Open Source Procedure for Assessment of Loss using Global Earthquake Modelling software (OPAL-GEM1)

James E. Daniell

PhD Student, Geophysical Institute, Karlsruhe Institute of Technology, Germany.
Researcher, CEDIM (KIT, Karlsruhe and GFZ Potsdam), Germany.
MEEES (Masters in Earthquake Engineering and Engineering Seismology) - Université Joseph Fourier, Grenoble, France, IUSS Pavia and Università degli studi di Pavia, Italy.
BE Hons. (Civil and Structural), BSc (Geology and Geophysics) – The University of Adelaide, Australia.
Email: j.e.daniell@gmail.com

Abstract

This paper provides a comparison between Earthquake Loss Estimation (ELE) software packages and their application using an "*Open Source Procedure for Assessment of Loss using Global Earthquake Modelling software*" (OPAL-GEM1). The OPAL procedure has been developed to provide a framework for optimisation of a Global Earthquake Modelling process through:

1) Overview of current and new components of earthquake loss assessment (vulnerability, hazard, exposure, specific cost and technology);
2) Preliminary research, acquisition and familiarisation with all available ELE software packages;
3) Assessment of these software packages in order to identify the advantages and disadvantages of the ELE methods used; and
4) Loss analysis for a deterministic earthquake (Mw7.2) for the Zeytinburnu district, Istanbul, Turkey, by applying 3 software packages (2 new and 1 existing): a modified displacement-based method based on DBELA (Displacement Based Earthquake Loss Assessment, Crowley et al., 2006), a capacity spectrum based method HAZUS (HAZards United States) and the Norwegian HAZUS-based SELENA (SEismic Loss EstimatioN using a logic tree Approach) software which was adapted for use in order to compare the different processes needed for the production of damage, economic and social loss estimates. The modified DBELA procedure was found to be more computationally expensive, yet had less variability, indicating the need for multi-tier approaches to global earthquake loss estimation. Similar systems planning and ELE software produced through the OPAL procedure can be applied to worldwide applications, given exposure data.

Keywords: OPAL, displacement-based, DBELA, earthquake loss estimation, earthquake loss assessment, GEM, OPAL-GEM, open source, HAZUS

NOTE:- This paper is derived from the full OPAL-GEM1 report which provides a full synopsis of ELE research and many open source software packages from around the world. It also discusses OPAL-GEM2 and is available upon request from j.e.daniell@gmail.com. This work was done in conjunction with my work done at CEDIM (GFZ Potsdam and KIT), Germany, and University of Pavia, IUSS Pavia, Italy.

1. INTRODUCTION

The OPAL procedure (Figure 1) has been developed to provide a framework for optimisation of a global earthquake modelling process, and to provide a state-of-the-art look at what open-source software tools are available globally.

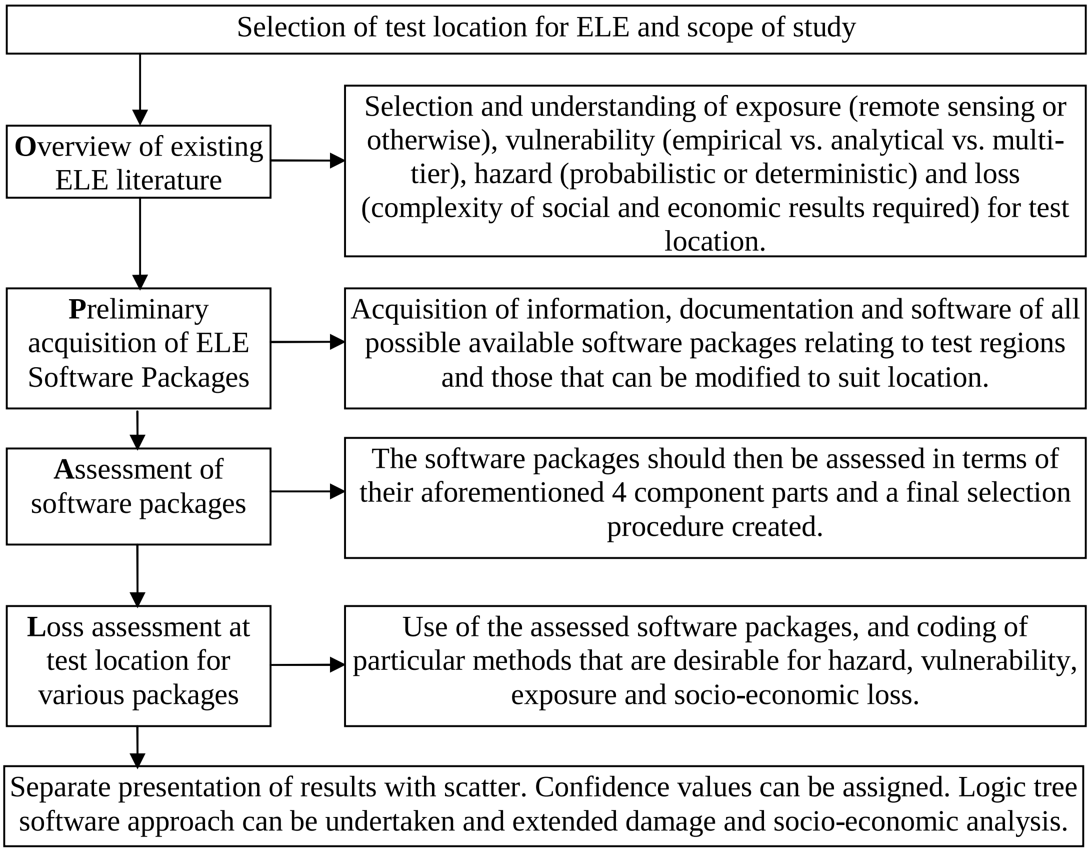


Figure 1: Flowchart of the generalised OPAL Procedure

It is up to the user to select those software packages that are deemed appropriate for use, and to then critically review using both the user manual (Daniell, 2009b) and the references to next test the applicability. A logic-tree approach is subsequently applied between the software packages in order to achieve a subjective result, as no one system will be correct due to uncertainties in each of the four steps of the Earthquake Loss Estimation procedure, as discussed below. This weighting is based on the quality of the ELE software package. This will minimise outlier results. For insurance purposes, the software package results should be critically reviewed and the variance of the separate models used.

2. OVERVIEW OF EARTHQUAKE LOSS ASSESSMENT

Earthquake Loss Assessments are produced in order to detect possible economic, infrastructure and social losses due to an earthquake. In order to produce an effective ELE, four components must be taken into account in that:-

Seismic Loss = Exposure * Vulnerability * Hazard * Damage Loss Conversion

Where:- Exposure is defined as the amount of human activity located in the zones of seismic hazard as defined by the stock of infrastructure in that location (usually defined by geocell); Vulnerability is defined as the susceptibility of the infrastructure stock; Hazard is defined as the probability of a certain ground motion occurring at a location, which can be determined by scenario modelling via stochastic catalogues, PSHA (Probabilistic Seismic Hazard Assessment) or other such methods, and can include different types of earthquake effects; and Damage Loss Conversion can be defined as the mean damage ratio (ratio of replacement & demolition to repair & restoration cost (economically-speaking)), or the social cost (i.e. number of injuries, homeless and deaths).

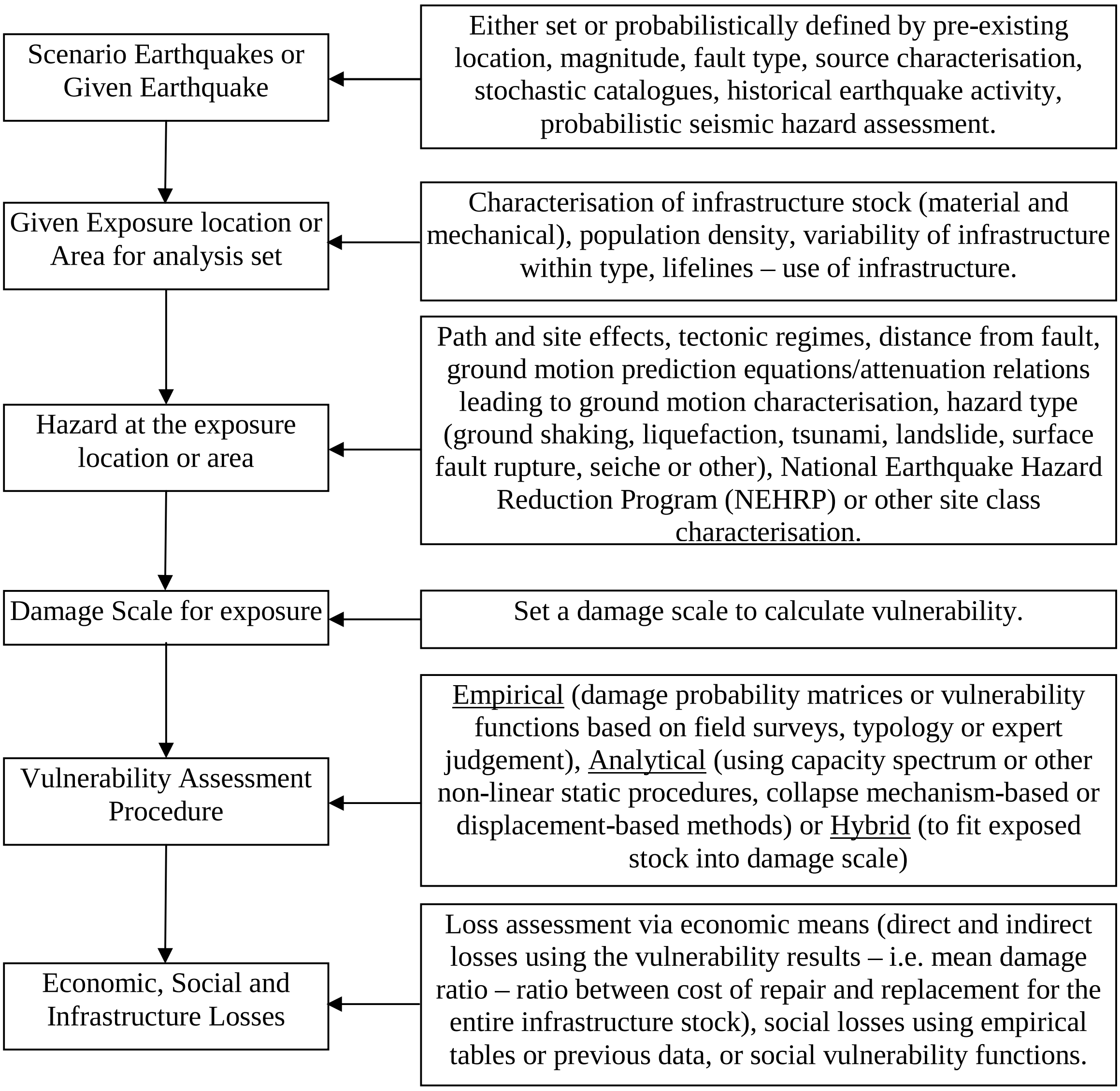


Figure 2: Flowchart of Identified Components of an Earthquake Loss Assessment (Rapid-Response, Post- or Pre-Earthquake).

Because of the myriad of ways that each of these components seen in Figure 2, which make up seismic loss, can be determined, there is a large range of earthquake loss estimation methods available. For some regions one particular method may be more applicable. This is because of a possible reduction in epistemic uncertainty (lack of knowledge) due to data collection and scientific assumptions used for the ELE method not being the same at any location in the world. In addition, probabilistic regional uncertainties in source, path and site occur, quantified by aleatory variability. Thus, it is impossible to ever have a 100% accurate seismic loss estimate, and ELEs should quantify this uncertainty (both epistemic and aleatory).

It is necessary to define an area of interest in which the seismic hazard should be pinpointed at every location. For this paper, the Zeytinburnu district in Istanbul, Turkey, with 50 x 0.05º geocells was defined as the location where full earthquake loss estimation would be undertaken. The vulnerability of the infrastructure stock exposed to this hazard can be convolved with this hazard and therefore a damage distribution is able to be established based on various classes of infrastructure damage. From this damage distribution, economic and social losses can be derived. All of these components constitute an ELE. Calculation of the losses can either be done in a proactive way (pre-earthquake scenario modelling) or a reactive way (post-earthquake fixed scenario modelling).

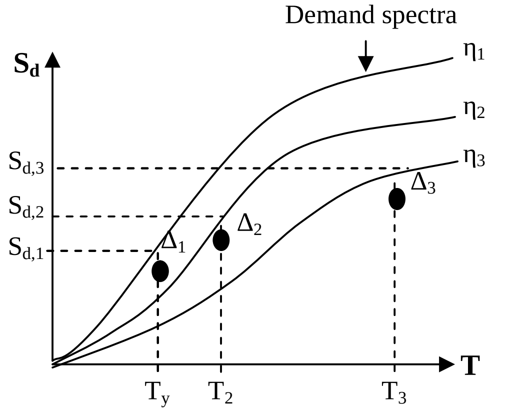
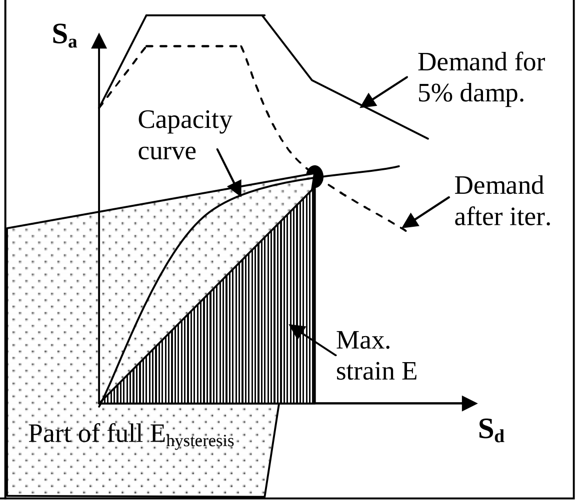
DISPLACEMENT-BASED METHOD	**CAPACITY SPECTRUM METHOD**
The steps are as follows for each building:- 1. Material & mechanical properties of buildings for Monte Carlo simulation required. 2. Multiple Degree-of-Freedom (DOF) → equivalent Single DOF system to produce a random pushover curve (F-Δ) 3. Relate displacement capacities (Δ) of SDOF systems to the demand (η) of displacement response spectrum at effective response periods of vibration i.e. yield (T_y), limit state 2 and 3 (T_2 and T_3) to check limit state position, using formulae. Full method can be seen in Crowley et al. (2006) or Daniell (2009b).  $S_{d,3} > \Delta_3$ = complete damage (LS3) occurs	Looks at the crossover of capacity (via a pushover curve) with acceleration-displacement response spectrum (ADRS) demand to define performance point. This relies on the same step 2 as in displacement-based. However, then an area method (area under curve/full hysteresis loop) is used to define equivalent non-linear damping (ξ) and ductility for the iteration to get the exact % of ξ. The corresponding displacement capacity (Sd) can then be compared with vulnerability curves and placed in damage states, as done in HAZUS. 

Figure 3: Displacement-based vs. Capacity Spectrum Method

A review of all recent literature available in these 4 components can be seen in Daniell (2009b), but only the difference between capacity spectrum (Applied Technology Council (ATC), 2005) and displacement-based methods is shown above in Figure 3 as part of the overview for use in the loss assessment. Displacement-based models will be examined here, as these types of models have been seen to provide a significant reduction in error in terms of calculating structural and non-structural damage (Calvi, 1999, Priestley et al., 2007).

3. PRELIMINARY ACQUISITION AND ASSESSMENT OF ELE SOFTWARE

Considerable research has been done to provide adequate earthquake loss estimation (ELE) models for region specific scenarios and other studies. Many different software packages have been produced around the world in order to provide accurate loss estimates; however, these can be used simultaneously in order to reduce uncertainty in the result. With the wealth of software packages available for these risk assessment studies and economic, social and infrastructure loss estimations, a synopsis of many available packages has been undertaken and a full documentation can be viewed in Daniell (2009b). ELE software packages are both closed (proprietary or not freely available but documented) and open-source (freely available or by contacting the developers), and the study first requires a preliminary research, sourcing and familiarisation stage with these ELE software packages. These packages are detailed in Table 1 below with a quick synopsis of the applicable region, software availability/modifiability, ownership, vulnerability types examined, complexity of the socio-economic module, exposure level and hazard types examined, which are all needed for the loss assessment process in the Zeytinburnu case study. Major insurance company models classed as private all-encompassing ELE software were not reviewed due to lack of open source information i.e. developed by ABS Consulting/EQECAT (RISKMAN), Risk Engineering and Degenkorb (FRISK), AIR Worldwide (CATrader), PBS&J (HAZUS) and RMS (IRAS) (Daniell, 2009b).

The test regions for ELE software packages are generally synonymous with the owner, i.e. NORSAR with the SELENA software, and the test region was Oslo (Lindholm et al., 2007) or a high seismic risk city such as Istanbul, Tokyo or Los Angeles. The region that the software is applicable to defines which software packages can be used for a globally chosen test case. All software packages shown can be run on a standard PC; however, some require GIS (Geographical Information System) licences and other software. The complexity differs significantly between the various software packages and the problem is that most software is not freely available as open source. Thus, although documentation and reproduction of every software package is available, the actual versions are not available in most cases, as seen in the modifiable (mod.) column. Many of these procedures can be changed by the user to add complexity to the social and economic loss outputs.

Table 1: A synopsis of the components of 30 mostly open source worldwide ELE software packages.

ELE Software	**Mod.**	**Region**	**Owner**	**Exp.**	**Haz.**	**Vuln.**	**SE.**
CAPRA	Ya	Cent. A.	EIRD	Mult.	DP, DO, P	Both	Unk.
CATS		North A.	DTRI, FEMA	Mult.	DP, DO	Emp.	Ec, Sc
DBELA	Yes	World	EUCENTRE	D, Ci	DP, DO, P	Anl.	Ec, Ss
ELER*	Ya	Europe	JRA-3, NERIES	D, Ci	DP, DO, P	Both	Es, Ss
EmerGeo*	Unk.	World	EmerGeo	Mult.	DP	Emp.	Ec, Sc
EPEDAT		North A.	EQE International, California OES	D, Ci	DP, DO	Emp.	Es, Ss
EQRM*	Yes	Aust.	Geoscience Aust.	D, Ci	DP, P	Both	Es, Ss
EQSIM*	Ya	Europe	KIT, CEDIM	D, Ci	DP, DO	Anl.	Sc
Extremum		World	Extreme Situations Res. Ctr. Ltd.	Ci, R, Co	DP, DO	Emp.	Es, Ss
HAZ-Taiwan*		Asia	National Science Council	Mult.	DP, DO, P	Anl.	Ec, Sc
HAZUS-MH		North A.	FEMA, NIBS	Mult.	DP, DO, P	Anl.	Ec, Sc
InLET*		North A.	ImageCat Inc.	D, Ci	DP, DO	Emp.	Es, Ss
LNECLOSS		Europe	LNEC	D, Ci	DP	Anl.	Ec, Ss
LOSS-PAGER	Ya	World	USGS	Mult.	DO	Anl.	Es, Ss
MAEViz*	Yes	North A.	Uni. Illinois	D	DP, DO, P	Both	Ec, Sc
OPENRISK	Yes	World	AGORA, USGS, OpenSHA	Mult.	DP, DO, P	Emp.	Ec, Ss
OSRE*	Yes	World	Kyoto U., AGORA	Mult.	DP, DO, P	Emp.	Es
PAGER*		World	USGS, FEMA	Ci, R, Co	DO	Emp.	
QLARM*		World	WAPMERR	Ci, R, Co	DP, DO	Emp.	Es, Ss
QL2		World	M. Wyss	Ci, R, Co	DP, DO	Emp.	Ec, Ss
RADIUS	Ya	World	Geohazards Int., IDNDR	Ci	DP	Emp.	Ss
REDARS		North A.	MCEER, FHWA	D, Ci, R	DP, DO, P	Emp.	Ec
RiskScape	Ya	Aust.	NIWA, GNS	D, Ci, R	DP, DO	Emp.	Ec, Sc
ROVER-SAT	Ya	North A.	Uni. of Boulder	Mult.	DP, DO	Emp.	
SAFER*		World	23 worldwide institutions	D, Ci	DP, DO, P	Both	Es, Ss
SELENA*	Yes	World	NORSAR	D, Ci	DP, DO, P	Anl.	Es, Ss
SES2002 & ESCENARIS		Europe	DGPC, Spain	Mult.	DP, P	Emp.	Es, Ss
SIGE		Europe	OSSN, Italy	Mult.	DP, DO	Emp.	Es, Ss
SP-BELA**	Yes	Europe	EUCENTRE	D	DP, DO, P	Anl.	Es, Ss
StrucLoss*	Ya	Europe	Gebze IT, Turkey	D, Ci	DP, P	Both	Ec, Ss

*those have had a past influence based on HAZUS, ** those on DBELA
Mod =Modifiability, Ya=Yes, but subject to availability, Aust = Australasia, World = Worldwide, North A. = North America, Cent. A. = Central America
Exp =Exposure, D=district, Ci=city, R=regional, Co=Country, Mult.=Multiple levels
Haz =Hazard, DP=deterministic predicted, DO=deterministic observed, P=probabilistic.
Vuln =Vulnerability Type, Anl.=Analytical, Emp.=Empirical
SE =Socio-economic loss, Unk=Unknown as yet, due to pending release of software, Es=simple economic, Ec=complex economic, Ss=simple social, Sc=complex social.

Exposure is a function of the population, remote sensing, building use and other building inventory data used for the test region. Some software coding has been hardwired for only a district or city, whereas some are also able to include regional (R) and full country level analysis. With further coding, some city-district style procedures can be increased to a country level analysis.

In terms of demand or hazard, ground shaking, as demonstrated by Bird and Bommer (2004) in 50 earthquakes reviewed from 1980-2003, contributes most (approx. 90%) to the social and economic losses in earthquakes and therefore only ELE software packages which consider ground shaking have been tabulated. Secondary effects such as liquefaction, fault rupture, landslides and slope stability, tsunami and standing waves can cause much damage. However, due to complexity, these have not been included in most of the ELE software packages.

Table 1 considers the various demand (hazard) possibilities between analysis modes that can be undertaken for earthquake loss estimation. The difference between probabilistic (multiple scenario) and deterministic (scenario-based) SHA is important and thus a desirable software package should allow for both methods, including using real-time, historical and user-specified data to provide a pre- and post- earthquake analysis tool.
The temporal distribution of earthquakes in probabilistic methods is generally looked at in two ways: a Poisson distribution process in which earthquake probability is independent of time from the last earthquake (earthquakes are a random process as shown by the Parkfield prediction exercise – Bakun, 1985); or time-dependent methods which assume that earthquake events are linked temporally. Considering the difficulty of interseismic Coulomb stress modelling, a Poisson distribution process is a reasonable assumption.

For the single scenario deterministic-predicted method, the software can be utilised for a certain chosen earthquake by the user. PAGER and QLARM are the only methods which do not allow this, due to their real-time nature. A user-defined event for the ground motion can sometimes be applied, allowing the user to apply a complex theoretical model or any model desired. In contrast, deterministic-observed values are also used in various packages, utilising either historical ground motions or corresponding to ShakeMap ground motions from an automated near real-time network (i.e. strong-motion networks). This can usually only be applied for a few locations in the world, but the new methodologies of PAGER and QLARM make it possible to employ ground-motion maps.

The Intensity and Response Spectrum are generally linked with the vulnerability component i.e. intensity→empirical & response-spectrum→analytical methods. Regional and Next Generation (NGA) GMPEs are used in many methods. HAZUS uses a response spectrum based on PGA, S_a=0.3s, 1s, 3s and many are based on such theories. Most of the software packages also allow for observed, theoretical or empirical ground motions. Observed spatial ground motion distributions generally use past earthquake catalogues or real-time ground motions to develop the ground motions. Theoretical ground motions derived from seismological models for various earthquake scenarios have also been allowed through this user-defined setting in a few different ELE software packages (DBELA, EQSIM, OPENRISK, REDARS and SP-BELA and most likely in CAPRA, QUAKELOSS2 and SAFER). However, these are time-consuming. Site effects are generally taken into account via geotechnical site classification i.e. NEHRP site classes (1997) and the relative changing of the bedrock frequency spectrum due to shear wave velocity. Geological classification is also used in a number of city-specific software packages and a few use borehole-based classification.

The vulnerability module can be empirical (Damage Probability Matrices, vulnerability indices, functions and curves, or screening method), analytical (analytical vulnerability curves, capacity spectrum, collapse-based and displacement-based) or hybrid (combination). Occupancy criteria generally include use (residential etc.) and sometimes occupancy rate (day/night). Structural criteria include basic structural criteria such as number of floors, material properties, and member dimensions. SP-BELA and DBELA use complex failure mechanisms i.e. simplified pushover- and displacement-based respectively. Quality criteria also include age of buildings (generally 4 categories) and relative quality of construction, but in complex cases, such as DBELA, SP-BELA, QLARM and EQSIM, variability in construction materials and type is examined.

Social and economic losses are generally a function of damage. Simple social (Ss) losses usually only include deaths, but sometimes include levels of injuries and homeless. More complex social (Sc) losses include indirect losses, commuting disruptions, dislocation and shelter analysis, as well as social vulnerability. Simple economic (Es) losses include simple damage-based multiplication of floor areas and housing prices, whereas complex economic (Ec) losses include economic vulnerability analysis, indirect economic loss, flow-on market effects and ripple effects.

By applying the test case of the user into Table 1 and setting what the desired complexities are, software packages and/or a coding system can be chosen.

4. LOSS ASSESSMENT FOR ZEYTINBURNU DISTRICT, TURKEY

For Zeytinburnu, Turkey, as a test case, it was decided that SELENA (HAZUS-based) and a modified HAZUS (MHAZUS) and modified DBELA (MDBELA) software would be used as they could all be applied at district level, analytical methods could be used (since the given exposure data was of high quality), the software was open-source based, and socio-economic functions and algorithms could be changed. MHAZUS and MDBELA were coded and produced in MATLAB™, the source code of which is available in part in Daniell (2009b), and SELENA was modified and adapted in MATLAB™. MHAZUS and MDBELA are transferable to the open source Octave.

The four key components include exposure, hazard, vulnerability and socio-economic loss for a scenario earthquake of Mw7.2, located at approximately 28.84E, 40.9N between fault segments 7 and 8 on the Marmara Sea fault (seen in Crowley et al., 2006). A deterministic seismic hazard assessment (DSHA) was therefore chosen.

Exposure

Zeytinburnu District consists of mainly commercial buildings in the north, and primarily residential buildings in the south. It consists of 37 building types (4 masonry types, 33 RC types), 1 to 9 stories high, with 11250 buildings in 50 0.05º geocells. The no. of buildings in each geocell is shown in Figure 5 below. From aerial photos from a Turkish Govt website, most of the buildings in the Zeytinburnu district were built between 1966 and the present but Turkish seismic code was only defined from 1975 to the present and not enforced well (H. Sucuoglu, pers. comm, 2008).

Hazard

The Ground Motions used were 100 spatially correlated ground motion (GM) fields, 100 spatially uncorrelated GM fields for MHAZUS and MDBELA and 1 median GM field and variability for SELENA, HAZUS and MDBELA. Temporal correlation was not taken into account for this study; however, has been discussed in Daniell (2009a).
The GMPE used was Boore et al. (1997) with the erratum. Site classes using NEHRP, latitude and longitude are as shown in Figure 5.
The distance from the closest fault source to the geocell is, as shown in Figure 5, ranging from 11-16km. Both aleatory variability (σ) and epistemic uncertainty (ε) were accounted for in the randomised ground motions up to ±3 standard deviations.

Vulnerability

The Capacity Spectrum Method was used for SELENA and MHAZUS (with a modified iteration) and the Modified Acceleration Displacement Response Spectrum method (MADRS) also utilised for SELENA. Displacement-based design was used for MDBELA. The flowchart in Figure 4 shows the process to develop a damage matrix based on limit states. A pre-code assumption was used for the Zeytinburnu district for MHAZUS and SELENA, based on the aerial photos and seismic code enforcement assumption. The material and mechanical properties for MDBELA were contributed by Bal et al. (2008b).

Socio-Economic Loss

Using the 37 building classes of MDBELA, and the 5 HAZUS building classes for MHAZUS and SELENA, and the number of buildings in each damage limit state, the following formula could be used to calculate economic cost of repair.
Repair cost per damage limit state is a convolution of floor area, an economic cost of 187 to 225€ per m^2, depending on size of building, number of storeys, damage class repair % as below and the number of buildings in that damage limit state.
The mean damage ratio (the ratio of repair to replacement) in each limit state for Turkish conditions was found in Bal et al. (2008a) where any building which is extensively or completely damaged must be demolished.

Table 2: Turkish vs. HAZUS mean damage ratios, Bal et al. (2008a)

	None	**Slight**	**Moderate**	**Extensive**	**Complete**
Turkish Conditions	0	0.16	0.33	1.05	1.04
HAZUS	0	0.02	0.1	0.5	1

Social losses for day and night populations were calculated via equations for night and day. Deaths, injuries and homeless by Spence (2007) equations were calculated as a function of building damage. These are in turn a function of number of storeys and occupancy rating.

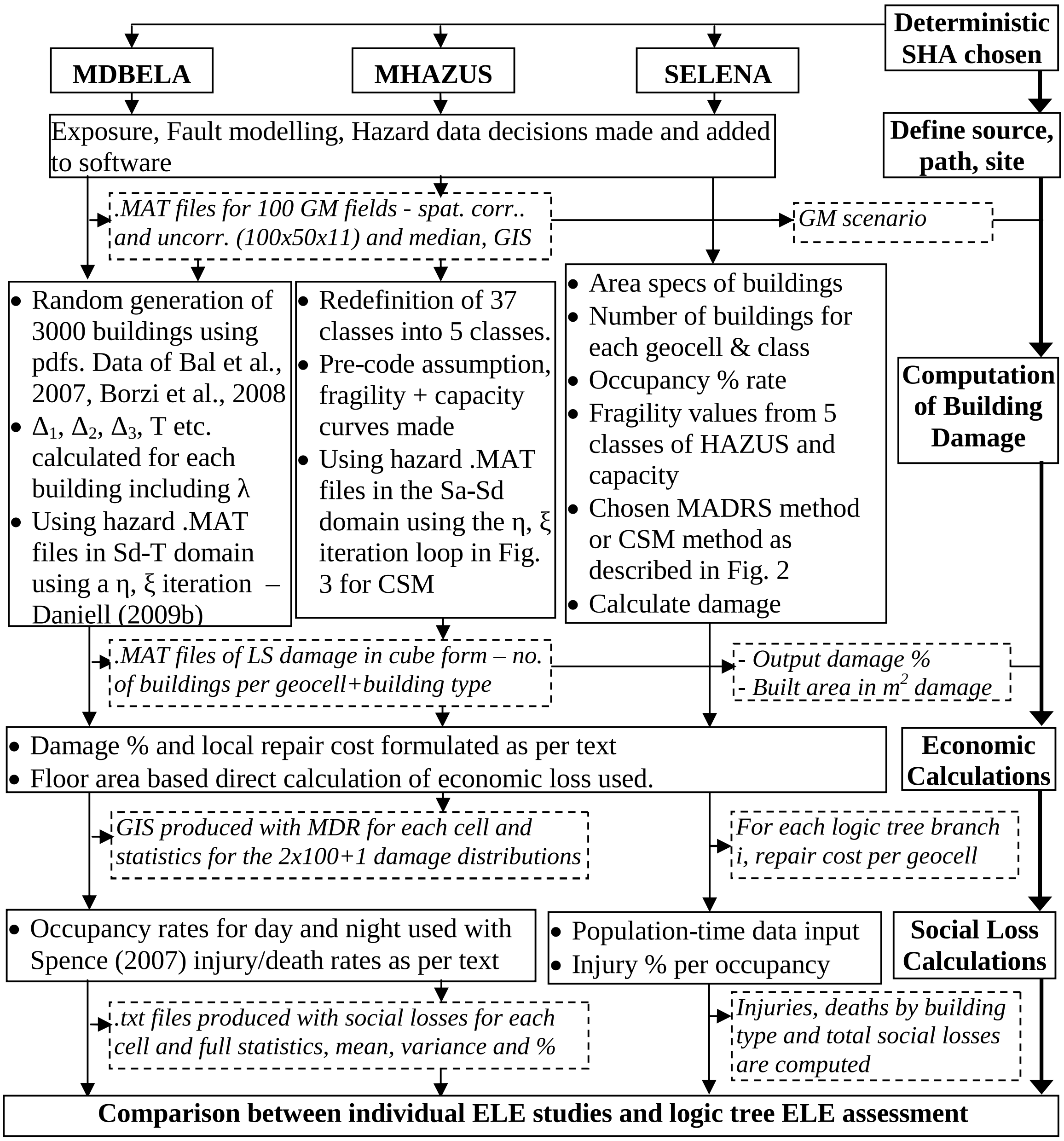


Figure 4: Process Flowchart for application of 3 ELE Software Packages

MDBELA and SELENA showed approximately the same number of buildings within MHAZUS-based damage classes, whereas MHAZUS showed a high percentage in the complete bracket. Presented in Table 2 is the total damage % for the median of the 100 runs for the spatially correlated ground motions and those of the median ground motion.

Table 2: Building damage % in HAZUS-based classes for the 3 ELE Packages

Method	Type	None	Slight	Moderate	Extensive	Complete
MDBELA	**Median**	8	8	29	29	26
MDBELA	**Correlated**	8	9	28	28	27
MHAZUS	**Median**	16	13	17	4	50
MHAZUS	**Correlated**	30	6	5	4	55
SELENA	**Median**	4.9	8.7	29.6	29.7	27.1

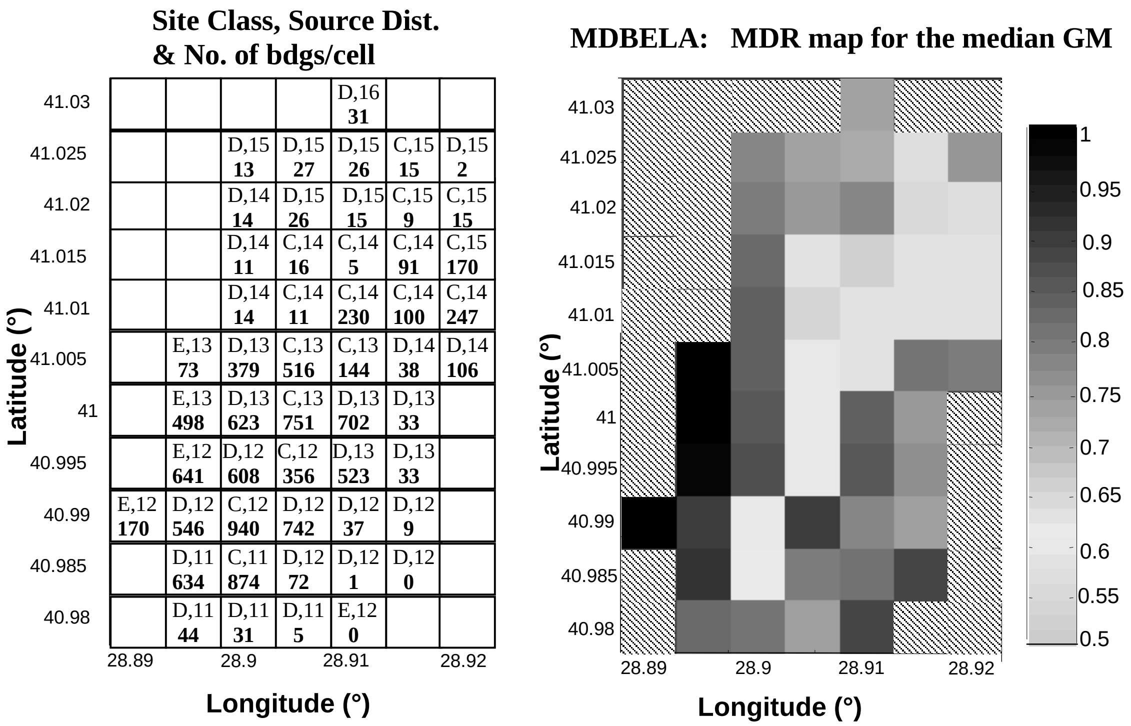


Figure 5: Left:-Geocell NEHRP Site Class (C, D or E), Distance from the closest source (in km) and no. of buildings in that geocell, Right:- Mean Damage Ratio per geocell for MDBELA given Bal et al. (2008a) damage ratios for Turkish settings

The geocell mean damage ratio values are reasonably similar between all methods. As expected, as the site class moves from E to C (i.e. from around a shear wave velocity of 200m/s to approx. 600m/s), and as distance increases (attenuation effects) the mean damage ratio decreases, due to the lower relative ground motions for the median case. For the randomized ground motions this is not the case, due to spatial correlation. Both the MHAZUS and MDBELA methods produce the same spatial distribution of social losses despite having considerably different estimates (thus only MDBELA is presented in Figure 5). However, MHAZUS gives higher and more variable social and economic loss values (Figure 6 and 7).

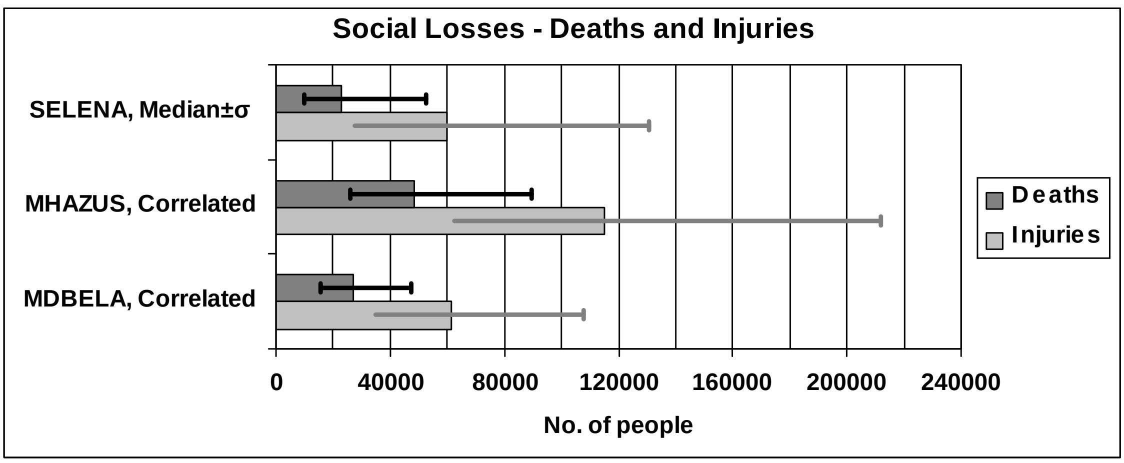


Figure 6: Daytime social losses for the 3 ELE software packages including the 16% and 84% (±1σ) values from the 100 runs, fitting a lognormal distribution.

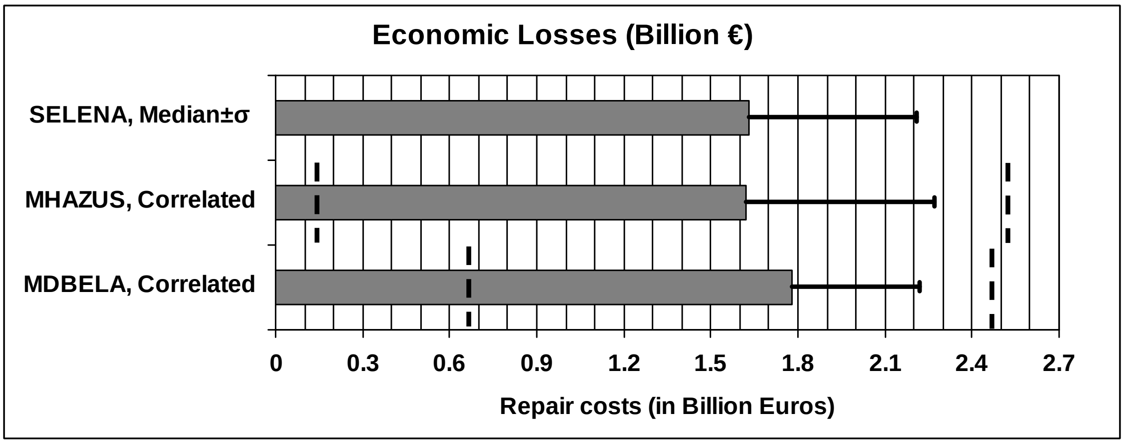


Figure 7: Daytime economic losses for the 3 ELE software packages including the minimum, maximum and 84%(+1σ) values from the 100 runs. SELENA was only run using the available median and 84% values.

This type of socio-economic information shown in Figures 5, 6 and 7 can be very useful for emergency response planning and it is encouraging that all methods show consistent patterns for both day-time and night-time events. Similar analyses can be undertaken by the user for the test case. A conclusion was made that the MHAZUS version had unrealistic bias due to the pre-code assumption employed (it was decided that most of Zeytinburnu was built of pre-1975 quality, even if designed under post-1975 seismic coding). Thus, the complete damage ratio was greater and more deaths and injuries resulted, as in Spence (2007) they are only based on the complete damage class (Level 4). A subsequent test was done with a median ground motion for MHAZUS using 50% of buildings in Zeytinburnu as medium code, and 50% pre-code, and the collapse ratio reduced from 50%, as shown in Table 2, to 31%, with approximately 31000 deaths predicted. However, the variance when calculating the correlated version was still larger than MDBELA. SELENA used a slightly different algorithm which was not as susceptible to the high end failure. It did not give such a high level of completely damaged buildings but more in the extreme damage range, thus reducing the casualty number which is calculated based on completely damaged buildings, again using Spence (2007).

The lesser variability shown in MDBELA as a function of the way it uses displacement-based methods indicates that this may be the best method and more weighting of an expert panel for software package use should be given to this result. Based on a participatory modelling of the quality of the ELE software package result, weights of 0.6 for MDBELA, 0.3 for SELENA and 0.1 for MHAZUS were given. Thus a reasonable median estimate of 28,000 deaths during the day was found, with a standard deviation of 25,000 deaths, depending on random variability within ground motions.

5. CONCLUSION

For the Zeytinburnu District an earthquake of significant magnitude would be catastrophic and by looking at the information provided as to the locations of the social effects, such as deaths and injuries, as well as the infrastructure and lifeline damage locations, disaster response planning can be put in place in order to greatly reduce the number of casualties. SAFER, ELER, MAEviz and most other major software packages have attempted to model the Istanbul scenario earthquake. Policy is currently in place within Zeytinburnu to retrofit buildings within the district to seismic standards, in order to reduce the approximately 27,000 median deaths (DBELA-based) with a possible range of 20,000 deaths (by SELENA) to 50,000 deaths (by MHAZUS), depending on the time of day. This can be done on a district level or a geocell level. The Zeytinburnu district (building value 2.4 billion €) will have repair costs for a mean disaster of approx. 1.6-1.8 billion €, which is substantial. This is because repair costs are higher in Turkey than in HAZUS for the USA, due to Turkish post-earthquake rebuilding laws. Standard deviations over the 100 ground motions also provide a good prediction of the uncertainty of these figures for insurance and reinsurance.

Using the OPAL procedure, enough knowledge can be gained to undertake an ELE for a desired test case anywhere in the world. Many ELE software packages have been produced globally, allowing for reasonably accurate damage, social and economic loss estimates of scenario earthquakes to be made. Displacement-based methods have been found to give less variability in results, but require a reasonable sample of building data to be useful. MHAZUS and SELENA require less information, but appear less accurate. Thus, a combination of two or more software packages into a multi-tier approach is desirable for greater accuracy and flexibility. OPAL-GEM is an ongoing open-source project with further software production and global data tools to be generated as part of a second phase, including further production of MDBELA and MHAZUS in open-source coding software.

6 ACKNOWLEDGEMENT This paper has been written as part of the development of the author's PhD, funded by the General Sir John Monash Foundation and CEDIM.

7 REFERENCES

ATC (Applied Technology Council) (2005) "Improvement of Nonlinear Static Seismic Analysis Procedures", FEMA 440 Report, Redwood City, California, U.S.A.

Bakun, W.H., Lindh, A.G. (1985) "The Parkfield, California, earthquake prediction experiment", Science, Vol 229, pp. 619-624.

Bal, I.E., Crowley, H., Pinho, R., Gülay, G. (2007) "Structural characteristics of Turkish building stock in Northern Marmara Region for Loss Assessment Applications", ROSE Research Report 2007/03, IUSS Press, Pavia, Italy.

Bal, I.E., Crowley, H., Pinho, R. (2008a) "Displacement-Based Earthquake Loss Assessment for an Earthquake Scenario in Istanbul", Journal of Earthquake Engineering, Vol. 11, No. 2, pp. 12-22.

Bal, I.E., Crowley, H., Pinho, R., Gülten Gülay, F. (2008b) "Detailed assessment of structural characteristics of Turkish RC building stock for loss assessment models", Soil Dynamics and Earthquake Engineering, Vol. 28, pp. 914-932.

Bird, J.F., Bommer, J.J. (2004) "Earthquake Losses due to Ground Failure", Engineering Geology, Vol. 75, No. 2, pp. 147-179.

Boore, D. M., Joyner, W. B., Fumal, T. E. (1997) “Equations for estimating horizontal response spectra and peak acceleration from Western North American earthquakes: a summary of recent work”, Seismological Research Letters, Vol. 68, No. 1, pp. 128–153.

Borzi, B., Pinho, R., Crowley, H. (2008a) “Simplified pushover-based vulnerability analysis for large scale assessment of RC buildings”, Engineering Structures, Vol. 30, No. 3, pp. 804-820.

Calvi, G.M. (1999) “A Displacement-Based Approach for Vulnerability Evaluation of Classes of Buildings”, Journal of Earthquake Engineering, Vol. 3, No. 3, pp. 411-438.

Crowley, H., Pinho, R., Bommer, J.J., Bird, J.F. (2006) “Development of a Displacement-Based Method for Earthquake Loss Assessment”, ROSE Research Report 2006/01, IUSS Press, Pavia, Italy.

Daniell, J.E. (2009a) “Comparison and Production of Open Source Earthquake Loss Assessment Packages”, MEEES Thesis, ROSE School, Pavia, Italy.

Daniell, J.E. (2009b) “Open source Procedure for Assessment of Loss using Global Earthquake Modelling – OPAL-GEM1”, CEDIM Research Report 09/01, Karlsruhe, Germany.

MDBELA - see Daniell, J.E. (2009b) as above.

MHAZUS - see Daniell, J.E. (2009a) as above.

NEHRP (1997) “Recommended provisions for seismic regulations for new buildings and other structures”, Report FEMA-303, Building Seismic Safety Council, Federal Emergency Management Agency, Washington DC, U.S.A.

Priestley, M.J.N., Calvi, G.M., Kowalsky, M.J. (2007) “Displacement-Based Seismic Design of Structures”, IUSS Press, Pavia, Italy.

SELENA - Lindholm, C.D., Molina-Palacios, S., Lang, D.H. (2007) “SELENA-Seismic loss estimation using a logic tree approach”, Vilnius Conference, Lithuania.

Spence, R. Ed (2007) ‘‘Earthquake disaster scenario predictions and loss modelling for urban areas”, LESSLOSS Report 7, IUSS Press, Pavia, Italy.

Turkish Government Website (2009) Zeytinburnu District Aerial Photos, available from URL: http://sehirrehberi.ibb.gov.tr/Default.aspx?&ap=istanbulresim

Reviewed Software Packages

CAPRA – Anderson, E. (2008) “Central American Probabilistic Risk Assessment”, World Bank, Presentation at EIRD Barbados Conference 8/7/08.

CATS – Swiatek, J.A., Kaul, D.C. (1999) “Crisis Prediction Disaster Management”, SAIC Science and Technology Trends II, Online document, Science Applications Int. Corp.

DBELA – see Crowley, H. et al. (2006) as above.

ELER – Erdik, M., Safak, E. (2008) “Earthquake Early Warning and Rapid Response System Istanbul”, Bogazici University Presentation – ELER, Istanbul, Turkey.

EmerGeo – EmerGeo Solutions Inc. (2009) “Hazard Models”, available from URL: http://emergeo.net/hazard_models.aspx.

EPEDAT – Eguchi, R.T., Goltz, J.D., Seligson, H.A., Flores, P.J.N., Blais, C., Heaton, T.H., Bortugno, E. (1997) “Real-Time Loss Estimation as an Emergency Response Decision Support System: The Early Post-Earthquake Damage Assessment Tool (EPEDAT)”, Earthquake Spectra, Vol.13, No. 4, p. 815-832.

EQRM – Robinson, D., Fulford, G., Dhu, T. (2005) “EQRM: Geoscience Australia’s Earthquake Risk Model”, Geoscience Australia Record 2005/01, Geoscience Australia, Canberra, Australia.

EQSIM – Markus, M., Fiedrich, F., Leebmann, J., Schweier, C., Steinle, E. (2004) “Concept for an Integrated Disaster Management Tool”, Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.

Extremum – Frolova, N., Larionov, V., Bonnin, J. (2006) “Multi-Hazard Risk Assessment at Different Levels with Extremum System Application”. The Third International Conference on Early Warning, Bonn, Germany.

HAZUS-MH - FEMA (2003) HAZUS-MH Technical Manual, Federal Emergency Management Agency, Washington, DC, U.S.A.

HAZ–Taiwan – Yeh, C.H., Loh, C.H., Tsai, K.C. (2006) “Overview of Taiwan Earthquake Loss Estimation System”, Natural Hazards, Vol. 37, No. 1-2, pp. 23-37.

InLET – ImageCat, Inc. (2008) “Loss Estimation Online Using Inlet: The Inter-Based Loss Estimation Tool”, ImageCat, Inc. Whitepaper, c/o Ron Eguchi.

LNECLOSS – Sousa, M.L., Campos Costa, A., Carvalho, A., Coelho, E. (2004) “An Automatic Seismic Scenario Loss Methodology Integrated on a Geographic Information System”, Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, Canada, Paper No. 2526.

LOSS-PAGER – Porter, K., Jaiswal, K., Wald, D., Earle, P., Hearne, M. (2008a).“ Fatality models for the U.S. Geological Survey's Prompt Assesment of Global Earthquake for Response (PAGER) system”, Proc. 14th World Conf. Earthq. Eng., Beijing, China, 8 pages.

MAEViz – MAE (2009) “ZEUS-NL Registration”, available from URL: http://mae.ce.uiuc.edu/software_and_tools/zeus_nl_registration.html.

OPENRISK – Porter, K.A., Scawthorn, C.R. (2007) “OpenRisk: Open Source Risk Estimation Software”, SPA Risk, available from http://risk-agora.org

OSRE – OSRE (2009) “OSREIII”, available from URL: http://quake.kuciv.kyoto-u.ac.jp/OSRE/.

PAGER –USGS (2009) “Earthquake Hazards Program – PAGER: Prompt Assessment of Global Earthquakes for Response”, available from URL: http://earthquake.usgs.gov/eqcenter/pager.

QLARM/QL2 – Wyss, M. (2004b) “Real-time prediction of earthquake casualties”, paper presented at International Conference on Disasters and Society – From Hazard Assessment to Risk Reduction”, edited by D. Malzahn and T. Plapp, Logos Publishers, Universität Karlsruhe, Karlsruhe, Germany, pp.165-173.

RADIUS – Geohazards International (2009) “ RADIUS – Risk Assessment Tools for Urban Areas Against Seismic Disasters”, available from URL: http://www.geohaz.org/projects/radius.

REDARS – Eguchi, R.T., Huyck, C.K., Cho, S., Ghosh, S., Basoz, N., (2003) “Review of REDARS 1.0; Seismic Risk Analysis Software (Task B1-4)”, ImageCat Inc., January.

RiskScape – RiskScape (2009) “RiskScape”, available from URL: http://www.riskscape.org.nz.

ROVER-SAT – ROVER Emcode (2009) “RedROVER - A simple phyton Rover-InCast Web conversion Script”, available from URL: http://code.google.com/p/emcode/wiki/RedROVER., Applied Technology Council (2009) “ATC-20i Mobile Postearthquake Building Safety Evaluation Data Acquisition System (Version 1.0)”, available from URL: http://www.atcouncil.org/ATC20i.shtml.

SAFER – Zschau, J., Gasparini, P., Papadopoulos, G., the SAFER Consortium (2007) “Status of the SAFER Project (Seismic eArly warning For EuRope)”, American Geophysical Union (AGU) Fall Meeting, San Francisco, USA.

SES2002 & ESCENARIS – Roca, A., Goula, X., Susagna, T., Chàvez, J., Gonzàlez, M., Reinoso, E. (2006) ‘‘A simplified method for vulnerability assessment of dwelling buildings and estimation of damage scenarios in Spain’’, Bulletin of Earthquake Engineering, Vol. 4, No.2, pp. 141–158.

SIGE – Di Pasquale, G., Ferlito, R., Orsini, G., Papa, F., Pizza, G., Van Dyck, J., Veneziano, D. (2004) “Seismic scenario tools for emergency planning and management”, XXIX General Assembly of the European Seismological Commission, Potsdam, Germany.

SP-BELA – Borzi, B., Crowley, H., Pinho, R. (2008) “Simplified pushover-based earthquake loss assessment (SP-BELA) method for masonry buildings”, International Journal of ArchitecturalHeritage, Vol. 2, No. 4, pp. 353-376.

StrucLoss – KOERI (2002) Earthquake Risk Assessment for Istanbul Metropolitan Area. Kandilli Observatory and Earthquake Research Institute, Istanbul, available from URL: http://www.koeri.boun.edu.tr/depremmuh/EXEC_ENG.pdf.