Vulnerability assessment of urban building stock: a hierarchic approach

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ABSTRACT: In the last decades the evaluation of the seismic risk are of rising concern, considered essential in the activity and definition of strategy planning and urban management. The evaluation of the seismic vulnerability of the existent building stock in the perspective of the seismic risk mitigation should not be placed only in relation to the isolated buildings of relevant historical and cultural importance, but also, in relation to the agglomerate of buildings in urban centres. The chronological construction process frequently results in characteristic heterogeneity of masonry and wall connection quality. In addition, buildings do not constitute independent units given that they share the mid-walls with adjacent buildings and the façade walls are aligned. This way, as post-seismic observations proved, buildings do not have an independent structural behaviour, but they interact amongst themselves, mainly for horizontal actions and so the structural performance should be studied at the level of the aggregate and not only for each isolated building. In most cases, for masonry structures there is no need for sophisticated dynamic analyses for seismic resistance verification or vulnerability assessment. This is even more relevant when an assessment at the level of a city centre is pursued. In this work, the results of evaluation of the vulnerability will be presented in accordance to three proposed methodologies based on a vulnerability index that consequently allows the evaluation of damage and creation of loss scenarios (economical and human) not only at the level of the building and its façade walls but also at the level of the aggregates. It will be discussed and evaluated the application of the referred methodologies and its integration in an SIG platform.

Keywords: Seismic risk, vulnerability, aggregates, façade walls, damage scenarios.

1. INTRODUCTION

When assessing the seismic vulnerability of buildings it is essential to first establish the project objectives, before subsequently choosing the most appropriate strategy and tools necessary for building assessment and fulfilment of these objectives. It is also extremely important to understand the difference between the detailed approaches used for individual buildings and those methods most efficient for larger scale analysis of groups of buildings. With respect to the former, the use of a detailed methodology implies a very reliable evaluation with a necessarily in-depth level of information regarding the analysed structure. However when increasing the number of buildings and enlarging the area to be assessed, the resources and quantity of information required are also increased and thus the use of less sophisticated and onerous inspection and recording tools is more practical. Methodologies for vulnerability assessment at the national scale should be based on few parameters, some of an empirical nature based on knowledge of the effects of past earthquakes but also including statistical analysis.

Recently, European partnerships constituting various workgroups on different aspects of vulnerability assessment and earthquake risk mitigation have defined, particularly for the former, methodologies that are grouped into essentially three categories in terms of their level of detail, scale of evaluation and use of data (first, second and third level approaches). First level approaches use a considerable amount of qualitative information and are ideal for the development of seismic vulnerability assessment for large scale analysis. Second level approaches are based on mechanical models and rely on a higher quality of information (geometrical and mechanical) regarding building stock. The third and final level involves the use of numerical modelling techniques that require a complete and rigorous survey of individual buildings. The definition and nature of the analysed criteria (qualitative and quantitative) naturally condition the formulation of the methodologies and their respective evaluation level, which can vary from the expedite evaluation of buildings based on visual observation to the most complex numerical modelling of single buildings (see Fig. 1).

The systemisation of these vulnerability assessment approaches has been developed by many researchers and therefore differs due to varying levels of dependence of the following factors: nature and objective of the assessment, quality and availability of information, characteristics of the building stock inspected, scale of assessment, methodology criteria, degree of reliability of the expected results and use by the end-user of the information produced. As a result of these differences, the coherency of and consensus regarding this classification is still a contentious issue.

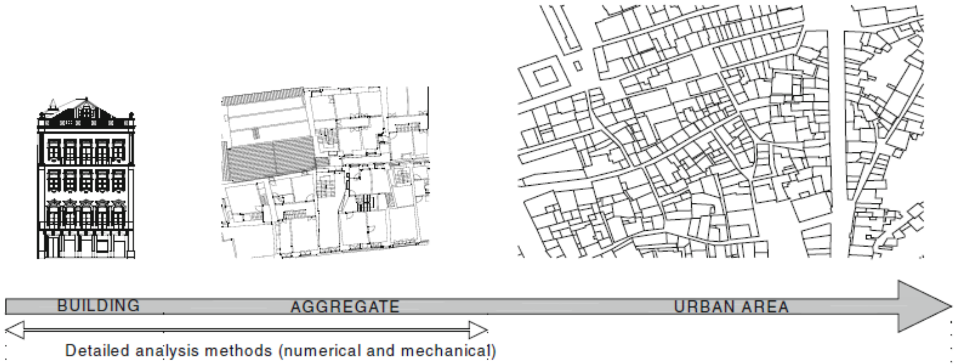


Fig. 1: Different analysis scales

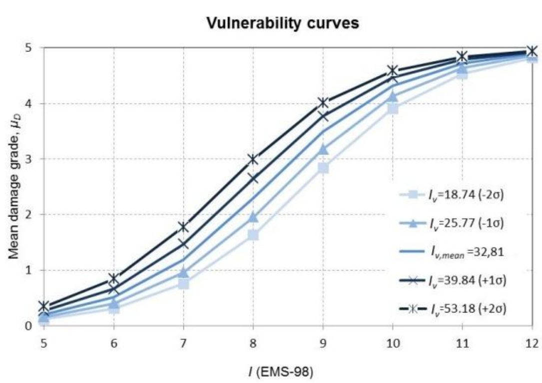
2. SEISMIC VULNERABILITY ASSESSMENT OF FAÇADE WALLS

The seismic risk evaluation of built-up areas is associated with the level of earthquake hazard in the region, *H*, building vulnerability, *V*, and exposure, *E* (see Eqn. (1)). Within this holistic approach defining seismic risk, the assessment of building vulnerability assumes great importance, not only because of its obvious physical consequences in the eventual occurrence of a seismic event, but also because it is a factor which engineering research may influence.

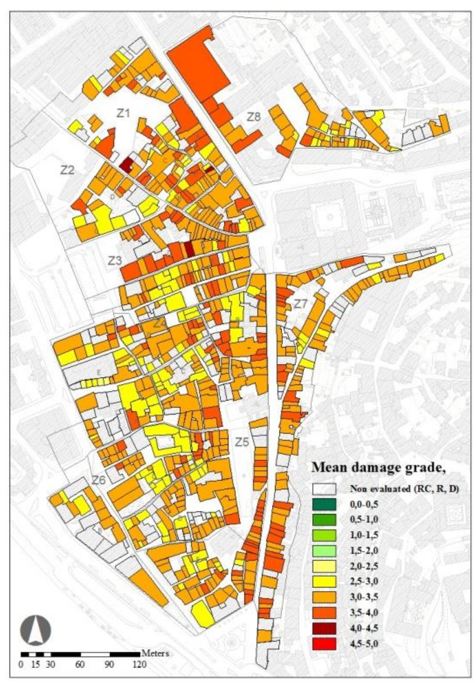
$$R = E \otimes V \otimes H \tag{1}$$

As a result of the set of damage mechanisms that can develop during an earthquake, the out-of-plane movement of masonry facade walls is very common, but depends particularly on the efficiency of the connection between the facade itself and orthogonal walls, and can be evaluated resourcing to mechanical methods. Out-of-plane mechanisms are characterized by brittle behavior and, therefore, may represent a threat to human safety, as was the case of many killed by the collapse of wall panels in the Messina Earthquake in 1908 and in Carlentini in 1990 (see Fig. 2 (a)). Therefore, in the case of assessing masonry facade walls of the old building stock in city centers, the need of a more expedite but reliable approach in terms of qualitative and quantitative evaluation was necessary.

(a)



(b)



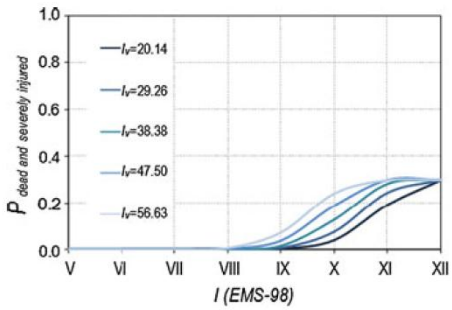
(c)

Fig. 2: (a) Examples of out-of-plane collapses; (b) Vulnerability curves in the I_{EMS-98} versus μ_D format; (c) Example of a damage distribution for a certain seismic intensity (Ferreira et al, 2010)

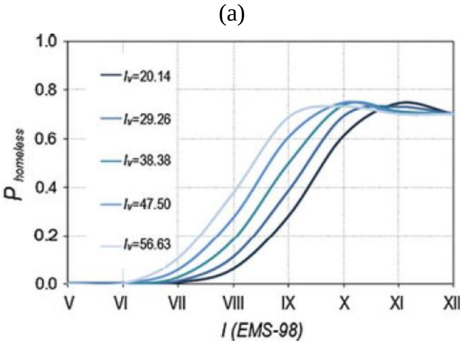
3. SEISMIC VULNERABILITY ASSESSMENT OF BUILDINGS

Masonry buildings do not have adequate seismic capacity and consequently require special attention due to their incalculable historical, cultural and architectural value. The amount of resources spent on the vulnerability assessment and structural safety evaluation of these old masonry buildings is justifiable, since not only does a first level assessment (Vicente et al, 2011) include building inspection, but also can help in the identification of building for which a more detailed assessment is required, as well as the definition of priorities for both retrofitting and in support of earthquake risk management (Vicente et al, 2010).

As for the case of the façade walls, the results presented here result from the application of an hybrid methodology, i.e. a methodology which combines features of different methods, such as vulnerability functions based on observed vulnerability and expert judgment, in which vulnerability is based on vulnerability classes defined in the European Macroseismic Scale, EMS-98 (as in the methodology used in the seismic vulnerability assessment of masonry façades, presented previously). This methodology was adapted for the Portuguese reality and later applied in the seismic vulnerability assessment of old city center of Coimbra, Portugal, by Vicente et al (2011). The entire traditional limestone masonry building stock of the city center of Coimbra was assessed and the vulnerability results was mapped using GIS software connected to a relational database of structural building characteristics obtained from a series of detailed inspection actions. As described for the case of the façade walls, the GIS tool were used in order to both provide a good overview of the vulnerability assessment and risk scenarios, including potential damage mapping and loss scenarios (see Fig. 3) and foresee the impact or retrofitting strategies in the reduction of vulnerability and consequent economic losses.



(a)



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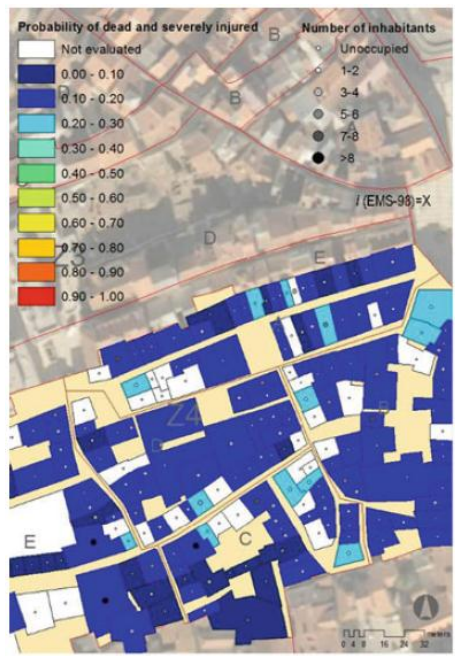


(c)

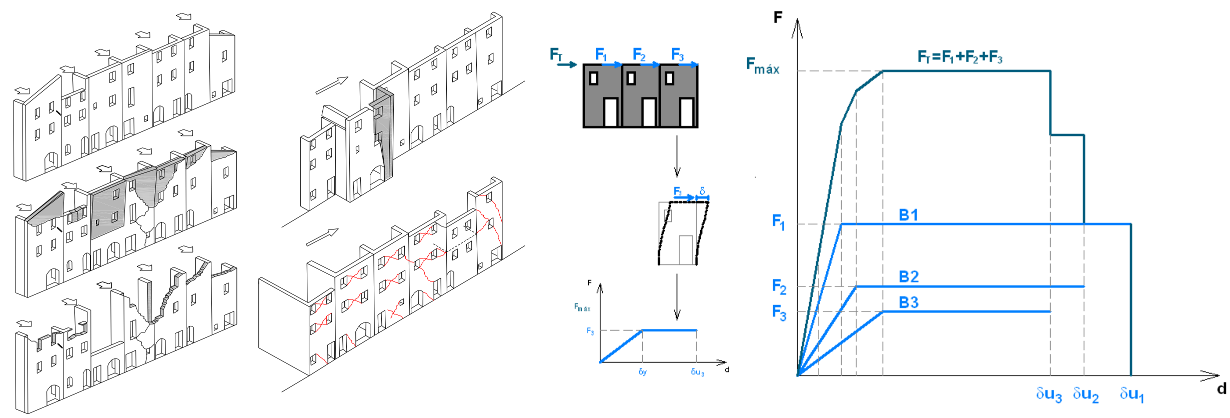
Fig. 3: (a) and (b Estimation of homeless and casualty rate for different values of vulnerability; (c) Probability of dead and severely injured and the number of inhabitants

As shown in Fig. 3 (c), through the GIS tool it is possible to link all the information to the building data collected, combining different data layers. In this case, an example of a mapping for the evaluation of death rate and shelter requirements for a seismic intensity I_{EMS-98}=X is presented.

4. SEISMIC VULNERABILITY ASSESSMENT OF BUILDING AGGREGATES

To undertake vulnerability assessment, evaluate seismic risk and estimate loss at the urban scale for old city centers in which building stock is aggregated consequence of a diachronically construction process. A building aggregate can be considered as a unit, for which it is fundamental, the knowledge on building typology, conservation state and connection scheme between buildings consequence of the evolution of the urban layout in which the diachronic construction of buildings creating a urban mesh very characteristic of old city centers. This growth implies the connection between buildings, through sharing and using existent load-bearing walls for floors and roof structures, lateral and façade wall connections, etc. These changes cause differences in the structural behavior of single buildings within the building aggregate. For the case of a row of buildings, many situations can arise from the interaction between buildings. Normally flexural failure is expected for buildings with slender masonry piers at ground floor due to big openings and shear failure for buildings with thick masonry piers between openings, but these kind of failure modes are altered because of the group response. The misalignments of building front, misalignments of window openings of adjacent buildings, big differences in wall area and stiffness from aligned buildings change completely the failure mechanisms and stress and load paths for the horizontal forces. In figure 4 a) and b) is shown an example of the influence of the aggregate geometry over building failure.

For each direction a very straightforward mechanical approach for the vulnerability assessment is attained for each building using the mechanical model in which a simplified bilinear capacity curve (SDOF system) is constructed for each building and a global pushover curve of the building aggregate constructed (see Figure 4 c)), limit states and the level of seismic action are defined, consequently the performance point is retrieved through the capacity spectrum methodology. Once obtained the fragility curves for the four damage states, the evaluation of the probabilistic damage distribution is performed (Pagnini et al, 2011).



a) Out-of-plane collapse due to fragile wall connections

b) Collapse and damage pattern for unleveled diaphragms and misalignments

c) The force displacement curves of each single building and the global pushover curve of the building aggregate for one direction

Figure 4: Building interaction and construction of the global push-over curve

5. FINAL COMMENTS

The resilience of urban areas is highly dependent on the quality and level of conservation of the building stock, therefore the study of simple to more complex vulnerability assessment methodologies is crucial to support post-disaster validated decisions based on damage scenarios, as well as aid emergency and relief planning.

The methodologies presented and the GIS applications and database management system enables the storage of building features and survey information, assessment of seismic vulnerability and damage and risk scenario prediction, as well as allowing the upgrading and improvement of data. This integrated tool can be helpful for the development of strengthening strategies, cost-benefit analyses, and aid decision making of civil protection bodies.

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