16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 1916

Registration Code: S-H1462965136

METHODOLOGY FOR AN EFFECTIVE RISK ASSESSMENT OF URBAN AREAS: PROGRESS AND FIRST RESULTS OF THE MERISUR PROJECT

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Abstract

The progress and results the MERISUR, Methodology for an Effective RISk assessment of URban areas, are presented. This project aims at developing an effective methodology for urban seismic risk assessment that provides solutions to some deficiencies detected after recent damaging events worldwide, including risk mitigation actions based on benefit/cost ratios.

In a fisrt stage, the hazard and vulnerability models are developed and improved. A procedure to determine the hazard-controlling seismogenic fault, contsistent with different probability levels, is established. Methods to include active faults as individual sources and to consider near filed effects that significantly amplify ground motions are proposed.

A more complete description of seismic vulnerability encompassing structural, non-structural components is accomplished. Vulnerability modifiers to incorporate effects or urban parameters on vulnerability classes are also quantified.

A distinction is also made between damage to structural and non-structural building elements. For this purpose, a pushover analysis is specifically carried out to model building response and damage trends on non-structural elements. This gives the primary damage. In addition, the area covered by the resulting debris is also estimated both in inner spaces (within the building) and in the outer space (public roads and streets). In this way, a volume of debris will be associated to each area unit of the city, and the potential damage to persons and elements exposed, such as urban furniture and vehicles, will be assessed. This constitutes the secondary damage.

A static level of occupation (building, urban furniture, etc.) and a dynamic level of occupation (persons, vehicles) will be assigned to each area unit of the city, hereby defining the exposure in time and space.

Earthquake losses related to primary damage of building components and to secondary damage (such as urban furniture and vehicles) will be also assessed. Cost/benefit ratios between ex ante risk mitigation measurements will be developed in order to decide whether risk transfer or risk retention is preferable for different risk scenarios. This analysis will confer effectiveness to the results of a seismic risk study. Overall, the estimate of earthquake losses and cost/benefit ratios are topics with little presence in the scientific literature concerning damaging earthquakes in Spain. Thus, the results of this study will provide effective solutions to the challenge to society tackled in this proposal.

Keywords: Seismic Hazard; Seismic Risk, Vulnerability Assessment, Loss Estimate; Urban Risk.

1. Introduction

This contribution presents an overview of the *MERISUR* project for implementing a new *Methodology for an Effective RISk assessment of URban areas*. The main objective of the project is to design, develop and implement new approaches to assess seismic hazard, vulnerability and loss assessments in urban environments. Special attention is given to issues such as:

- incorporation of active as faults as independent seismogenic sources for hazard computation.
- inclusion of vulnerability modifiers related to urban features and the effect of non-structural elements in capacity and fragility curves.
- quantification of the volume of earthquake-related debris material that covers public spaces and impacts on pedestrians, vehicles and other elements populating the urban space.
- cost estimation for damage structural building components according to actual market costs.
- evaluation of temporal exposure variations (of pedestrians, vehicles, etc.) in the final damage and loss tolls.
- design of reinforcement approaches of building elements for the prevention of losses and cost/benefit assessment.

The methodology elaborated in the project is applied to the city of Lorca, located in southeastern Spain. The selection of this geographic location is based on a number of reasons, including:

- it is located in a high-hazard and high-risk area in relation to other parts of the Spanish territory.
- availability of the data required to perform the study (cartographic, seismological, geological, administrative, cadastral, census and market data).
- the relative abundance of specialized work published after the M 5.1, 2011 Lorca earthquake, which caused nine fatalities, hundreds of harmed people and thousands of reallocated/displaced dwellers whose building resulted (temporally) uninhabitable.

Below we present the ideas, methods and first results obtained. Firstly, we describe the overall scheme, objectives and the different work packages (WPs). Secondly, we present the progress and results and, finally, we discuss the results and draw some conclusions about the work done so far and future research directions.

2. Objective and organization of the work

Three are the principal objectives of the work:

1- To update approaches to seismic hazard, vulnerability, damage and loss assessment.

2- To consider damage not only on exposed buildings (internal space) but also over the individuals and the elements exposed in public spaces (external space), such as vehicles or urban furniture and equipment, particularly as a result of the fall of broken parts of damaged building components in pavements and roads.

3- To introduce a cost/benefit approach to investigate whether certain reinforcement measurements could be effectively implemented in order to mitigate the expected risk.

The project is divided in eight interrelated work packages (Fig.1): WP1 refers to the distribution of exposed elements (including inhabitants and assets). A geographical division in internal and external spaces and a temporal division in morning, afternoon-evening and night periods are considered (WP3). WP2 deals with the assessment of the seismic scenario and the corresponding seismic action. WP4 focuses on the vulnerability assessment testing innovative approaches to building classification using remote sensing techniques (LiDAR and aerial images) and developing capacity/fragility curves for local building typologies, considering effects of non-structural elements. The impact of urban factors on seismic vulnerability is also analyzed in WP4. WP5 deals with the estimation of expected damage. A simplified analytical method is used for this purpose. Coupled to the building damage model, a debris estimation model is developed, which allows delimiting the areas undergoing secondary damage and potential road blockage. The quantification of economic losses is the focus of WP6. Loss estimates are obtained through a valuation model that computes the replacement cost of damaged elements. WP7 consists on the reevaluation of the risk modeling outputs considering temporal variations of exposed elements. Finally, WP8 deals with the proposal of ex-ante reinforcement measures leading to future damage reduction and estimation of cost / benefit ratios.

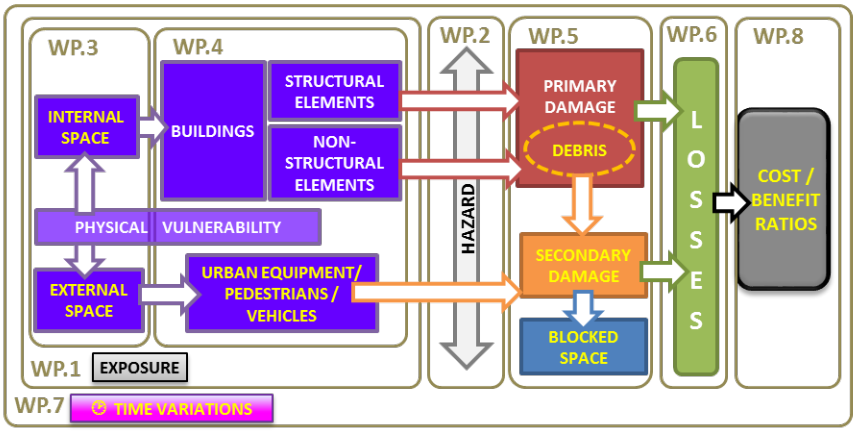


Fig. 1 – Structure of the project in work packages. Yellow text refer to risk topics explored in the study area.

3. Exposure

The assessment of geographical and temporal distributions of exposed elements are the subject of WP1. A number of official agencies and institutions providing open access data are used.

The base data for the project are the geographic locations and administrative limits taken from the Spanish Geographical Institute. Raw data about the built / unbuilt environment are obtained from the Spanish Cadaster. A detailed data mining and depuration procedure is accomplished in order to extract the information pertinent for the project (parcels layout, building type, age of construction, number of stories, etc.). Additional data concerning sidewalk geometries; open spaces such as squares, gardens and parks; location of urban furniture and equipment (street lights, benches, parking areas, bus and taxi stops, kiosks) and other infrastructure (power lines, water supply network) are obtained from the City Planning Department of Lorca. Finally, data on population distribution is obtained from the Spanish Institute of Statistics.

An important amount of time is dedicated to debug the databases from data that are not useful for the project and to combine and assemble data from different sources into a uniform geographical reference framework (Fig. 2). This work is critical to distinguish between internal spaces, which are basically those areas delimitating buildings, and external spaces, which constitute the rest of the areas of the urban setting of Lorca. This differentiation is the subject of WP3, and it is essential to identify the areas of temporal changes in exposure. The external spaces are mostly occupied during daytime, especially in commercial streets and during periods of transit of persons from residential buildings to commercial buildings (or other type of use, such as office buildings, schools and colleges, industries, etc). Within the external spaces, it is also important to separate sidewalks and pedestrian streets from road and other parts of the street where vehicle traffic is permitted, as they are the geographical entities used for allocating human exposure and traffic-related exposure.

Fig. 2 – Example of data depuration from the original database to the building polygons finally used.

It is worthy to mention that the distributions of buildings are also analyzed using aerial images corresponding to different periods. This analysis is not meant corroborate or to substitute the building distributions resulting or derived from the official databases mentioned above. Actually, this is a complementary analysis carried out to test and calibrate the performance of remote sensing techniques for exposure assessment. Two main results are advanced:

- There are no significant differences between the aerial images obtained for different epochs. This indicates that the growth of the city of Lorca through the last 40 years is due to densification of the built areas rather than to an outward expansion of the urbanized areas.
- The combination of aerial images and LiDAR data allows differentiating urban districts with characteristic and distinctive geometrical arrangement. Further, the automatized procedure implemented gives building contours and geometries with an excellent significance level.

Time variations on exposed elements are derived basically from the literature and from reports elaborated under demand of the Lorca municipality, as the study of traffic within the city. This is part of WP7 and it is still in progress.

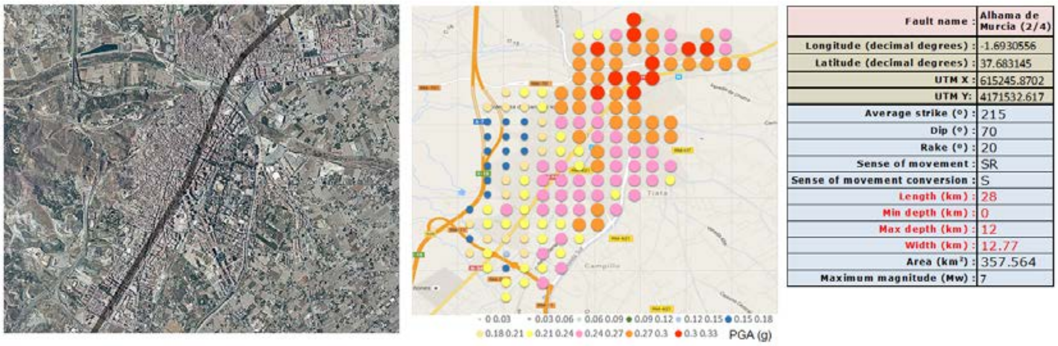
4. Hazard

The seismic action for an urban risk study is based on a seismic scenario. In this work, the seismogenic source for this seismic scenario is the Alhama de Murcia Fault (AMF) system, which crosses the urban center of Lorca. This is the source of the 2011 Lorca earthquake and it is one of the most important active faults in the Iberian Peninsula [1].

Two approaches are considered to infer the seismic action: one is obtained applying deterministic methods (ground motion generated by a single event at a given location) and another one using probabilistic methods (ground motion produced by a controlling earthquake corresponding to a target hazard-consistent ground motion). Both approaches are tested in this work.

4.1. Deterministic approach

The deterministic approach to define the seismic action consists on a set of response spectra corresponding to earthquakes generated in the AMF. In order to capture the aleatory variability of rupture locations and of the ground motion attenuation from the source to the site, several rupture locations within the fault plane and different rupture sizes (or equivalently, different earthquake magnitudes) are considered. Hence, a set of response spectra at each location of Lorca are obtained taking into account the site amplification map of [2].



Fault name :	Alhama de Murcia (2/4)
Longitude (decimal degrees) :	-1.6930556
Latitude (decimal degrees) :	37.683145
UTM X :	615245.8702
UTM Y:	4171532.617
Average strike (°) :	215
Dip (°) :	70
Rake (°) :	20
Sense of movement :	SR
Sense of movement conversion :	S
Length (km) :	28
Min depth (km) :	0
Max depth (km) :	12
Width (km) :	12.77
Area (km²) :	357.564
Maximum magnitude (Mw) :	7

Fig. 3 – Data of AMF (right) and location crossing Lorca (left); mean PGA for a M 5.5 earthquake (middle).

4.2. Probabilistic approach

The procedure to compute the seismic action following the probabilistic approach requires developing a full probabilistic seismic hazard analysis (PSHA) and subsequently performing the disaggregation of seismic hazard for a prescribed target motion. Three PSHA studies are examined for this case:

- The first one was developed by [3] and shows that the hazard-controlling event for target motions of 475 years (typical value for design of normal importance structures such as buildings) is a local very-short source-site distance event with a magnitude around 5.
- The second one considers a combined model of area-sources and fault sources, in which faults are modelled with a modified Gutenberg-Richter recurrence model and the seismic moment tensor is distributed between faults and area-sources taking into fault slip rates and the moment rate released by earthquakes all within the same time-magnitude interval in which the seismic catalog is considered complete [4]. In this approach fault slip rates are derived from paleoseismic data.
- The third one is a variant of the previous approach but using fault slip rates derived from geodetic (GPS) measurements in the most active faults (including the AMF).

The second and third approaches lead to controlling events also located in the AMF but with increasing controlling magnitude values (up to 6). This is consistent with the consideration of faults and area-sources with similar recurrence models for intermediate magnitudes (from 4.5 to 5.9) and close geographical locations, which doubles the expected accelerations near the active faults [5].

Given the variety of values for the controlling magnitude, it is decided to set a reference magnitude value to 5.5 (slightly higher to the 2011 event) to proceed with the calculations.

5. Vulnerability

Several aspects of seismic vulnerability are considered in this study and they all are the scope of WP4. The vulnerability of elements exposed in external spaces (including individuals, vehicles and urban furniture) is not yet assessed in the project. Building vulnerability is studied from different perspectives.

5.1. Empirical study.

Two campaigns for data collection are carried out in four selected districts of Lorca. A specific form is completed for each building containing its characteristics (structural and non-structural elements) and other data regarding urban features, such as height differences with adjacent buildings, position within the building block, plan irregularities, etc. These data are used to check the reliability of the cadastral database and to estimate the distribution of seismic vulnerability using empirical methods (vulnerability index approach and EMS98 vulnerability classifications, Fig. 4). Results show the need of increasing the vulnerability assigned to buildings presenting a soft-story [6].

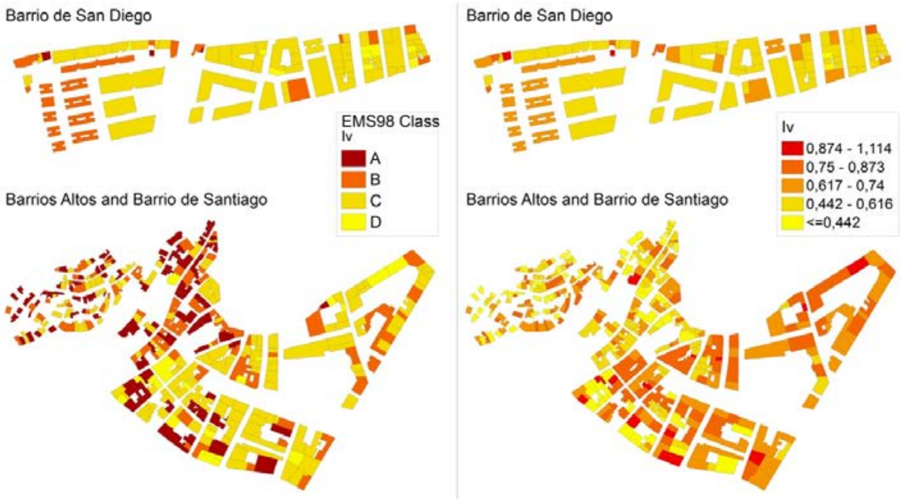


Fig. 4 – Vulnerability distribution of selected districts of Lorca considering the EMS98 vulnerability class distribution (left) and the vulnerability index approach (right).

5.2. Mechanical modeling.

Finite element models of several building types representing common buildings found in the study area are set up. The capacity-demand spectrum method (static approach) is carried out with the idea of developing representative capacity and curves fragility curves (Fig. 5). In this way, it is intended to obtain vulnerability and damage models adapted to the local building typologies.

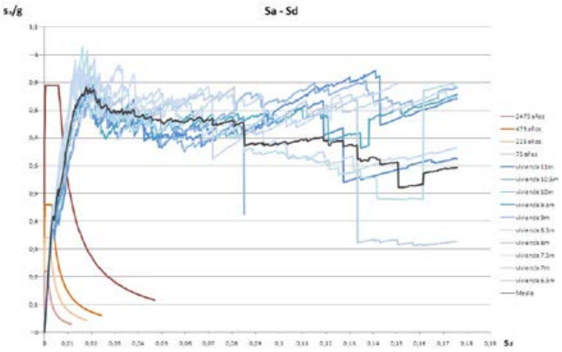


Fig. 5 – Mean capacity curve (in black) derived from the capacity curves of a set of buildings (in blue) subjected to the seismic action of the current building code.

5.3. Remote sensing study.

Segmentation of aerial images following the Sobel method is carried out to obtain building footprints and areas. In combination with LiDAR data and considering different channels of the spectrum, the cloud of data points is classified in order to extract building heights and roof inclinations (Fig. 6). All these parameters are combined to infer different building classes. Results are compared with the statistical distribution of vulnerabilities derived from the empirical study.

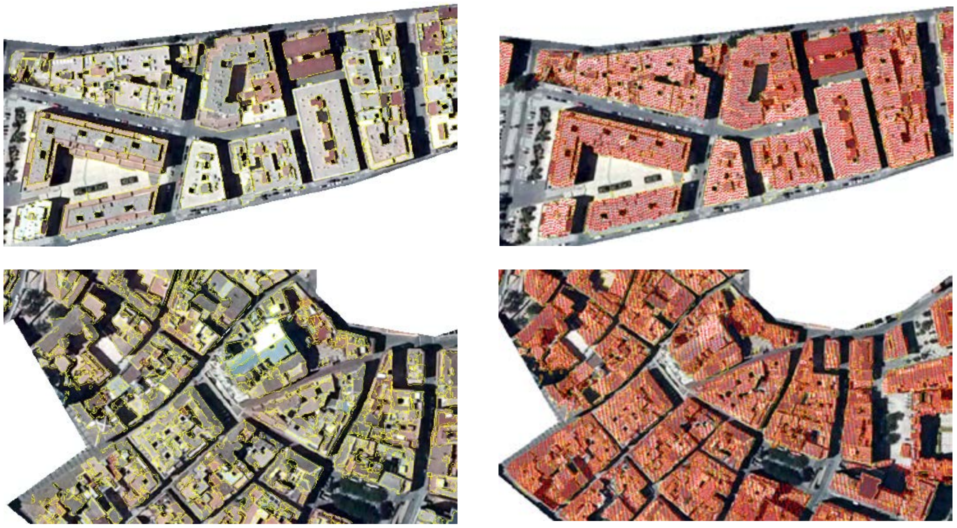


Fig. 6 – Detection of contour and area (left) and determination of roof slope and building height (right) in two sections of Lorca.

6. Damage

Damage estimation is the subject of WP5. Primary damage is the damage observed in buildings and it is estimated using the IDCM method (work in progress).

Secondary damage is the damage inflicted to pedestrians, vehicles and assets located in external spaces because of falling debris. The area covered by debris is estimated from the distance to the adjacent buildings, the damage degree of the building and the area and linear extent of the façade of damaged buildings. A buffer from the contact line between the façade and the street toward the axis of the street is set up (Fig. 7). The larger the amount of debris generated, the larger the width of the buffer.

Fig. 7 – Buffers for allocation of debris falling from buildings (blue) to the sidewalks (gray) and roads (white). Red, yellow and green colors denote large, medium and small amount of fallen debris.

7. Losses and cost / benefit ratios

Losses are analyzed in WP6 and cost / benefit ratios in WP 8. Losses depend on the damage grade. Total damage (i. e., collapse) is constitutes the highest loss. Losses related to lower damage grades are typically computed as a percentage of the loss of total collapse. The calculation of these ratios is not evident. In the present work, losses are considered as the replacement cost of damaged elements. These include the reparation of fissures and cracks and the demolition / reconstruction of fallen building elements. The question that arises is: how many cracks and fissures presents a building of a given damage grade? This depends on the dimensions of the building, the number of stories, the number of openings (windows, doors) and the presence of elements such as parapets, balconies, etc.

In order to generalize the loss estimate modeled in a single building to the entire building stock of the city it is necessary to describe the building by a set of parameters that can be obtained from the cadastral database and that can be translated by means of simple calculations into the parameters representing the building (number of stories, number of openings, etc.). This parameterization should be calibrated with the actual distribution of these parameters observed in the buildings of Lorca.

Once damaged buildings components, their cost can be estimated. In this work, we take as a reference cost value the cadastral value of the building. This value is computed from the following cadastral data:

- Date of construction
- Typology
- Reformation date (if applicable)
- State of maintenance
- Quality of the building
- Use of the building
- Elevation below ground (street) level
- Elevation above ground (street) level

Cost and losses estimates and cost / benefit ratios are still work in progress.

8. Conclusions

The approach to seismic risk in urban areas developed in the MERISUR Project is presented. The project is basically halfway, but some preliminary conclusions may be already drawn:

- The differentiation between internal and external spaces is useful to allocate primary damage to buildings and secondary damage to pedestrians and other assets situated in external spaces.
- The definition of the seismic action is multifold: the proximity of the fault to the city multiplies the amount of possible earthquake ruptures that may produce the scenario event. This is a critical aspect of this approach. This, different source models and rupture locations are considered and their corresponding response spectra are computed for each site at Lorca.
- The development of building models is useful for many WPs of the project: This means that the same building model can be used for several purposes:
    - to develop a capacity / fragility curves
    - to define the damaged building elements that are valued for loss accounting

- to estimate the amount of debris that fall to internal spaces

For this reason, it is very important to develop a building model that is sufficiently specific for vulnerability of loss assessment and at the same time, sufficiently generic to allow its application to the building stock of the entire city.

- The debris model is a significant novelty of this study. However, the lack of real data to calibrate it constitutes a limitation for its application in past seismic scenarios.

9. Acknowledgements

The MERISUR Project: Methodology for an Effective RISk assessment of URban areas is funded by the Spanish Ministry of Economy and Competitiveness, National Program for Research, Development and Innovation oriented to Societal Challenges, reference CGL2013-40492-R. We also thank M.A. Sánchez Águila, Azadeh Haghi and Vanessa Torres for providing some figures.

10. References

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