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Application of the SELENA risk assessment tool in a real time context

- Earthquake risk scenarios for Bucharest, Romania -

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1 The SELENA methodology

Aware of the importance of a proper seismic risk estimation, the International Centre for Geohazards ICG, through NORSAR (Norway) and the University of Alicante (Spain), has developed a software tool running under MATLAB (The MathWorks, Inc.) in order to compute seismic risk of urban areas using the capacity spectrum method (CSM). The current version 4.1 of the software tool SELENA (*Seismic Loss Estimation using a Logic Tree Approach*; Molina *et al.*, 2009) is open to any type of input data and can thus be applied to any region of the world. Based on necessary input data (e.g., building inventory data, demographical data, definition of seismic scenario etc.) which has to be provided by the user in plain ASCII format, SELENA v4.1 is able to compute ground shaking maps (with and without soil amplification effects), damage probabilities, absolute damage estimates as well as economic losses and numbers of casualties (**Figure 1**). It should be noted that the core of the HAZUS methodology (FEMA, 1999, 2003) was adopted for SELENA. However, one of the main difference between both tools is that SELENA works independent of any Geographic Information System, while HAZUS is connected to the ArcGIS software (ESRI, Inc.). The main innovation of SELENA is the implementation of a logic tree computation scheme (**Figure 2**), which allows the user to define weighted input parameters and thus being able to account for epistemic uncertainties. Final damage and loss results are provided with corresponding confidence levels. SELENA v4.1 allows the provision of earthquake ground motion on three different ways:

- the provision of spectral ordinates (e.g., PGA, S_a at 0.3 and 1.0 seconds) taken out from probabilistic shaking maps and assigned to the geographical units (*'probabilistic analysis'*),
- the definition of deterministic scenario earthquakes (e.g. historical or user-defined events) and adequate/suitable ground motion prediction equations (attenuation laws) in order to compute the spectral ordinates in each geographical unit (*'deterministic analysis'*),
- provision of spectral amplitudes of recorded ground motion at the locations of seismic (strong motion) recording stations (*analysis with near-real-time data*).

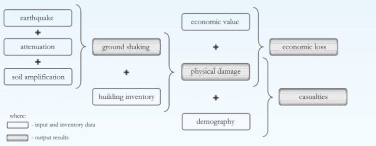


Figure 1. Principle flowchart of a deterministic analysis using SELENA. Outputs are provided on the level of geographical units (GEOUNITS).

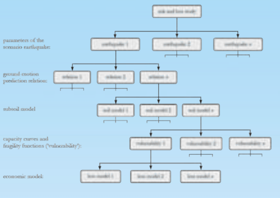


Figure 2. Logic tree computation scheme. Each branch will be weighted in order to compute the expected mean values and confidence levels.

The first step of each analysis type consist in the provision of seismic ground motion amplitudes at the center of each geographical unit. Thereby it has to be considered that these amplitudes can either represent the motion on rock conditions (*deterministic and probabilistic analysis*) or already include amplification effects of local (near-surface) subsoil conditions (*analysis with real-time data*). Based on these acceleration values SELENA generates an elastic response spectrum (damping factor $\xi = 5$ %) following a selectable seismic code provision.

Currently, the provisions of the U.S. seismic building code IBC-2006 (International Code Council, 2006), Eurocode 8 – Type 1 and Type 2 (CEN, 2002) and the Indian seismic building code IS 1893 (Part 1):2002 (BIS, 2002) with their soil amplification factors are incorporated. To determine the structural performance of a building under a lateral seimic load, the spectral displacement along its capacity curve is determined so that it is consistent with the seismic demand and at the same time reduced for nonlinear effects (**Figure 3**). In order to identify the so-called performance point on the building's capacity curve, two different capacity spectrum methods (CSM) are implemented: the traditional methodology as proposed by ATC-40 (ATC, 1996) and a recent modification of this procedure, the Modified Acceleration Displacement Response Spectra (MADRS) method as given by FEMA 440 (FEMA, 2005).

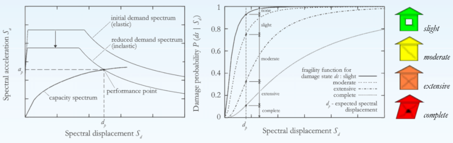


Figure 3. *(left)* Principle of the capacity spectrum method finding the performance point. *(right)* The respective spectral displacement is used to assign discrete damage probabilities on the fragility functions. Damage is classified into the four damage states *ds:* no, slight moderate, extensive and complete damage as defined by FEMA (1999).

The MADRS (FEMA 440) procedure having some advantages with respect to the application of different demand spectra (other than the IBC spectrum) as well as in terms of visualizing a direct comparison between capacity and demand (**Figure 4**). Once the performance point is found the damage probabilities for the different damage states can be assigned by overlaying the expected spectral displacement with pre-defined fragility curves (**Figure 3**).

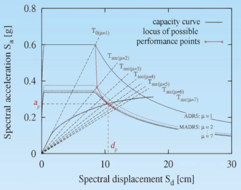


Figure 4. Principle of the FEMA 440 procedure.

Based on the damage results, both economic losses and number of casualties are calculated. The first requires a suitable economic model, which provides realistic costs for the repair or replacement of partly or completely damaged buildings and which then allows the appraisal of the total amount of economic loss in each geographical unit.

The computation of economic losses caused by direct structural damage is done by adopting the methodology described by FEMA (2003). The economic losses reflect those numbers which are required to repair or replace the damaged buildings.

SELENA v4.1 facilitates the computation of casualties (i.e. injured people and fatalities) using two different methodologies using the HAZUS approach (FEMA, 2003) or the basic approach following Coburn and Spence (2002). Irrespective of the methodology chosen, casualty numbers are computed for three different day time scenarios (night time, day time, commuting time). Thus, extreme cases of occupancy are covered which are strongly dependent on the time of the day. These scenarios are expected to generate the highest casualty numbers for the population at home (night time), the population at work or educational facilities (day time), and the population during rush hour (commuting time).

For SELENA all necessary data and required input information has to be provided as input files in ASCII-format which can be easily created in any table editing program, as e.g. MS-Excel. Currently, SELENA consists of 33 different MATLAB-scripts which are consecutively accessed during the program sequence (**Figure 5**). The algorithm is transparent such that the user is able to implement any modifications.

The results are provided in terms of ASCII-output files that can easily be implemented and visualized in GIS programs (such as ArcView or Google Earth) or be plotted in conventional graphical systems.

Figure 5. The computational process.

2 Case study: Bucharest (Romania)

The city of Bucharest, capital of Romania, comprises around 2 million inhabitants and a considerable number of high-risk buildings and infrastructure facilities of nationwide importance. Economically, Bucharest is the most prosperous city in Romania and among the main industrial centers and transportation hubs of Eastern Europe. As the most developed city in Romania, Bucharest hosts a wide range of educational facilities.

Administratively, the city is known as the 'Municipality of Bucharest' being divided into six sectors as illustrated by **Figure 6**. The geological setting of the city is characterized by the presence of deep sedimentary and partly soft deposits which are known to imply significant amplification effects of earthquake ground motion. Bucharest is located in the central part of the Moesian platform at an average epicentral distance of about 140–170 km from the Vrancea region which is characterized by a multitude of different earthquake types (Moldoveanu and Panza, 1998). **Figure 7** demonstrates some of the features of the seismic activity of the Vrancea zone where the most important is the frequency of earthquakes in the depth range 100–150 km.

The largest recent earthquake in the Vrancea region happened on March 4, 1977 with a moment magnitude Mw 7.3 at a hypocentral depth of 90 km. This event caused significant structural damage to the building stock in Bucharest and surroundings. Due to the political circumstances in Romania during that era, a thorough documentation of building damage and losses has not been conducted and is consequently not available for comparative studies.

Figure 6. Overview map of the city of Bucharest with its six main city sectors (areas filled with bright color) which are extended to the administrative city limits (areas filled with toned color).

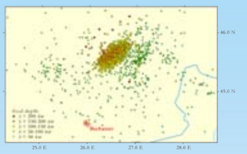


Figure 7. Seismicity around the city of Bucharest especially coming from the Vrancea zone. Different colors reflect on focal depth ranges of the PDE located earthquakes between 1973 and 2009.

Table 1. Classification of prevalent building typologies in Bucharest.

'Bucharest' model building type	Description	HAZUS mbt	No. of stories
M1A	RC shear walls	C2L	1–3
		C2M	4–7
		C2H	≥ 8
M1B	RC large panel	C1L	1–3
		C1M	4–7
		C1H	≥ 8
M1C	RC frames	C3L	1–3
		C3M	4–7
		C3H	≥ 8
M2	brick masonry with rigid floors	RM2L	1–3
		RM2M	4–7
		RM2H	≥ 8
M3	brick masonry with flexible floors	RM1L	1–3
		RM1M	4–7
M4	wood	W1	1–3
M5	adobe	URML	1–3

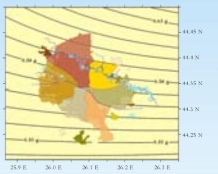


Figure 9. Simulated PGA values in Bucharest for the 1977 Vrancea event using ShakeMaps (data provided by NIEP).

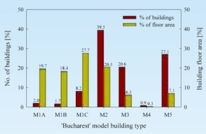
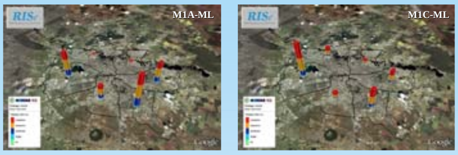


Figure 8. Distribution of the seven main model building types in Bucharest in terms of number of buildings and building floor area.

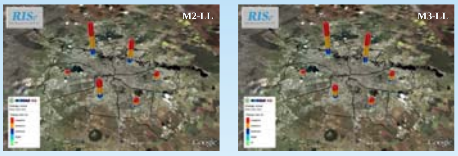
For the current study the building inventory and population database of Bucharest was reviewed and rearranged in terms of city distribution and prevalent building typologies (Marmureanu, 2007). As **Figure 6** illustrates, the city of Bucharest is subdivided into six sectors which serves as geographical units. The entire study area comprises a total of 117,592 individual buildings (i.e. 813,075 living units) and a population of 1.9 million inhabitants.

Based on information given in the database and experience of local engineers a categorization of the predominant building typologies in Bucharest was conducted (**Table 1**, **Figure 8**).

Using SELENA's real time analysis mode, spectral ground motion values for a repeat of the 1977 Vrancea earthquake have been simulated for the urban area of Bucharest. PGA values were provided in equidistant locations by using the ShakeMap tool (Wald *et al.*, 1999). **Figure 9** exemplarily illustrates distributions of predicted structural damages for the five different damage states for selected model building types using the Google Earth-based illustration tool ***RISe***. An overview of predicted losses for the respective event striking during night time is given in **Table 2**.



(a) RC shear walls (mid-rise, low-code) *(b) RC frames (mid-rise, low-code)*



(c) Brick masonry with rigid floors (low-rise, low-code) *(d) Brick masonry with flexible floors (low-rise, low-code)*

Figure 9. Distribution of mean damage extent for selected building typologies using the Google Earth-based software tool ***RISe*** (Lang *et al.*, 2008).

Table 2. Distribution of predicted structural damages, total economic losses and casualty numbers in the six different geographical units to be caused by a repeat of the 1977 Vrancea earthquake.

Geographical unit (GEOUNIT)	Buildings suffering at least slight damage	Economic loss (in million Euro)	Casualty numbers disaggregated acc. to level of severity *i*			
			Light injuries ($i = 1$)	Moderate injuries ($i = 2$)	Heavy injuries ($i = 3$)	Fatal injuries ($i = 4$)
1	30,593	3,905	9,343	2,990	489	949
2	25,235	5,617	21,055	6,492	993	1,914
3	13,348	5,781	23,487	7,200	1112	2,156
4	11,206	4,271	13,006	4,022	639	1,246
5	26,606	4,586	14,529	4,624	690	1,304
6	8,650	4,998	17,517	5,302	839	1,645
Total	**115,638 (98.3 %)**	**29,158**	**98,937**	**30,631**	**4,761**	**9,215**

SELENA - Recent developments

C code now available

The current MATLAB-based version of SELENA (v4.1) has recently been translated into C. The C code can be compiled both as a stand-alone binary, which is then independent of both MATLAB and its toolboxes, and as binary (mex) functions which can be used from within the MATLAB environment. The compiled C code runs approximately 50 times faster than the original 4.1 MATLAB m-code, thus resulting in a significant reduction of computation time. Furthermore, the code has also been adapted in such a way that it now can run in the free (open source) MATLAB clone Octave.

RISe - Risk Illustrator for SELENA

RISe is a stand-alone, open-source tool that is mainly intended to be applied in parallel to SELENA in order to allow an easy conversion of the geo-referenced SELENA input and output files into Google Earth kml-files. Since it is linked to the Google Earth visualization, the user automatically takes full advantage of the partly high-resolution satellite images provided by Google Earth. This is particularly important in situations where other commercial GIS packages do not provide a high resolution database or for developing countries where many cities and municipalities cannot be displayed on high resolution base maps other than Google Earth satellite images.

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Acknowledgments

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The recent versions of the loss assessment software SELENA and its illustration tool ***RISe*** can be received from the NORSAR/ICG-webpage. (http://www.norsar.no).