spectral parameters[a]	●	●	–	●	Open GIS
PACT (ATC-58) (Naeim et al., 2007)	Deterministic and time-based analysis (probabilistic)	Intensity	●	–	●	Planned for later versions	n. a.
QUAKELOSS (Wyss, 2005)	Real-time	Intensity	●	–	●	●	n. a.
ResRisk – WH (USGS; Luco, 2007)	Deterministic, probabilistic	Spectral parameters[a]	●	–	In develop-ment	–	n. a.
SELENA (Molina et al., 2009)	Deterministic, probabilistic, near-real-time	Spectral parameters[a]	●	–	●	●	Open GIS

[a] Spectral ground motion parameters, i.e., spectral acceleration S_a, spectral displacement S_d.