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ASSESSMENT METHODS FOR EARTHQUAKE-INDUCED VULNERABILITY IN BUILDING STRUCTURES

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ABSTRACT

Seismic risk is one of the most researched topics in recent years. The negative consequences that earthquakes can cause, damage or losses, which can occur directly or indirectly, is defined as seismic risk. Strategies and methodologies for seismic risk assessment aim to reduce economic and social losses due to earthquakes. Assessment of seismic risk and seismic vulnerability of the existing building stock is essential for setting priorities in long-term prevention policies. The purpose of the assessment is to calculate the probability of damage that any group of buildings may experience during an earthquake.

Various studies have been conducted so far and different methods have been proposed to assess the vulnerability of structures. Methods for assessing seismic vulnerability are used from individual buildings to large urban areas. To choose an appropriate method, the purpose of the research, the scope of the work, the approach to obtaining information should be taken into account. available resources and computational effort.

This paper provides an overview of the primary methodologies used to assess the seismic vulnerability of buildings, including empirical, analytical, and hybrid approaches. Each method is examined in terms of its applicability, required data, computational demand, and accuracy

Keywords: Seismic risk, vulnerability, vulnerability assessment methods

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1. Introduction

To determine the seismic behavior of structures, it is necessary to know the different characteristics such as: foundations, interfloor construction, number of floors, material properties, etc. (Binda et al., 2003). For existing buildings, before starting any study of their structural load-bearing capacity or strengthening intervention, a complete knowledge of their behavior is necessary. In fact, the level of knowledge about the geometric and structural characteristics of a building has an impact on the definition of numerical models and the reliability of the assessment of the response of the building. In order to maintain the durability of buildings, it is necessary to know the load-bearing capacity and behavior of masonry structures exposed to earthquakes for the safety of users and the need for possible strengthening of the structures (Dominik et al., 2017).

The assessment of the vulnerability of structures consists of determining its susceptibility to damage at a given earthquake intensity. Various studies have been conducted and various methods have been proposed to assess the vulnerability of structures (Hodza Djafer, 2024). Methods for assessing seismic vulnerability can be divided into two categories: empirical methods, which are based on observation of damage caused by earthquakes, and analytical methods, based on the evaluation of the performance of the structural system using analytical models (Lumantarna et al., 2014).

2. Seismic Risk

Seismic risk is the possibility or potential for loss due to the occurrence of an earthquake. Risk is a combination of three main elements, hazard (danger) from an earthquake, assets at risk i.e. exposure and vulnerability of assets to the effects of an earthquake.

Earthquakes can directly or indirectly cause negative consequences and damage to the population, the built environment, as well as social and economic systems. The analysis of seismic risk is based on three key components that must be measured and analyzed separately: hazard, exposure and vulnerability (see Figure 1). Each category includes different parameters that need to be assessed through specific studies and methodological research (Climate change, 2014).

Figure 1- Inter governmental Panel on Climate Change (Climate Change, 2014 p.3)

The first step in protecting the existing building stock from earthquakes is to create a theoretical prediction of the structural damage and socio-economic losses that may occur after an earthquake. In fact, to prepare for disaster management, it is necessary to assess the effects of a potential earthquake and anticipate and take appropriate measures to reduce vulnerability and losses (Hadzima, 2016).

To make an accurate measure of vulnerability, it is necessary to choose the right parameters to express the cause-effect relationship.

Vulnerability assessment methods aim to provide a measure of the likely level of damage to a structure if an earthquake occurs, providing what is often called a vulnerability index. In recent years, various vulnerability assessment methods have been developed, in order to assess and reduce the susceptibility to damage of classes of buildings defined on the basis of an appropriate classification system (Gilda, 2010).

The choice of an appropriate method for assessing the seismic vulnerability of buildings depends on the nature of the study, its purpose and the reliability of the expected results. A qualitative assessment (simpler approaches) can be made for a large group of buildings or a detailed study (quantitative) for a single building (Precidao et al., 2015).

According to Caicedo et al., there is a wide range of methods proposed by different authors for assessing the vulnerability of buildings. The choice of a particular method depends on several factors, which are:

1. The nature and purpose of the study;

2. Available information;

3. Characteristics of the building or group of buildings under study;

4. Appropriate assessment method (qualitative or quantitative) and

5. The organization receiving the results and the decision-makers (Caicedo et al., 1994).

3. Vulnerability Assessment Methods

The probability of damage to a building during an earthquake of a certain intensity is the seismic vulnerability of the building. From this definition arose the need to establish a correlation capable of providing the expected level of damage for each intensity level, identifying the appropriate parameters for measuring damage and intensity. (DMTP, 1994). Seismic risk is one of the unexplored topics in recent years, and strategies and methodologies for reducing economic and social losses resulting from earthquakes are the main goal in seismic risk research (Riuscetti et al., 1997).

The purpose of developing earthquake loss models is to estimate the potential economic losses in future earthquakes. The loss model can be an important step in emergency response and disaster planning to reduce risk. The loss model can also be used to calibrate existing seismic codes for the design of new buildings. The most fundamental element of the loss model is the methodology developed to detect the vulnerability of the built environment. Various methods have been proposed to assess vulnerability, which can be classified into two groups: experimental and analytical. There are also hybrid methods that use both methods (Calvi et al., 2006). Figure 2 shows the components of seismic risk assessment and the choices for the vulnerability assessment procedure.

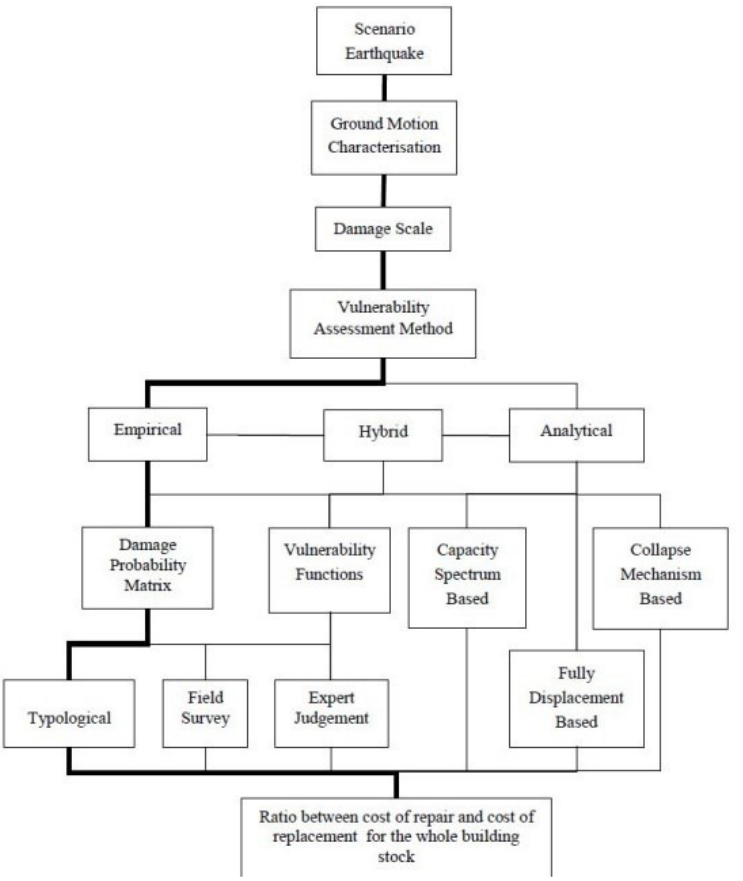

Figure 2 - Components of seismic risk assessment and choices for the vulnerability assessment procedure (Calvi et al., 2006 p.76)

Dolce (1994) classifies vulnerability assessment methods into four main groups, depending on the available information: empirical, experimental, analytical and hybrid methods.

According to Vicente (2011), the choice and applicability of vulnerability assessment methodologies are as follows:

1. Methods that are characterized by specificity related to a certain typology of building or group of buildings with very specific characteristics;

2. Universality of methodologies is possible, but it should be remembered that the evaluation of specific aspects must be taken into account in the adopted evaluation methodology;

3. The quality of the results is very dependent on the level of detail of the required input data;

4. The degree of reliability of the obtained assessment always reflects the level and quality of the available information;

5. The information resulting from the assessment can be used to support decisions and define intervention and emergency plans. Therefore, the adaptability of the objectives of the vulnerability assessment in question to the nature of the chosen methodology must be analyzed;

6. The operational scale conditions the choice of the evaluation methodology. The formulation of the fastest methodologies, based mainly on qualitative criteria rather than quantitative ones, are more appropriate for assessments at an urban, regional or territorial scale. While more complex formulations are desirable in the analysis of small groups of buildings or buildings of high heritage interest.

Figure 3 shows the recommended list of different methodologies depending on the scale of the analyzed buildings.

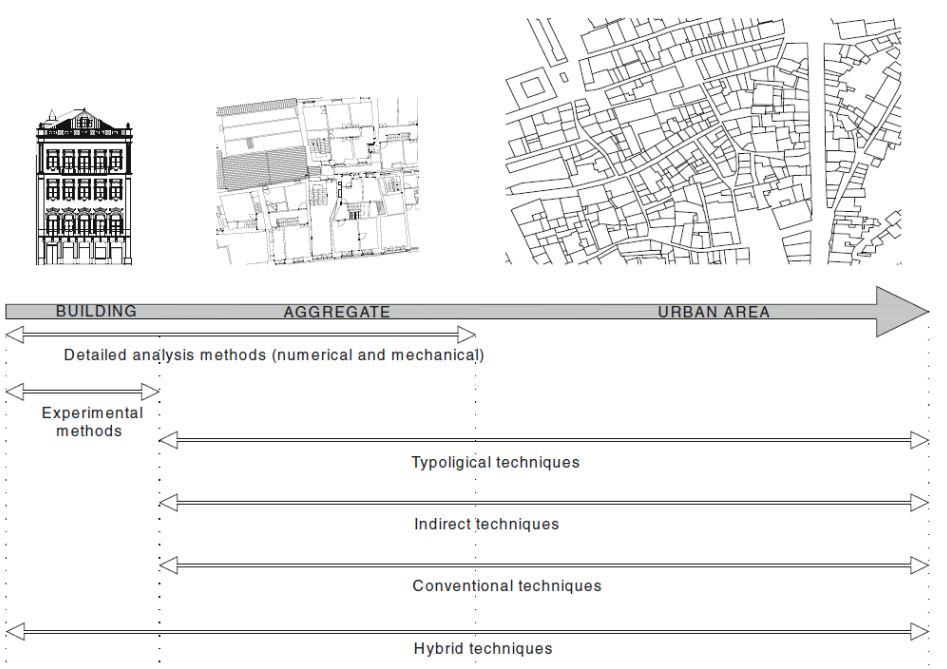

Figure 3 – Areas of application of seismic vulnerability analysis methods (Vicente et al., 2011 p.310)

3.1 Empirical Methods

Techniques for assessing the seismic vulnerability of buildings over large areas have been developed since the early 1970s, using experimental methods developed and calibrated as a function of macroseismic intensities (Calvi et al., 2006).

Empirical methods are based on statistical functions that relate the probability of damage suffered by a building type to the expected earthquake intensity, which requires knowledge of the building's previous seismic performance. To reliably produce such functions, large datasets are needed that cover the full range of performance of a given building typology, the full range of possible seismic intensities, and multiple observations of the building's performance for the same intensity level. After this, when an earthquake scenario is defined, it is sufficient to evaluate the individual building or typology according to a predefined probability of damage based on structural and functional details to assess the vulnerability of structures. (D'Ayala et al., 2015).

According to (Safina, 2002), empirical methods are subjective because they are based on experience with earthquake damage observed in different types of buildings.

Empirical methods are qualitative and are widely used to assess the vulnerability of the built environment. These methods are used when a rapid preliminary assessment of a single building or a large group of buildings at a regional level is required. In these methods, the available information is limited and the estimates are developed on-site through an evaluation survey or visual surveys. The most commonly used empirical methods are vulnerability class and vulnerability index (Precidao et al., 2015).

There are two main empirical methods for assessing seismic vulnerability based on observed damage to buildings after an earthquake, namely:

1. Damage Probability Matrices (DPM): Expressing the conditional probability of obtaining a certain level of damage due to an earthquake in a discrete form;

2. Vulnerability functions: They are continuous functions that express the probability of overcoming a given damage situation, given a function of the earthquake intensity (Calvi, 1999).

3.2 Analytical Methods

The analytical approach is based on discovering the response of a building that represents a typology, using techniques, structural analysis and numerical tools.

The reliability of the results in the analytical method, which is an appropriate method when it comes to a single building or typology, is the availability of data that characterize the material and structural behavior of the building or typology (D'Ayala et al., 2015).

These approaches are mainly computational numerical methods based on classical theories of elasticity and plasticity. The more widely accepted analytical methods are the finite element method (FE) and the limit analysis. Figure 4 shows empirical and analytical methods for assessing seismic vulnerability.

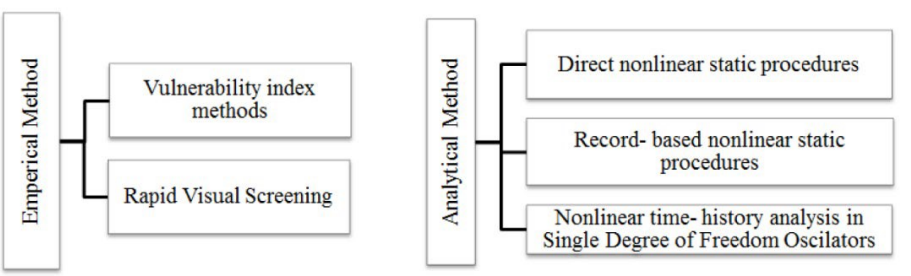

Figure 4 - Empirical and analytical methods for assessing seismic vulnerability (Guzman et al., 2022 p.18)

Analytical methods are complex and time-consuming, as many parameters are required to model the physical properties of a real structure. Therefore, unlike empirical methods used for large groups of buildings, these quantitative methods are most often used to assess the seismic vulnerability of buildings that require special attention. (Precidao et al., 2015).

3.3 Experimental Methods

Experimental methods consist of tests that are applied to determine the mechanical and dynamic properties of the structure under study. The purpose of mechanical tests is to determine the properties of building materials and in this way it is possible to determine the quality of the materials and to evaluate the vulnerability through mechanical characterization. (Precidao et al., 2015).

Dynamic characterization of buildings allows the user to obtain relevant information about the actual state of damage of the structure under study before or after an earthquake. (Safina, 2002).

3.4 Hybrid Methods

Hybrid methods refer to methods that correspond to any combination of the previous three methods (empirical, analytical and experimental). In this way, the shortcomings of any method can be eliminated by adding a second or third method. For example: the uncertainties in the creation of the analytical model of the structure can be compared and supported by the real physical properties obtained in the experimental methods. Or, from a group of buildings, empirically evaluated, a list can be created according to vulnerability, and accordingly the most vulnerable buildings can be analyzed in more detail with experimental or analytical methods. (Precidao et al., 2015).

4. Conclusion

This study has explored various assessment methods used to evaluate earthquake-induced vulnerability in building structures. The increasing frequency and severity of seismic events globally highlight the urgent need for reliable and scalable methodologies, especially in densely populated urban environments. From empirical models based on past earthquake data to advanced analytical and hybrid approaches, each method serves a specific purpose depending on the scale of the assessment, data availability, and required precision. While empirical methods offer quick evaluations, analytical and numerical models provide deeper insights into structural behavior under seismic loads. Selecting an appropriate method is crucial and should be guided by the objectives of the study, available resources, and the level of detail required. Continued development of integrated tools that combine structural data, geographic information systems (GIS), and modern computational techniques will be key to improving the accuracy and efficiency of seismic vulnerability assessments in the future.

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