MINISTÉRIO DAS OBRAS PÚBLICAS, TRANSPORTES E COMUNICAÇÕES

Laboratório Nacional de Engenharia Civil

DEPARTAMENTO DE ESTRUTURAS

Núcleo de Engenharia Sísmica e Dinâmica de Estruturas

proc. 0305/17/15525

SEISMIC RISK MITIGATION OPTIONS AND ACTIONS TO BE STUDIED FOR LISBON METROPOLITAN AREA

REPORT 161/2005 — NESDE

Lisbon, April 2005

Project LESSLOSS – Risk Mitigation for Earthquakes and Landslides

Sixth Programme for Research, Technological Development and Demonstration of European Comission

Contract No.: GOCE-CT-2003-505448

I&D
UNDERGROUND STRUCTURES

INDEX

INDEX OF FIGURES

INDEX OF TABLES

1. Introduction

The project *LESSLOSS – Risk Mitigation for Earthquakes and Landslides* is a European integrated project developed within the framework of the Sixth Programme for Research, Technological Development and Demonstration of European Comission.

The project started in September, 2004, has a duration of 36 months, is coordinated by University of Pavia (Italy) and involves the participation of 46 European institutions.

Summarizing LESSLOSS objectives, it aims to promote a coordinated approach to the assessment of seismic risk, its environmental, urban and infrastructural impact, and prevention and protection strategies [Calvi & Pinho, 2004]. The LESSLOSS project addresses natural disasters, risk and impact assessment, natural hazard monitoring, mapping and management strategies, improved disaster preparedness and mitigation, development of advanced methods for risk assessment, methods of appraising environmental quality and relevant pre-normative research [Calvi & Pinho, 2004].

The LESSLOSS is a multidisciplinary project divided in eleven Research Components or Subprojects.

The National Laboratory for Civil Engineering (LNEC) is involved in the sub-project 5 - In-situ – assessment, monitoring and typification of buildings and infrastructure and in the subproject 10 - Earthquake disaster scenario predictions and loss modelling for urban areas.

Globally, LNEC participation in subproject 10 involves the following tasks:

Task 1 – To present the data available for Lisbon on earthquake catalogues, seismotectonic environment, and site geology. To investigate and purpose possible strengthening techniques for non-ductile RC and Unreinforced Masonry buildings.

Task 2 – To develop scenario earthquakes for Lisbon site based on seismic deaggregation.

Task 3 – To present building inventory for Lisbon site based on Portuguese CENSOS 2001.

Task 4 – To present capacity curves fitting building inventory and compare them with Risk-EU for possible adjustments.

Task 5 – To adapt LNECloss software tool, that is an automatic seismic scenario loss estimate methodology, in order to re-evaluate loss estimation for specific mitigation policies. To perform all the computations for Lisbon site.

The present report addresses the first 6 months of LNEC participation in subproject 10. More precisely, this report was developed in order to accomplish LESSLOSS deliverable nº 82, that deals with mitigation options and actions to be studied for Lisbon Metropolitan Area. Similar options and actions will be carried out for two other cities, Istanbul and Thessaloniki.

In order to recognize how project tools could be used to answer Lisbon city authorities needs regarding seismic risk mitigations policies, LNEC promoted a panel, that took place last February 11th, 2005, with the participation of city authorities and the scientific community. That panel had two main objectives: (i) to introduce LESSLOSS project and (ii) to involve city authorities in identifying likely mitigation actions for consideration in LESSLOSS. City authorities and scientists that participate in that panel were the following:

1. LNEC research team.

2. Leader of subproject 10

3. City authorities:

a) National Civil Protection

b) City Council – Civil Protection Department

c) City Council – Urban Rehabilitation and Planning Department

4. Scientific community interested in seismic risk research.

Main conclusions derived from that panel, and from LESSLOSS posterior meetings, are addressed in Chapter 2. This chapter presents the identified mitigation strategies to be modelled with LNECloss software tool (see chapter 4), in order to assess the cost and the benefits of mitigation alternatives.

Chapter 3 summarises the mitigation actions presently supported by City authorities.

Chapter 4 presents the LNECloss seismic loss methodology integrated in a Geographic Information System, its overview, procedures and available data.

Final considerations are reported in chapter 5.

2. Proposed mitigation actions for Lisbon

Three main actions are proposed to mitigate seismic risk in Metropolitan Area of Lisbon (MAL) or in Lisbon town. It is envisaged that those action will be implemented during the period of the project.

Techniques to implement those actions will be presented. Also the updating of LNECloss tool to put into operation those alternatives will be studied.

Action 1. Modification of old masonry buildings in the MAL zones of highest population incidence, using a range of modification techniques.

Justification

Old masonry buildings represent a very high seismic risk when compared to new buildings designed in accordance with the requirements of present Portuguese seismic code [RSA, 1983]. According to 2001 Censos [INE, 2003], 27% of MAL population live in such buildings (see figure 7). Even if not in the immediate future, upgrading of these buildings will be needed, and it is essential to understand how potential life loss and other consequences of future earthquakes can be reduced. A range of techniques is available, and the effectiveness of these techniques can be studied, and the optimum level of intervention understood.

Methods

To develop new capacity curves for that class of buildings and describe what type of strengthening techniques could be used. To study the influence of these techniques on the vulnerability and fragility parameters.

To define the parametric exploitations necessary to calibrate the capacity curves (analysis of several representative structures using push-over analysis).

Action 2. Upgrading of reinforced concrete buildings to fit with code presently enforce in Portugal.

Justification

RC buildings constructed before present seismic code are essentially non-ductile and therefore present a significant vulnerability. Part of them (mainly post 1974 period) did not respect any legal regulation. According to 2001 Censos [INE, 2003], 32% of MAL buildings have a RC structure and where constructed before seismic code presently enforce. The inhabitants of those buildings represent 46% of MAL population.

Methods

Expected losses at present time will be compared against future losses referring to upgraded buildings. The benefits will be balanced against costs of upgrading.

Action 3. Enhancement of emergency planning facilities

Justification

Within the scope of Civil Protection its relevant to understand consequences of future seismic events, to support decisions on emergency, and to use seismic scenarios in training related to catastrophic situations.

Methods

In what concerns emergency competencies, GIS automatic tools may be improved in two main directions:

1. LNECloss needs to be upgraded in methodologies concerning casualty estimates.
2. Develop a new module to LNECloss concerning (a) the identification of critical hospitals and links in Lisbon town and (b) a network system to optimise injuries transportation after an earthquake.

3. Brief overview of existing mitigation programmes in place

3.1. National Civil Protection

National Civil Protection authorities (SNBPC – *Serviço Nacional de Bombeiros e Protecção Civil)* conducted a study, with several scientific partners [Anderson *et al.,* 2004 and Carvalho *et al.*, 2002a], finished in 2002, in order to establish an emergency plan for Lisbon Metropolitan Area.

One of the main results of that study was the development of an automatic tool, integrated on a Geographic Information System, that is able to support decisions on emergency management and planning. This tool simulates the effects of a seismic scenario on environment (intensity of ground motion, liquefaction, etc), on residential building stock, on population and on infrastructures. One of the drawbacks of this Simulator is the large dispersion of results related to human casualties.

The emergency plan for Lisbon Metropolitan Area, counting with the contribution of 16 counties, is currently under development.

3.2. City Council – Civil Protection Department

Lisbon Council Civil Protection had developed a seismic risk emergency plan, implemented since ninety decade of the XX century [Pais & Ribeiro, 1994 and Oliveira & Pais, 1993]. This municipal authority also counts with the support of an automatic GIS tool to model loss scenario on buildings and population. This Simulator needs to be upgraded in what concerns models of building damage and human losses.

This Department of Lisbon Council is presently developing a case studies booklet presenting recommendations in what concerns rehabilitation interventions on existing buildings. This booklet intents to prevent the increase of seismic vulnerability of buildings, resulting from the introduction of modifications not adapted to a correct structural behavior, and to suggest rules for seismic upgrading.

The idea of transforming those rules into a compulsory instrument for municipal code is being considered.

3.3. City Council – Urban Rehabilitation and Planning Department

Urban Rehabilitation and Planning Department is promoting Societies for urban rehabilitation dealing with the management of specific zones of Lisbon town.

Special attention is being given to *Baixa Pombalina*, a town 18th century block down, that submitted an application for listing as World Heritage by UNESCO. Presently is being prepared a master plan, or strategic document, for that zone.

4. Seismic loss methodology integrated in a Geographic Information System - LNECloss

4.1. Overview

The LNECloss tool [Sousa *et al.,* 2004] *is* an automatic seismic scenario loss estimate methodology, integrated on a GIS (ArcGIS, or other) that comprises several modules to perform seismic risk analysis. This modules are developed in an high level programming language and compiled in DLL (Dynamic Link Library-DLL) that may be accessed rather efficiently by any Windows program environment (ArcView, EXCEL, MathLab, etc.). The several modules are schematically represented in Figure 1 and are the following:

<u>Bedrock Seismic Input</u> - Given a seismic scenario (magnitude and epicentral location) it computes the Power Spectral Density Function (PSDF) of the strong ground motions at bedrock level of any site at a given epicentral distance.

<u>Local Soil Effects</u> - Given a stratified soil profile units it computes the new PSDF for any location at the surface level, taking into account the nonlinear behavior of the stratified geotechnical site conditions.

<u>Vunerability Analysis</u> - Giving the PSDF at surface level, it computes the response of building typologies following a displacement-based methodology based on the capacities curves.

<u>Fragility Analysis</u> - For a particular site, taking into account damage observed in each typology, the number of existing buildings in each typology (inventory) and respective occupancy, it computes number of building in each damage state.

<u>Human Losses</u> - Taking into account damages in each typology and the occupancy per typology it computes human casualties and homeless.

<u>Economic Losses</u> - Taking into account damages in each typology and damage state it computes building floor lost areas, that can be multiplied by the repair and replacement cost to obtain economic losses.

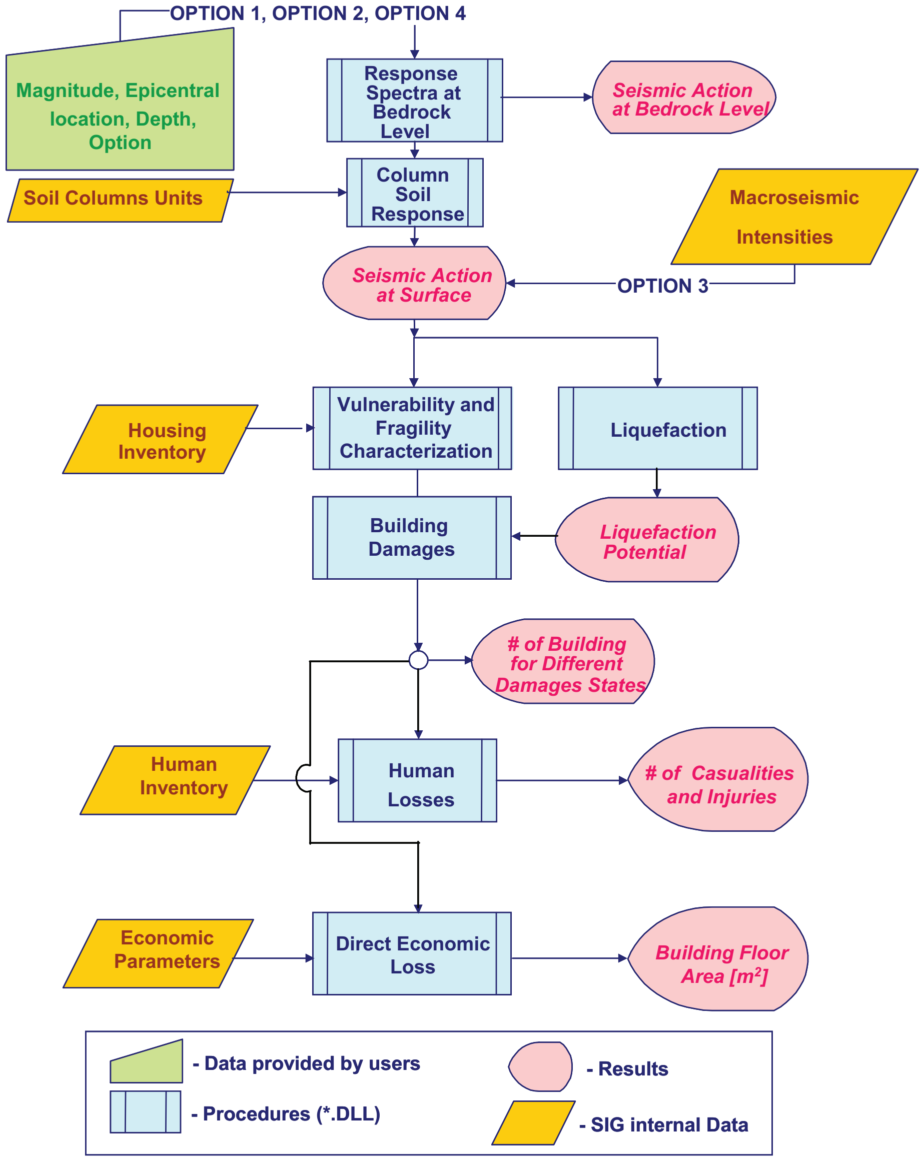

Figure 1: Diagram of LNECloss.

4.2. Input data

Generally speaking the required input data to LNECloss operation includes:

Shallow Geology – Data Base containing information on stratified soil profile units for the region under analysis. Each record comprises the thickness of shallow layers, shear waves velocity, density and plasticity index.

Figure 2 presents the geographic distribution of soil units for Metropolitan Area of Lisbon, MAL.

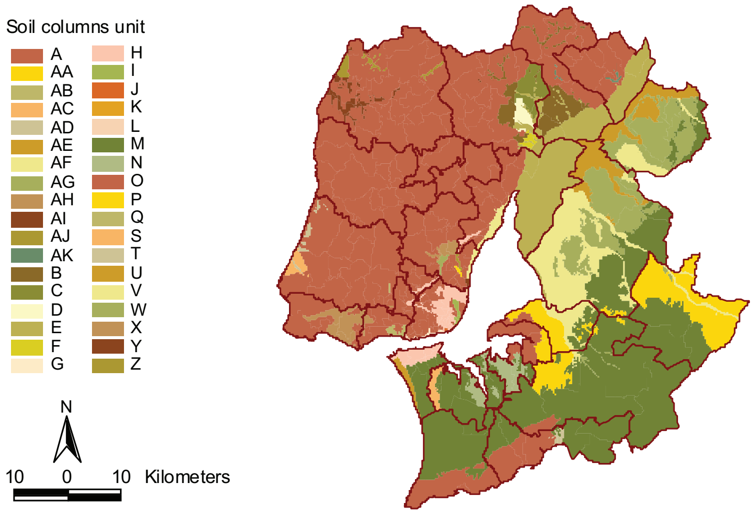

Figure 2: Soil columns units for MAL (after Carvalho et al. *[2002a]).*

Building stock – Residential building database, geographically desegregated by small administrative divisions (parishes), surveyed in the Portuguese 2001 Censos [INE, 2003] and classified by epoch of construction, building construction materials and number of floors.

Sousa [2003] analyzed the 2001 Portuguese Censos with three main purposes: (i) to build the statistics of the number of buildings and inhabitants in Portuguese mainland, (ii) to characterize their geographic distribution and (iii) to identify the most representative and frequent building types by region.

In the *Building Questionnaire* of that Censos there were identified some variables representing buildings characteristics that are expected to influence their performance when stricken by an earthquake: *epoch of construction*; *building structure*; *number of floors*. Table 1 presents the classes of those variables available in Censos 2001.

Table 1: Classes of vulnerability variables obtained in Portuguese Censos 2001.

Epoch of construction	Building structure	Number of floors
Before 1919	Reinforced concrete	1
1919 to 1945	Masonry with RC floors	2
1946 to 1960	Masonry without RC floors	3
1961 to 1970	Adobe ruble stone	4
1971 to 1980	Others (wood, steel, etc)	5 to 7
1981 to 1985		8 to 15
1986 to 1990		+ 15
1991 to 1995		
1996 to 2001		

Figure 3 to 6 present the histograms of number of buildings in MAL according to those vulnerability variables.

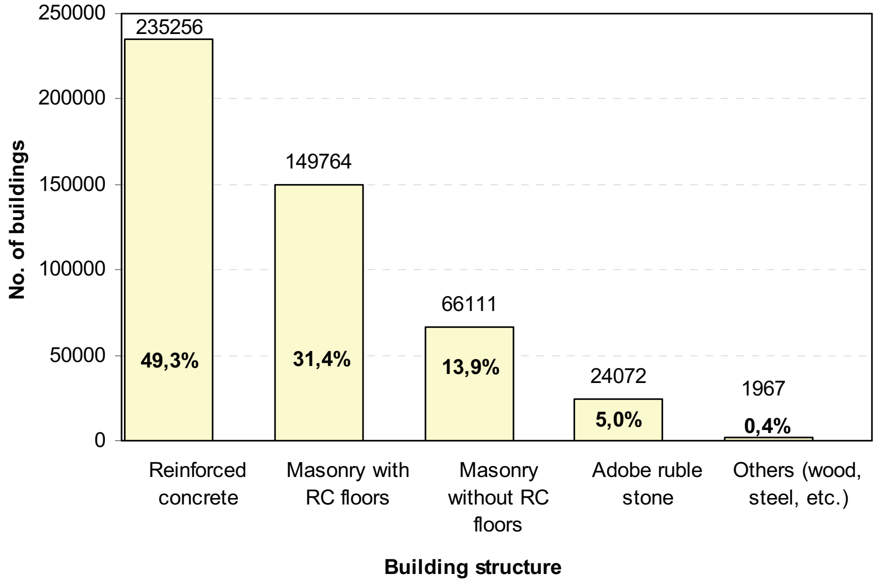

Figure 3: Number of buildings per structural typology in MAL.

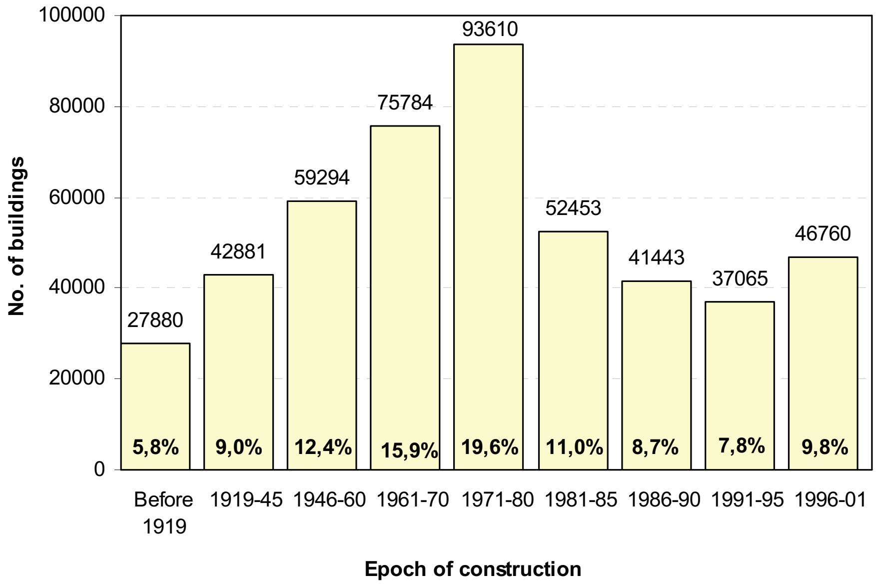

Figure 4: Number of buildings per epoch of construction in MAL.

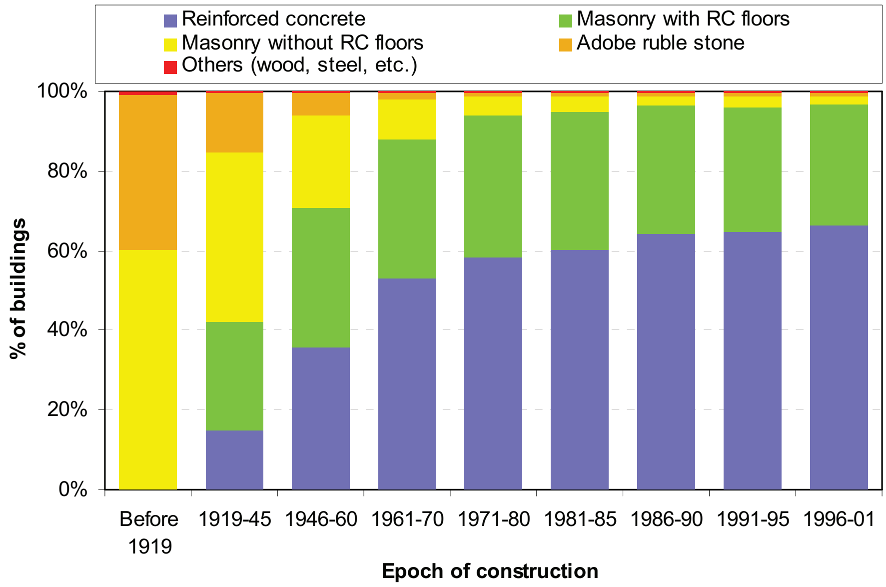

Figure 5: Percentage of buildings per structural typology given the epoch of construction in MAL.

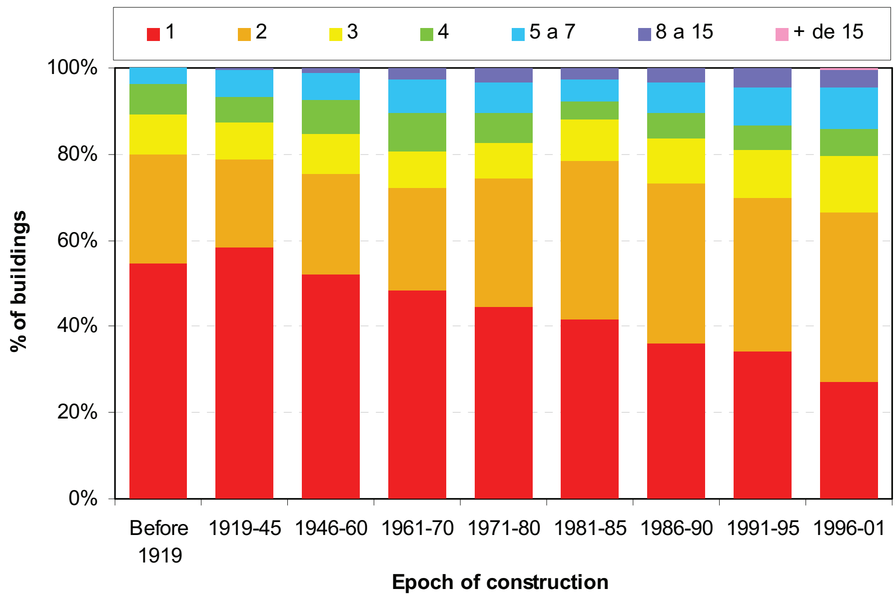

Figure 6: Percentage of buildings per number of floors given the epoch of construction in MAL.

Population at risk - Inhabitants database, with the same level of geographic desegregation (parishes), surveyed in the Portuguese 2001 Censos [INE, 2003]. This database settles accounts for the number of inhabitants living in buildings classified according to their age, structural elements and height.

Figure 7 to 10 present the histograms of number of inhabitants in MAL according to vulnerability variables.

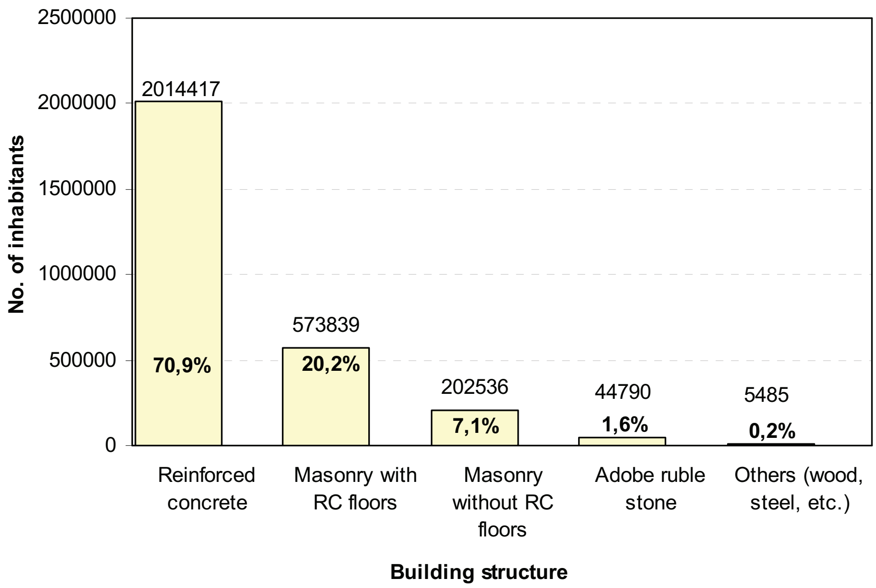

Figure 7: Number of inhabitants per structural typology in MAL.

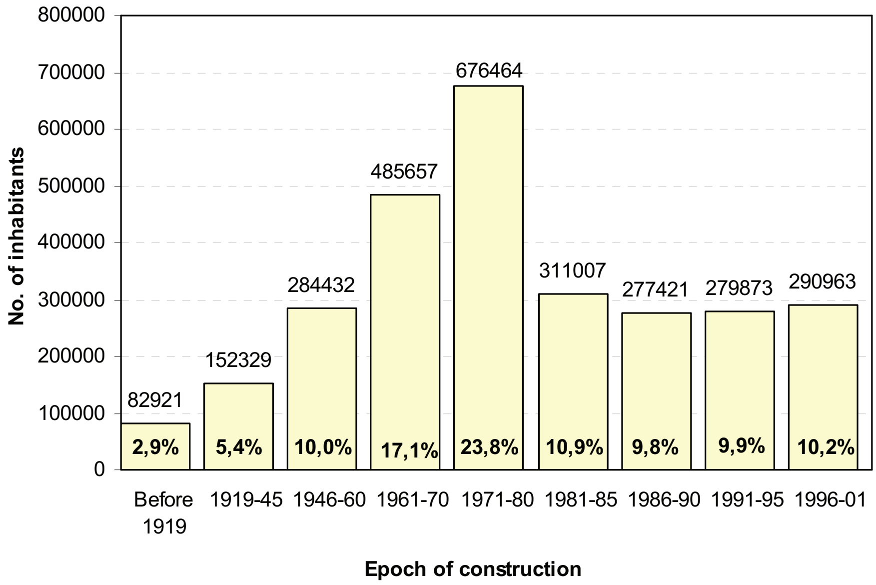

Figure 8: Number of inhabitants per epoch of construction in MAL.

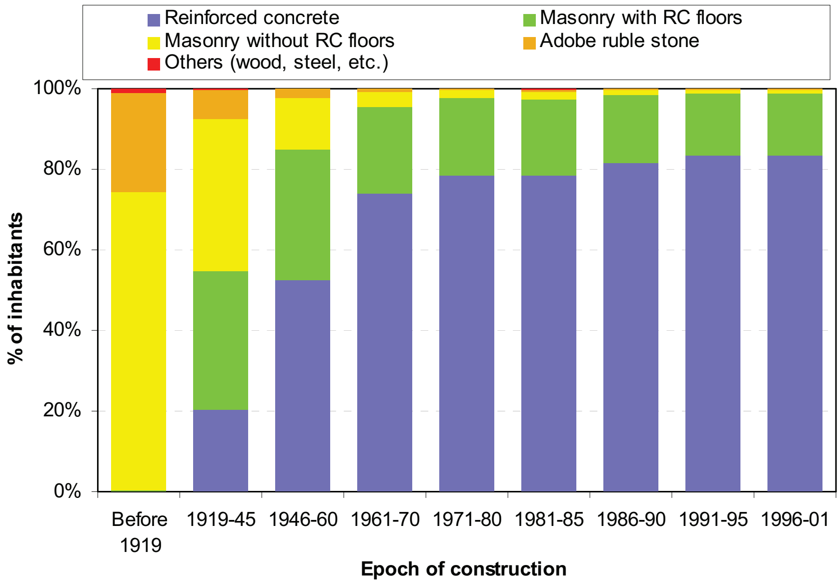

Figure 9: Percentage of inhabitants per structural typology given the epoch of construction in MAL.

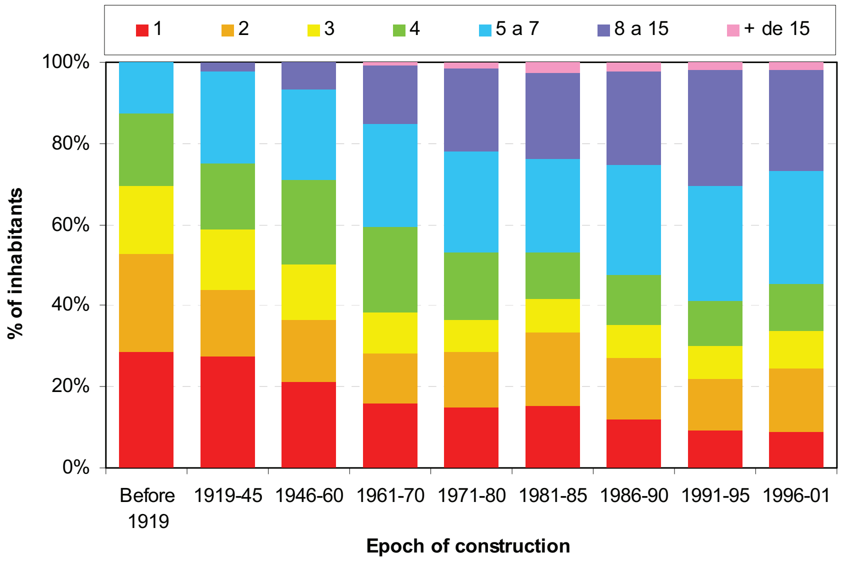

Figure 10: Percentage of inhabitants per number of floors given the epoch of construction in MAL.

Economic parameters – Average floor areas, repair and replacement costs by parish. It was assumed an unique value of average floor areas inside MAL. Replacement cost follows building official prices established by law: *Portaria* nº 1062-C/2000, 31th of October, decrees the values of 461,4, 509,3 e 582,6 Euros/m^2 for the year of 2001, for specified counties in Portugal.

Data provided by user - The user should provide the following information: (i) x, y coordinates of the scenario epicentre in a rectangular (planar) coordinate system, (ii) the scenario magnitude and (iii) the option to evaluate seismic intensities in each site (see the following section).

4.3. Procedures

4.3.1. Seismic action at bedrock level

Given a seismic scenario (magnitude and location) LNECloss computes the PSDF of the strong ground motions at bedrock level of any site. Spectral characteristics can be computed using different approaches that are the following:

Option 1 – uses Boomer *et al.* [1998] empirical spectral attenuation relationship;

Option 2 – uses Sousa [1996] attenuation model based on macroseismic intensities. These models were achieved by integrating intensity data concerning the events of the Portuguese catalogue. Intensity results are then converted into response spectra after Trifunac & Brady [1975];

Option 3 – uses observed macroseismic intensities of specific earthquakes, which are, then converted into response spectra after Trifunac & Brady [1975]; the seismic action is evaluated not at a bedrock level but at surface. User is required to provide a file with intensities;

Option 4 – uses seismological models. It performs non-stationary stochastic finite-fault modelling. Carvalho *et al*. [2004] describe theoretical aspects of this approach.

4.3.2. Seismic action at surface

Given the stratified soil profile units it is computed the new PSDF for any location at surface. The computer algorithms now developed and implemented take into account site effects due to soil dynamic amplification in rather efficient way. These effects are also evaluated by means of an equivalent stochastic nonlinear one-dimensional ground response analysis of stratified soil profile units designed for the region.

4.3.3. Vulnerability and fragility characterization

Methodologies using hysteretic displacement-based assessment and fragility analysis for building loss estimation are novel approaches in seismic risk analysis of urban areas. Damage procedures require a previous classification of the vulnerability of the building stock.

A typological classification of Portuguese building stock taking into account the referred analysis on Portuguese Censos 2001 and expert opinion was established. Experts gave information on the most relevant building practices in the Country, materials and technologies employed in construction, their evolution over time and space. The history of building seismic upgrade in Portugal is mainly related to the occurrence of earthquake disasters (*eg.* 1755 earthquake) or to the building codes enforcement.

Seven typological classes were identified allowing for the two Censos 2001 vulnerability variables *Epoch of construction* and *Building structure*. Each of those classes was further subdivided in seven categories, considering building height, leading to forty-nine building types with similar seismic response characteristics. For those 49 typologies of buildings authors proposed capacity (pushover) and fragility curves and those.

Table 2: Typological classes of the Portuguese housing stock, with reference to Censos-2001 [adapted from Carvalho et al., 2002b]

Typological class	:ription	Seismic design level	
Mansonry before 1919	Unreinforced stone or brick masonry	None	Minimum strength and ductility
Mansonry 1919-60	Unreinforced stone or brick masonry	Low	Low strength and ductility
Mansonry 1960-85	Unreinforced stone or brick masonry	Low	Low to medium yield strength; Low ductility
Mansonry 1960-2001	Masonry with reinforced concrete confining elements	Low	Low to medium strength; greater over-strength after yielding; Low ductility
RC before 1960	Reinforced concrete framed structure	Low	Low to medium strength; over-strength; Low ductility
RC 1961-85	Reinforced concrete framed structure	Medium	Medium strength and ductility
RC 1986-2001	Reinforced concrete framed structure	Medium	Medium strength and ductility, higher to previous class

Fragility curves allow the evaluation of the probability to exceed the threshold of a given damage state. As purposed by HAZUS 99 [FEMA & NIBS, 1999] five damage states were considered: No damage, Slight, Moderate, Severe and Complete Damage. The thresholds of those damage states are established in terms of global drift for each typology.

Figure 11 shows capacity curves and thresholds of damage states for two typologies identified in Censos 2001.

Capacity curves and fragility characterization need to be revised in the framework of LESSLOSS project (sub-project 8) taking into account previous EU-funded projects like Risk-UE and SEISMOCARE and the data on the typological classification of Portuguese building stock.

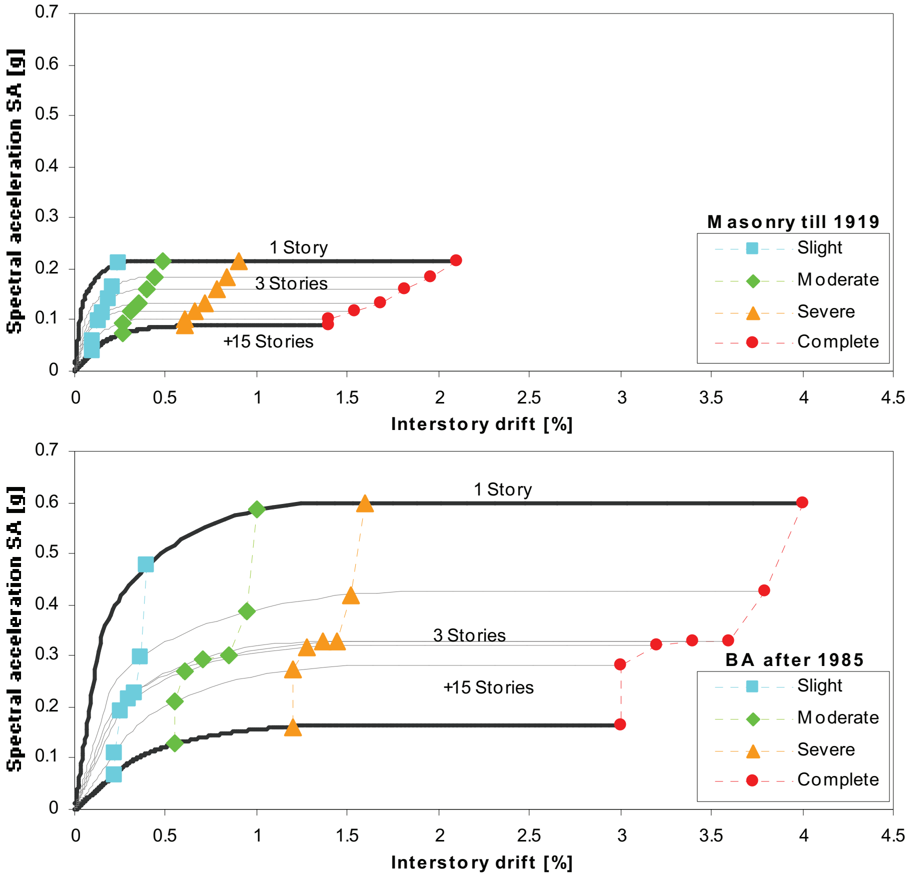

Figure 11: Capacity curves and thresholds of damage states for two typologies identified in 2001 Portuguese Censos.

Damage probability matrices based on European earthquakes can also be used to calibrate vulnerability and fragility information.

4.3.4. Human losses

LNECloss routine for casualty estimation implemented three methods to evaluate death rate and injuries as a consequence of earthquakes: (i) option Coburn & Spence [2002]; (ii) option Tiedemann [Tiedmann, 1992] and (iii) option HAZUS 99 [FEMA & NIBS, 1999].

4.3.5. Economic losses

The module of economic losses computes the lost area of building floors obtained by a weighted linear combination of the probability of the building type being in a given damage state summed over all the elements at risk. To obtain economic losses the lost area is simple multiplied by the replacement cost of one square meter, by parish (Lucantoni *et al.*, 2002; SSN, 1998 and FEMA & NIBS [1999]).

5. Final considerations

This report began with the presentation of LESSLOSS project - *Risk Mitigation for Earthquakes and Landslides*, and describe the first 6 months of LNEC participation in subproject 10 - *Earthquake disaster scenario predictions and loss modelling for urban areas*.

LNEC participation in subproject 10 includes the adaptation of LNECloss software tool to revaluate seismic risk in Lisbon region after the virtually implementation of specific mitigation policies.

In order to take note on existing mitigation policies and city authorities needs concerning that matter, LNEC promoted a panel open to the discussion on seismic risk mitigation actions. Three main actions were identified to mitigate seismic risk in Lisbon region.

These kind of meetings are expected to be repeated during the project lifetime. However, it is important to forewarn that the proposed actions may suffer some adjustments in the course of their development, according to the actual conditions found during the work and the results of cooperation with city authorities.

This report also includes a description of LNECloss, the seismic loss methodology integrated in a Geographic Information, specifically its procedures and available data.

LESSLOSS project will count with the contribution of other studies under development in LNEC, namely internal and cooperative projects on seismic evaluation and rehabilitation.

6. References

Anderson, M.; Serrano, S.;Oliveira, C.S. [2004].
"Potencialidades do simulador de risco sísmico da Área Metropolitana de Lisboa no apoio à decisão". 6º Congresso Nacional de Sismologia e Engenharia Sísmica, pp. 503-507. Escola de Engenharia da Universidade do Minho, Guimarães. Portugal.

Bommer, J. J.; Elnashai, A. S.; Chlimintzas, G. O; Lee, D. [1998].
"Review and development of response spectra for displacement-based design". ESEE research Report, 98 – 3, Imperial College, London.

Calvi, G. M.; Pinho, R. [2004].
"LESSLOSS – A European Integrated Project on Risk Mitigation for Earthquakes and Landslides". IUSS Press, Pavia.

Carvalho, A.; Campos Costa A.; Oliveira C. S. [2004].
"A stochastic finite – fault modeling for the 1755 lisbon earthquake", Proceedings, 13th World Conference on Earthquake Engineering, London, Elsevier Science Lt., CDRom, paper 2194.

Carvalho, E.C.; Campos Costa, A.; Sousa, M. L.; Martins, A.; Serra, J.B.; Caldeira. L.; Gomes Coelho, A. [2002a]
"Caracterização, Vulnerabilidade e Estabelecimento de Danos para o Planeamento de Emergência sobre o Risco Sísmico na Área Metropolitana de Lisboa e nos Municípios de Benavente, Salvaterra de Magos, Cartaxo, Alenquer, Sobral de Monte Agraço, Arruda dos Vinhos e Torres Vedras. Contribuição para uma Simulação Simplificada de Danos. Relatório final", Report280/02, G3ES, Proc. 037/1/13810, LNEC.

Carvalho, A; Coelho, E.; Campos Costa, A.; Sousa; M.L.; Candeias, P. [2002b]. "Vulnerability Evaluation of Residential Buildings in Portugal" Proceedings Londres. Proceedings da 12ª European Conference on Earthquake Engineering, Referência artigo 696, Londres, Reino Unido, Elsevier Science Ltd.

Coburn, A.; Spence, R. [2002].
"Earthquake Protection". Second Edition. John Wiley & Sons, 420 p.

FEMA & NIBS [1999].
"Earthquake Loss Estimation Methodology – HAZUS 99", Federal Emergency Management Agency and National Institute of Buildings Sciences, Washington, D.C., USA.

INE [2003].
"Censos 2001. Resultados Definitivos. Portugal." Instituto Nacional de Estatística, Lisboa (in portuguese).

Lucantoni, A.; Bramerini, F. & Sabetta, F. [2002].
"Last achievements in seismic risk assessment of Italy". 12th ECEE, artigo nº 464, Londres. Grã-Bretanha.

Oliveira, C.S.; I. Pais, I. [1993].
"Technical Approaches for Earthquake Emergency Planning Recent Applications to the City of Lisbon". International Conference on Natural Risk and Civil Protection, Belgirate.

Pais, I; Ribeiro, M. J. [1994].
"Plano de Emergência para o Risco Sísmico da Cidade de Lisboa". III Encontro de Técnicos da CMLisboa, Edição C.M.L. – Imprensa Municipal, Lisboa.

RSA [1983].
"Regulamento de Segurança e Acções para Estruturas de Edifícios e Pontes". Decreto-Lei nº 235/83, Imprensa Nacional - Casa da Moeda, Lisboa.

Sousa, M. L. [1996].
"Modelos Probabilistas para a Avaliação da Casualidade Sísmica em Portugal Continental", Master Thesis: IST, Universidade Técnica de Lisboa

Sousa, M.L.; Campos-Costa, A.; Carvalho, A.; Coelho, E. [2004].
"An automatic seismic scenario loss methodology integrated on a Geographic Information System". 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada.

Sousa, M.L.; Martins, A.; Campos-Costa, A. [2003].
"Levantamento do Parque Habitacional de Portugal Continental para o Estudo da sua Vulnerabilidade Sísmica com Base nos Censos 2001." Relatório 205/03, DE/NESDE, , Proc. 0305/14/13733, LNEC, Lisboa.

SSN [1998]. http://www.serviziosismico.it/PROG/1998/RISCHIO/start.html.

Tiedemann, H. [1992].
"Earthquakes and Volcanic Eruptions: A Handbook on Risk Assessment". Swiss Re. Editor. Zurich.

Trifunac, M. D.; Brady, A.G. [1975].
"On the correlation of seismic intensity scales with the peaks of recorded strong ground motion", BSSA, 65.

Acknowledgements

The authors are very thankful to Dra. Anabela Martins that provided computation support to the development of this report.

Lisbon, National Laboratory for Civil Engineering, April 2005

VISAS

Head of Earthquake Engineering and
Structural Dynamics Division

Ema Coelho

The Director
of Structures Departement

João Almeida Fernandes

AUTHORS

Maria Luísa Sousa
Assistant Officer

Ema Coelho
Senior Research Officer

Alfredo Campos Costa
Senior Research Officer