Chapter 9

9 Summary, Conclusions and Further Research

9.1 Introduction

This chapter summarizes the research developed in this dissertation, the main conclusions there from arising and the research required to further complete and enhance the objectives of the work.

9.2 Summary

This research presents a seismic risk assessment on the buildings of Mérida, Venezuela. It consists of a global hazard and vulnerability evaluation and a deeper vulnerability analysis for non-engineered constructions at the “La Milagrosa” settlement.

After an introductory chapter (Chapter 1, explaining the general scope, objectives and contents of this dissertation), Chapter 2 (a State of the Art in seismic risk assessment chapter) describes the general conceptual framework, the different scopes, and the relationships between the methodological approaches used in the assessment.

Chapter 3 presents three approaches for vulnerability assessment of buildings: the Italian Vulnerability Index Method (IVIM), and the RISK-UE WP4 LM1 and LM2. They are differentiated by the nature of the vulnerability-damage relationships and the quantity and quality of the required information about the buildings. IVIM and LM1 are score assignment methods; i.e. the vulnerability of a given building is quantified by an index, and such indicator is empirically related to observed damage, allowing then to create damage scenarios. LM2 is based on spectral displacements capacity-demand curves generated from numerical models of the buildings and allowing to generate fragility curves quantifying the vulnerability. A comparative analysis between these methodologies is performed; the use of LM2 is disregarded as there are no numerical models of the structural behavior of the considered buildings.

Chapter 4 describes the city of Mérida and its physical evolution throughout more than 400 years. The actual structure of the city responds both to the foundation trace and the particular characteristics of the tectonic valley over which is settled. Mérida lies in a alluvial plateau grooved by two river canyons; one of them is deep and steep while the other one is smoother. In the slopes of the canyons the risk of landsliding is high; in the other zones the quality of the soil is generally good. The total urban population in the city’s premises is 197,636 inhabitants. The city is administratively divided in “parroquias” (parishes), by means of which the different distributions of population, housing units, public services and health facilities are described. About one third of the population lives in informal settlements (called “Barrios”) with highly vulnerable non-engineered constructions. Mérida is the capital city of the Mérida state, where the headquarters of the national and regional institutions are settled. The city also counts with a public University, the University of the Andes which is the second biggest publicly owned University in Venezuela, accounting for facilities disseminated all over the city.

Chapter 5 describes a seismic hazard assessment for Mérida city. The tectonic framework as well as the seismogenic zones are taken from other studies. A non-zonified probabilistic analysis is performed obtaining the return periods and annual exceedance probabilities for events corresponding to the European Macroseismic Scale intensity degrees from I = VI to I = IX; they constitute the four basic scenario events for this research. The expected maximum horizontal accelerations (at rock base) for these events are estimated by means of an existing attenuation law (specially derived for western Venezuela). These accelerations are used for a number of representative site response analyses (in the plateau), which are performed via an equivalent-linear model (for horizontally layered soils). The obtained periods of maximum amplification and the corresponding amplification factors are used to carry out a microzonation of the Mérida plateau. Possible induced effects such as liquefaction and landsliding are estimated by the HAZUS® Earthquake Loss Estimation Methodology.

The two selected vulnerability assessment methodologies (IVIM and LM1) are used in Chapter 6. LM1 provides vulnerability distributions for Mérida; they allow preliminarily concluding that most of the constructions at “La Milagrosa” (and other informal settlements) are highly vulnerable. IVIM is used next to perform a more detailed vulnerability evaluation of these constructions; the required knowledge about them is acquired by studying the available damage reports for similar situations, by trying to understand their seismic behavior and by performing a code type analysis (following Venezuelan regulations) on three prototype buildings (with one, two and three floors, respectively). The output of the evaluation by the IVIM is a classification of the constructions according their vulnerability indices. This information is used to perform a new study inside “La Milagrosa” with LM1 methodology providing local damage scenarios.

Chapter 7 contains preliminary proposals for earthquake resistant construction of new buildings and for seismic strengthening of existing ones. A Cost-Benefit analysis is presented.

Chapter 8 presents global damage scenarios (in the surveyed sub-sectors of the city) obtained by the LM1 method. Several manners to display this information are available through the GIS ArcView® software used in this research; the distribution of the different damage grades occurring at the scenario intensities as a percentage of the total number of buildings in the sub-sectors, is primarily used to display the damage distribution in the city.

9.3 Conclusions

The main conclusions of this research are listed in this section. They are classified in two groups: those for the whole Mérida and those specific of La Milagrosa. These last can be extended to other similar settlements in Mérida, Venezuela and even other South American countries.

9.3.1 Conclusions about Mérida

- The seismic hazard for Mérida is high. The return periods for intensities VIII and IX are about 100 and 850 years, respectively. The greatest site response amplifications appear in the plateau's southern proximities to Albarregas river.
- There is an important risk of liquefaction near the outskirts of the northern mountains (La Culata range) limiting the Mérida's valley.
- The slopes of the Chama river have a serious landsliding risk.
- As expectable, the most vulnerable building typologies at Mérida are earthen ancient houses (in the downtown) and non-engineered constructions (in informal settlements). For inputs with intensity VIII, the percentages of collapsed earthen and non-engineered buildings are about 3% and 1%, respectively. For intensity IX, such values are about 20% and 3%.
- In the steepest zones of the informal settlements, the highest hazard coincides with the risk of landsliding and with the utmost vulnerability.
- The IVIM approach does not account for the risk of pounding due to adjacency. This issue is relevant as significant changes are observed in the resulting vulnerability indices.

9.3.2 Conclusions about "La Milagrosa"

- The buildings at "La Milagrosa" are unsafe, even for gravity loads alone (under serviceability conditions). Despite such constructions are conceived as (moment-resisting) reinforced concrete frames, the walls carry most of the loads. This conclusion can be extended to horizontal seismic forces.
- The buildings at "La Milagrosa" are highly vulnerable; for a given intensity, the percentages of damaged buildings are close to those of similar settlements.
- The predicted failure patterns fit those of the observed damage for similar situations.
- A rather moderate investment can provide a reasonable level of seismic safety (via self made retrofit) for settlements like La Milagrosa. Such amount is less than the 6% of the construction cost (under similar conditions) and is smaller than the economical losses in case of an earthquake with intensity VIII. For intensity IX, 265 lives (out of 275) would be saved.
- For new buildings, it might be acceptable to use similar technologies and follow a rather self construction process but the technical supervision and enforcement are musts.

9.4 Further research

- To spread the results of this research among the involved parts (mainly building officials and community representatives).
- To build a number of full-scale laboratory models of non-engineered constructions and to retrofit some of them following the proposed recommendations. To carry out shaking

table tests on these models. The results of these experiments will allow deriving practical conclusions.

- To investigate the use of close construction technologies, as reinforced masonry (e.g. concrete blocks); which are used in close countries.