SIMULATION OF SEISMIC SCENARIOS IN A WEBGIS ENVIRONMENT. APPLICATION TO AZORES ISLANDS

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ABSTRACT :

The aim of this paper is to present and analyze regional losses in Azores islands, when past earthquake ground motions are considered, and to describe recent upgrades in a seismic scenario simulation tool, named LNECloss (LESSLOSS, 2007). This automatic tool comprises several modules like the modelling of seismic action at bedrock and surface level, the evaluation of earthquake damage to buildings and the evaluation of human and economic losses (Campos Costa *et al*., 2004; Sousa *et al*., 2004; Sousa, 2006). Several development requirements were identified in LNECloss simulator, namely: (a) to make the simulator available on the Web, as a stand alone tool, with no need of a geographic information platform, although with the GIS capabilities of mapping and synthesis the seismic scenario effects and with a friendly graphic interface, so it could be used by agents of civil protection when planning and managing a seismic disaster emergency; (b) to extend the geographic domain of the application to Azores archipelago, as this is the Portuguese region with higher seismic rate. Damages and losses were simulated for the Faial island, located on the Central Group of Azores Archipelago, based on a strong motion seismic scenario similar to 1998 earthquake, revealing a reasonable agreement with the observations.

KEYWORDS: Simulator, WebGIS, Seismic Scenario, Azores Islands

1. INTRODUCTION

LNECloss is a computer tool that evaluates losses as a consequence of a user defined ground motion seismic scenarios. This automatic tool comprises several modules like the modelling of seismic action at bedrock and surface level, the evaluation of earthquake damage to buildings, and the estimation of human and economic losses (Campos Costa *et al*., 2004; Sousa *et al*., 2004; Sousa, 2006)s.

LNECloss have been developed and updated in the framework of previous projects (LESSLOSS, 2007). The simulation software was developed in a scientific programming language, FORTRAN 90, which was incorporated as an external application in a Geographic Information System. Till now, LNECloss was applied to any Census track (parish) of Mainland Portugal (Sousa, 2006). In the framework of the USuET project (Urban System under earthquake threat: An integrated global approach. Application to the Azores), this modeling tool was upgraded, intending to extend its geographic domain of the application to Azores archipelago, as this is the Portuguese region with higher seismic rate.

Furthermore, the seismic scenario simulator was upgraded to a WebGIS environment in order to develop a stand alone tool, with no need of a geographic information platform, although with the GIS capabilities of mapping and synthesising the seismic scenario effects. This upgraded simulator provides a WebGIS tool able to support decision makers on emergency management and planning, associated to a seismic disaster occurring in any parish of Mainland Portugal and Azores islands.

2. BUILDING DAMAGES AND HUMAN LOSSES MODELS

2.1. Building damage model

LNECloss uses the capacity spectrum method (ATC, 1996), worldwide divulged by the HAZUS loss estimation methodology (FEMA & NIBS, 1999), to evaluate the peak response for each type of building, called the performance point. The evaluation of peak response relies on the intersection of its capacity curve with the seismic spectral demand at the site. The initial elastic response spectrum is reduced to the so called demand spectra, taking into account the building degradation when exposed to the seismic motion. The procedure is illustrated in Figure 2.1 (LESSLOSS, 2007). The abscissa of this performance point corresponds to the effect of seismic action, measured in terms of spectral displacement. This value conditions the cumulative probability distributions that model building fragility. Fragility curves allow the evaluation of the probability to exceed the threshold of a given damage state, conditioned by a level of seismic ground motion. Five damage states were considered, dependent on the typology: No damage, Slight, Moderate, Severe and Total Damage. Approximately 10 to 25% of the total area of buildings in Total Damage state is likely to collapse totally, whereas the remaining is expected to collapse partially (LESSLOSS, 2007). The threshold of those damage states are established in terms of global drift for each typology, and fragility curves are defined by a lognormal distribution function conditional on the maximum response of each building, referred as $Sd\max \equiv Sd$.

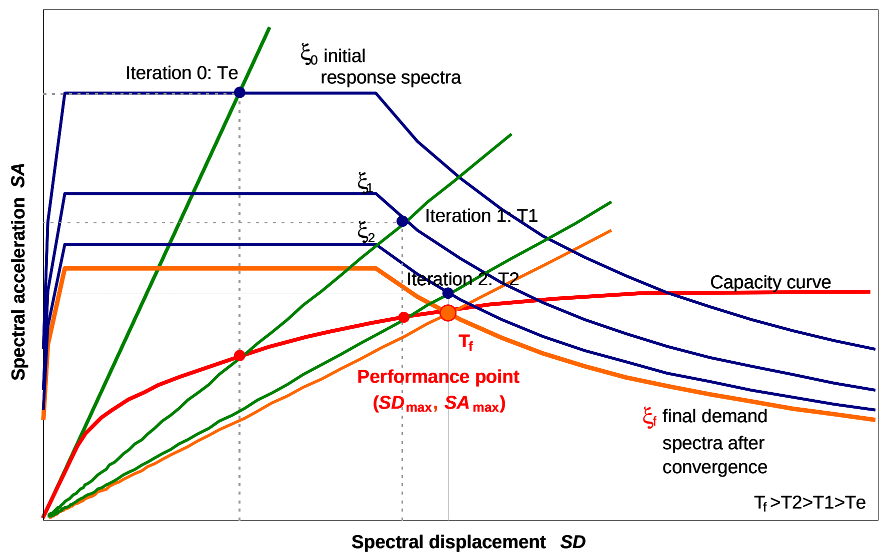

Figure 2.1 Iterative method to obtain the peak of building response in the capacity spectrum method (Campos Costa *et al.*, 2008)

2.2. Human losses models

LNECloss computes human casualties taking into account damages in each typology and the occupancy per typology, following two methodologies: (i) FEMA & NIBS (1999) methodology, adapted to Portuguese situation and (ii) Coburn and Spence (2002) worldwide applied methodology.

3. SEISMIC SCENARIO SIMULATOR LNECloss ON THE WEB

The availability of GIS tools through the Web, handles a very specific architecture. The global architecture of LNECloss, obeys in a general mode, to a model based on client/server, *three-tier*. For the implementation of the WebGIS environment, it has been adopted the Server-Side component.
This type of component allows the users to make their analysis requests to a Web Server. It processes the request and returns the results to the user, which may visualized them in a Web browser (Peng and Tsou, 2003).
The implementation of the Simulator, LNECloss, in a WebGIS environment was conceived and developed, over a Linux platform (Red Hat Enterprise v. 5.0) using mainly the Java language as the programming technology. Java language was chosen mainly because it is independent of the operating system, which allows the portability of the application between different platforms (Afonso, 2007).

As referred previously, it was implemented the *three-tier* architecture for the implementation of Simulator LNECloss in a WebGIS environment. This type of structure is constituted by three main components: (i) Client, (ii) Web Server and Application Server, and (iii) Data Server. (Peng and Tsou, 2003). In the next paragraphs, it is described how the referred three components were implemented in LNECloss (adapted from Afonso, 2007).

Regarding the Client component, it was created several Graphic User Interfaces (GUI's) with the objective of accepting user requests to trigger Simulator operation. User must choose scenarios characteristics and modelling options. Those options will condition the type of output maps and final results. The same GUI's are composed by a set of forms made available through a set of hyper connections with different functionalities. The GUI's were implemented using technologies like, HTML (Hyper Text Markup Language), JSP[1] (Java Server Pages), Javascript[2] routines and ArcXML[3] (communication language between the user and the Application Server).

On the subject of the second component, it was chosen the Apache Tomcat (developed under Jakarta Project on the Apache Software Foundation) for the Web Server. Apache Tomcat is an open-source Web Server that uses Java technology. As regards the Application Server, it was chosen the ArcIMS technology by ESRI. The ArcIMS Spatial Server communicates with the Web Server through the ArcIMS Application Server Connectors, which in this case was the Java Connector. The ArcIMS package is a map service platform, which makes the interpretation of spatial data, and makes them available on the Internet.

Concerning the Data Server, it was implemented a File System Management (FSM) rather than a traditional relational database structure. The connection between the FSM and the Web Server is made through a JDBC[4] protocol, which allocates queries and different types of operations, using SQL (Structured Query Language). This scheme allows that text files are handled in a similar way to tables in a typical relational database. A FSM was implemented, because, in order to create the output text files, the application must be previously executed and preceded by the user requests. Moreover, there is no need to record the generated output files in a database structure.

Figure 3.1 illustrates one of the available interfaces, which allows the user to specify the characteristics of a seismic scenario.

Recapitulating and summarizing how the application works: The user (Client), through a Web browser, requests different scenarios simulations through GUI's in JSP and HTML. This request is transmitted to the Server. The Web server (Apache Tomcat) receives the Client request, executes the Simulator routines (implemented in FORTAN 90), manages the results and forwards the request to the ArcIMS Application Server Connector. This Server Connector interprets the request and forwards it to the ArcIMS Spatial Server. The output will be a set of maps for the chosen scenario and for the chosen modeling options. The Web Server has access to these maps and returns them to the Client.

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[1] Java Server Pages (JSP) is a Java technology that allows developers to dynamically generate HTML, XML or other types of documents in response to a Web client request. The technology allows Java code and certain pre-defined actions to be embedded into static content.

[2] JavaScript is a scripting language most often used for client-side web development. It is a dynamic, weakly typed, prototype-based language with first-class functions.

[3]ArcXML is a XML specification which becomes possible the connection and creation of structured messages between the servers and clients. All requests made by the users (Client component), as the responses returned by the servers, are codified in ArcXML.

[4] Java Database Connectivity (JDBC) is a set of Java classes that sends SQL instructions for a specific relational database.

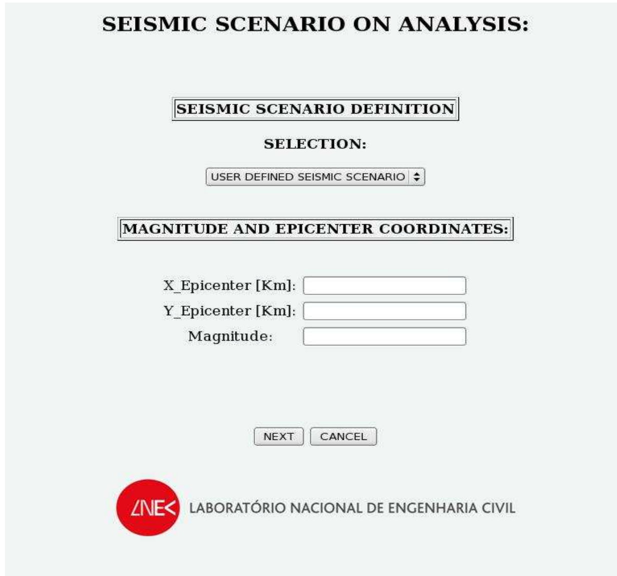

Figure 3.1 Web Interface of LNECloss Simulator; seismic scenario request (Client component) (adapted from Afonso, 2007)

4. EXPOSURE AND VULNERABILITY CHARACTERIZATION FOR AZORES ISLANDS

4.1 Building and inhabitants inventory

Characteristics of Azores building stock and their inhabitants were surveyed in the Portuguese 2001 Censos (INE, 2002). Table 4.1 presents Azores global statistics regarding inhabitants, dwellings and residential buildings. The same statistics to Faial and Pico islands are shown. Those were the most affected islands in the 1998 Azores earthquake.

Table 4.1 Global statistics for Azores archipelago and for Faial and Pico islands (after Censos 2001 and Sousa and Afonso, 2008)

Type of exposure	Azores archipelago	Faial island	Pico island
Buildings	87 585	5 053	7 571
Dwellings	92 867	5 405	7 654
Inhabitants	240 309	14 918	14 668

In order to inventory the Azores housing stock, and to classify its vulnerability, 3 variables, identified in Portuguese Censos 2001, were cross wised, simultaneously: building epoch of construction (9 classes), structural type (5 classes) and number of floors (7 classes), identifying 315 (9 × 7 × 5) different typologies. However, some of the typologies surveyed in Censos 2001 didn't exist in the Azores housing stock implying a reduction of the number of typologies surveyed in Censos 2001, in Azores, from 315 to 178.

Figure 4.1 illustrates the distribution of the number of buildings per structural type in Azores archipelago.

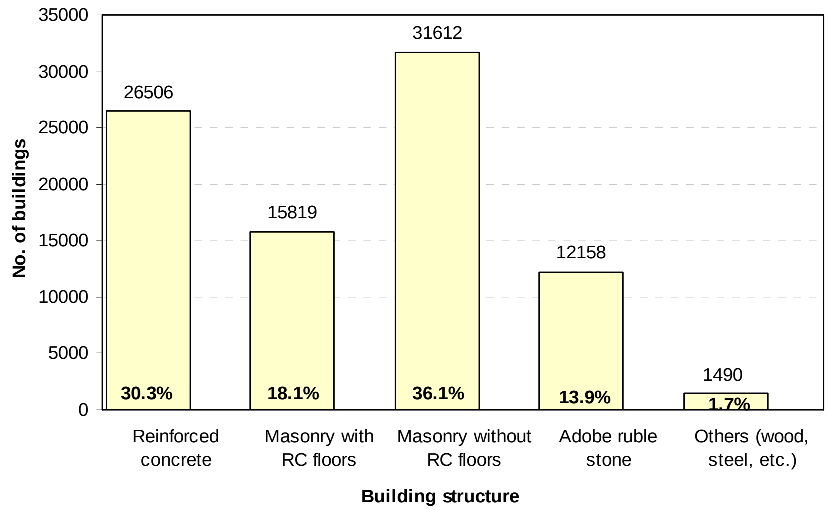

Figure 4.1 Number of buildings by structural type in Azores islands

4.2 Geographic distribution of exposed elements

Figure 4.2 shows the geographic distribution of housing inventory in the islands belonging to Central Group of Azores Archipelago. The map was plotted with the geographic disaggregation of a Census track parish.

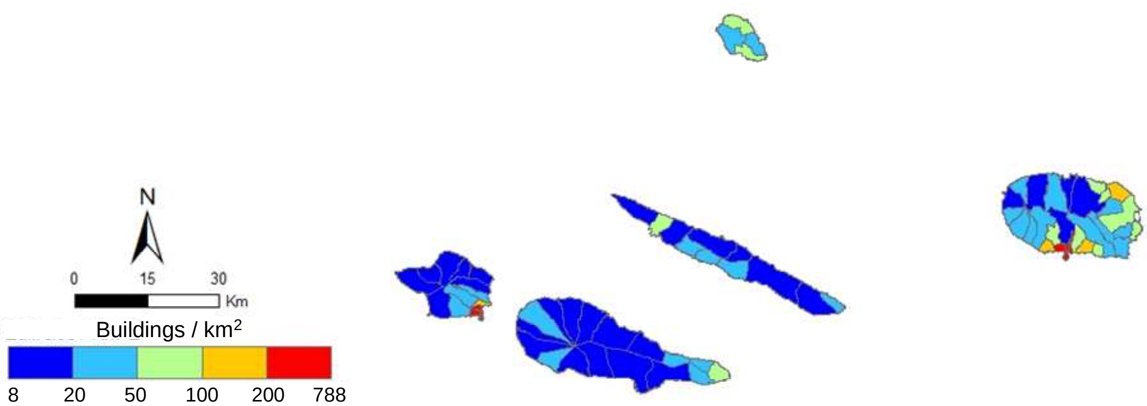

Figure 4.2 Housing stock geographic distribution on Central Group of Azores Islands

4.3 New inventory taking into consideration 9th July 1998 Faial earthquake

After the 9th July 1998 Faial earthquake the building stock surveyed in Censos 2001 didn't account for the event damaged buildings that remained uninhabitable [Sousa & Afonso, 2008]. As a result, if loss modelling was applied to Censos 2001, it would be unrealistic to expect that 1998 earthquake damages were reproduced, given that the most severely damaged buildings were not considered in the exposure.

So, a new inventory was constructed for Faial and Pico islands, adding together Censos 2001 inventory and some of the damaged building classified by Ferreira (2008) in the EMS-98 grades. This author surveyed 2 030 and 885 buildings of Faial and Pico islands, respectively, analysing post-earthquake photos and a damaged building database that was constructed after de earthquake («auto de vistoria»). In Ferreira (2008) survey the buildings were grouped according to the most common structural system of Faial and Pico islands, presented in Zonno *et al.*, 2008, and were available with the geographic disaggregation of a Census track (parish). A building was considered as uninhabitable if it was classified in the D4 and D5 EMS98 damage grades. Also 30% of the buildings that were classified in D3 damage grade were considered uninhabitable (see table 5.1). After accumulating the uninhabitable buildings to the Censos 2001 inventory, the same amount of buildings was subtracted from each parish building toll, focusing on pre-fabricated building typologies, used as temporary shelters, and on buildings constructed after the event. The same procedure was applied to the displaced households due to the loss of their housing habitability.

4.4 Vulnerability characterization

To emphasize the correlation of damages estimates and building classes the original 325 typologies were aggregated in 7 typological classes epochs of construction and structural types, namely, (i) Adobe + rubble stone + others, (ii) Masonry before 1960, (iii) Masonry 1961 85, (iv) Masonry 1986 01, (v) RC before 1960, (vi) RC 1961 85 and (vii) RC 1986 01. Each typological class was subdivided in 7 classes of number of floors, performing a total of 49 typologies. To characterize the vulnerability of Azores building stock it was necessary to define, for each one of the 49 identified typologies, a capacity curve and five fragility curves (one by damage state), according to HAZUS methodology (FEMA and NIBS, 1999; LESSLOSS, 2007).

5. MODELLING DAMAGES AND LOSSES IN THE 9TH JULY 1998 FAIAL EARTHQUAKE

5.1 Damages and human losses observed in 1998 Faial island earthquake

Table 5.1 (left) shows the number of buildings classified as uninhabitable as a consequence of 9th July 1998 Faial earthquake, derived from the number of buildings reported by Ferreira (2008) in D3, D4 and D5 EMS98 damage grades. The same table (right) presents death toll in 1998 earthquake by Census track.

Table 5.1 Left: Uninhabitable buildings in Faial and Pico, following Ferreira (2008) survey. Right: number of deaths in 1998 Faial earthquake (Sousa and Afonso, 2008).

EMS98 damage grades	Uninhabitable buildings in Faial	Uninhabitable buildings in Pico
30% of D3	125	39
D4	359	79
D5	90	7

Faial Census track (parish)	Deaths [#] Total = 8
Ribeirinha	5
Pedro Miguel	2
Salão	1

5.2 Faial 1998 ground motion simulation

The simulation of the effects of 9th July 1998 Faial earthquake was based on a 6.2M_W scenario, located at Madeira (1998) epicentre (38.64ºN, 28.59ºW) and using Bommer *et al*. (1998) and Akkar and Bommer (2007) empirical attenuation laws that predict elastic response spectra for three classes of soils conditions (rock, stiff and soft soils). Zonno *et al*. (2008) 1998 earthquake fault geometry was used to estimate the shortest distance between site and surface projection of fault rupture (strike=165º, dip=85º, depth of top=1.1km, length=16.5 km and width=9.4 km). A third ground motion scenario was used to simulate damages: the results of EXSIM finite fault stochastic ground motion simulation for Faial and Pico parishes (Zonno *et al*., 1998). This results describes ground motion as a PSA response spectra (5 % damping) correspondent to the maximum PGA of 30 trials.

5.3 Simulation of the effects of Faial 1998 earthquake

Table 5.2 put together the results of the simulations of a ground motion scenario similar to 9th July 1998 Faial earthquake.

Table 5.2 Total damaged buildings and death toll simulated in Faial and Pico islands

Island	Faial			Pico		
Strong motion model	Bommer *et al.* (1998)	Akkar & Bommer (2007)	EXSIM Azores	Bommer *et al*, (1998)	Akkar & Bommer (2007)	EXSIM Azores
Total damage [#]	314	144	131	61	22	20
Deaths [#] Coburn & Spence, (2002)	37	14	17	1	0	0
Deaths [#] FEMA & NIBS (1999)	8	4	3	1	0	0

Figure 5.1, top, presents a map of isoseismals observed in 1998 earthquake in Faial Island and some of the results of this scenario simulation.

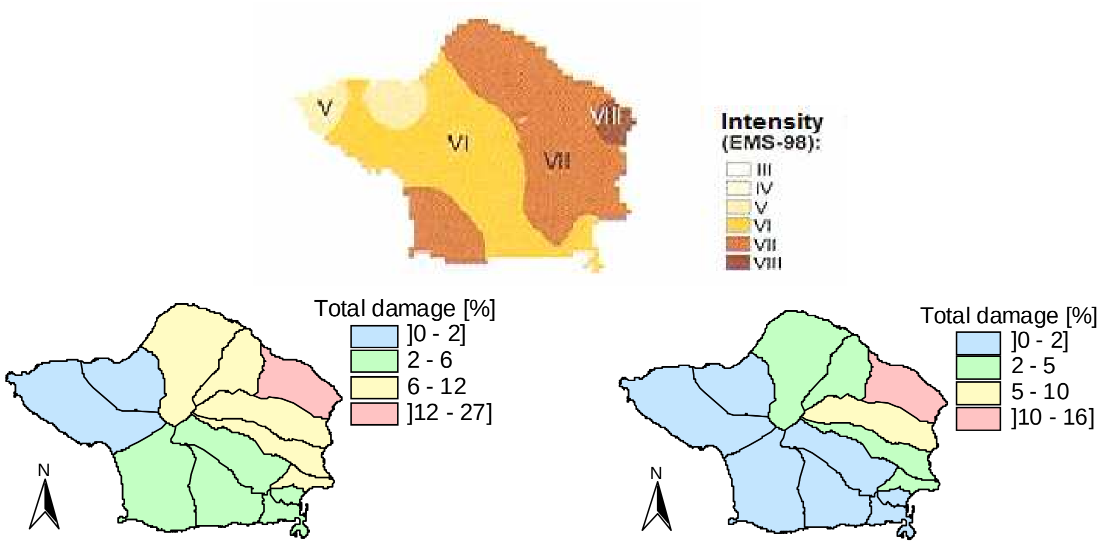

Figure 5.1 Top: Isoseismals of 1998 earthquake in Faial island (after Ferreira, 2008); bottom: geographic distribution of simulated Total Damaged buildings (collapse and partial collapse) for (left) 1998 scenario; Bommer *et al*. (1998) and (right) EXSIM ground motion simulation (right) (Zonno *et al.*, 1998)

6. FINAL CONSIDERATIONS

The Seismic Scenario Simulator on the Web is a stand-alone tool, with some GIS capabilities for mapping and synthesis of seismic scenario effects. This service is useful for several users, like civil protection authorities, as it may simulate a real seismic scenario in just a few minutes, offering essential information for emergency management. Also stakeholders interested in scientifically based seismic risk mitigation strategies benefit from this application and may use it to simulate alternative seismic scenarios with no need to be proficient on GIS software packages or have it available.

In what concerns the application of the Simulator to 1998 scenario, one may conclude that: (i) Coburn & Spence (2002) casualty model overestimates death toll; (ii) the parameters of the mechanical building damage model and of the casualty model may be calibrated according to the characteristics of the existing building stock, don't constraining it to pre-defined vulnerability classes, as statistic damage models do; (iii) the flexibility of the mechanical building damage model and of the casualty model favors good agreements between simulations and observations.

Nevertheless, further improvements should be expected in the future, namely it is recognized the importance (i) of obtaining refined geotechnical characterization of the region in order to study site effects due to non-linear soil dynamic amplification and (ii) of the upgrading of the WebGIS to a more recent type of technology, like ArcGIS Server.

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