Seismic Vulnerability Assessment of Buildings: A Review and Comparative Study

Prabhu Agrawal [1], S.K. Jaiswal [2]
[1] P.G. Scholar, [2] Associate Professor
Prabhuagrawal.india@gmail.com

Dept. of Civil Engineering, Bhilai Institute of Technology, Durg (C.G.), India

Abstract

India is one of the fastest developing countries in the world, where its economic stability is hugely reliant on its infrastructure and people. In India, 85% of existing buildings are unreinforced masonry (URM) and 5-7% are reinforced concrete and 5-7% are traditional buildings. And most buildings do not qualify to resist earthquakes, technically we can say they would not be able to resist earthquake loads. In the past, we have seen at the time of several earthquakes, we lost millions of lives and the economy of that region. In the Study, we have reviewed various research papers on Seismic Vulnerability and conclude its findings.

Keywords: *Seismic vulnerability, Existing Building, Vulnerability Assessment*

1. Introduction

The country is threatened by India's expanding population and extensive unscientific structures such as multistory luxury flats, vast manufacturing complexes, gigantic malls, supermarkets, warehouses, and brick buildings. In the previous 15 years, ten big earthquakes rocked the country, killing approximately 20,000 people. According to India's current seismic zone map (IS 1893: 2002), more than 59 per cent of the country's geographical area is at risk of moderate to severe seismic hazard—that is, it is prone to shaking of MSK Intensity VII or above (BMTPC, 2006). In fact, the entire Himalayan region is thought to be prone to massive earthquakes with magnitudes more than 8.0-, with four such events occurring in the last 50 years.
Damage from earthquakes and floods is increasing all over the world, resulting in a major increase in the loss of human life, economic assets, and infrastructure. We cannot currently prevent natural disasters from occurring; however, the negative repercussions connected with them can be significantly reduced by implementing better preventive techniques. Earthquakes can have a significant impact on the built environment, and the extent of damage is largely determined by

building types, materials, construction procedures, and institutional regulations. As a result, the susceptibility of the existing building stock can have a significant impact on the number of casualties, injuries, and asset losses in an earthquake. Different types of buildings, such as residential, commercial, industrial, and educational structures, can sustain varying degrees of infrastructure damage and fatalities. Exploring the seismic vulnerability of structures might thus aid in comprehending the diverse concept of vulnerability and, more broadly, disaster risk.

1.1. Seismic Vulnerability

Vulnerability is defined as the inability to withstand a danger, and seismic vulnerability is the likelihood of structural and non-structural damage to buildings, services, infrastructures, and so on due to earthquakes. The three major components of seismic risk assessment are hazard, vulnerability, and exposure. However, it is uncontrollable. On the other hand, a community's susceptibility and exposure can be controlled and decreased to a significant extent in order to lower total seismic risk. The seismic vulnerability of a structure is a measure of its seismic capacity and is thus one of the most important aspects of seismic risk assessment. When a structure's vulnerability is assessed, it suggests that a thorough study and retrofitting are required.

A structure's seismic vulnerability can be defined as its vulnerability to damage caused by ground shaking of a certain intensity. The vulnerability function relationship is established by defining the expected damage for a building or a class of buildings as a function of ground motion (Figure 1). The two most important parts of vulnerability assessments are the building's capacity and seismic demand. The seismic damage is evaluated by comparing the building's ability to resist restrictions (capacity) with the limitations on the structure caused by earthquake ground motion. The susceptibility of those sections of a building that are necessary for physical support when confronted with a violent earthquake or another disaster is referred to as structural vulnerability.

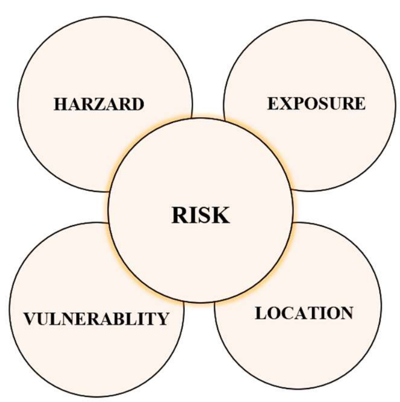

Figure 1: Risk Associated with building

(1) Hazard:

The occurrence of an earthquake of the significate magnitude capable of causing damage to the man-made structure. The intensity at the epicenter is high.
It can't be controlled in its occurrence.

(2) Exposure:

Objects and structure built by man which are exposed to the effects of the 'hazard'. It can be also expressed as the factor such as time period.
It can be controlled by man.

(3) Vulnerability:

Damageability of the 'exposure' under the action of the hazard; Weaker ones being more vulnerable and 'risky' than the stronger ones.
It can be minimized by adopting the better preventive strategies.

(4) Location:

(i) How far the 'exposure" is situated from the Hazard location nearer one being in the greater danger than those far away.
(ii) Local site condition which can affect the hazard or the stability and exposure, such as topography, soil condition, water table etc.
Seismic Risk = **function** {Hazard, Exposure, Vulnerability, Location}

1.2. Performance Based Seismic Design

(1) Performance-based Design is a philosophy of designing structures for predictable building performance with design loads considered at initial stage.
(2) This approach is adopted in designing a new building or in evaluating an old existing structure.
(3) In performance-based design, associated structural engineers recognize the specific performance of the structure and discuss its philosophy with the owner of the building.
(4) It is aggressively used in designing a seismic resistant structure.

(5) It is a used in structure or designing a resilient structure stand against probable seismic load.

(6) The performance-based design of structures considers the behavior of the nonstructural members also.

(7) Because of the dynamic behavior of loads such as winds and blast loads, structural engineers are now considering these sorts of structures.

(8) The structure's deformation is assessed in terms of a drift of monitoring the behavior of structural and nonstructural elements. Guidelines such as FEMA 273 and FEMA 356 have outlined the drift's restrictions.

(9) The recommendations in FEMA 356 can be used to define the performance standards. It can be expressed in terms of the building's lateral deflection/drift or as the hinge formation.

(10) The occupancy level has three states defined Based on the rotation of the element; the occupancy level has three states. They are specified based on the hinge's rotation. The figure below, taken from the FEMA 356, depicts the formation of occupancy levels based on global displacement.

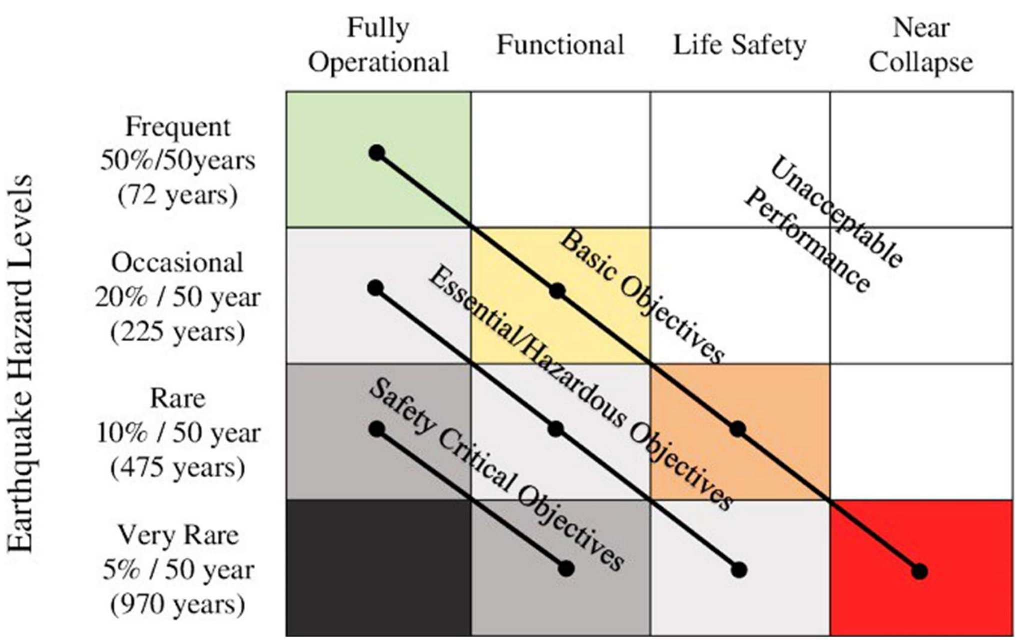

Figure 2: Performance Criteria

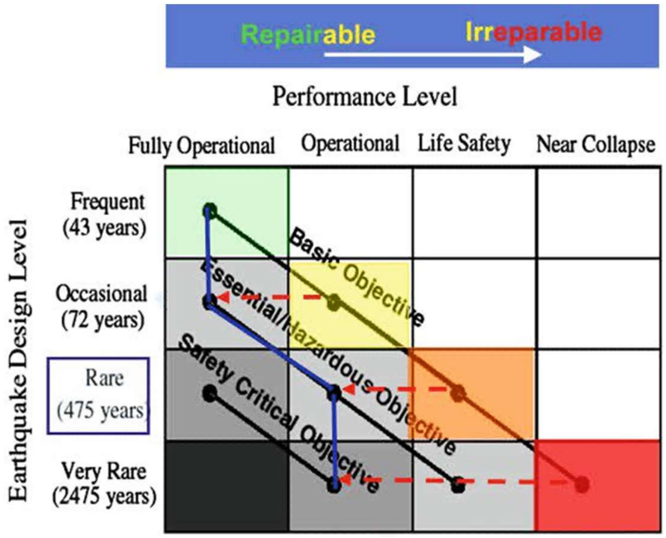

Figure 3: Performance Level Grid

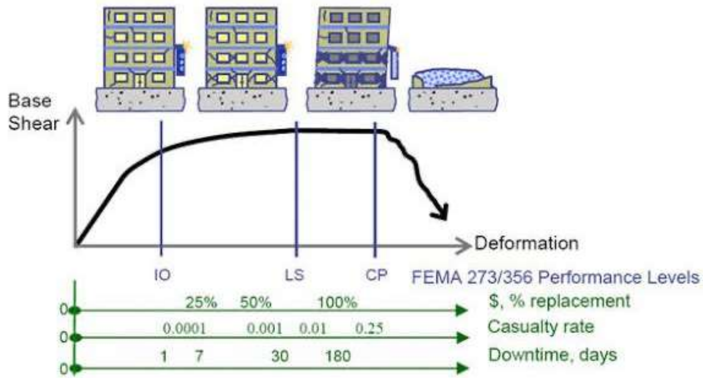

Figure 4: Performance Level based on FEMA 273/356

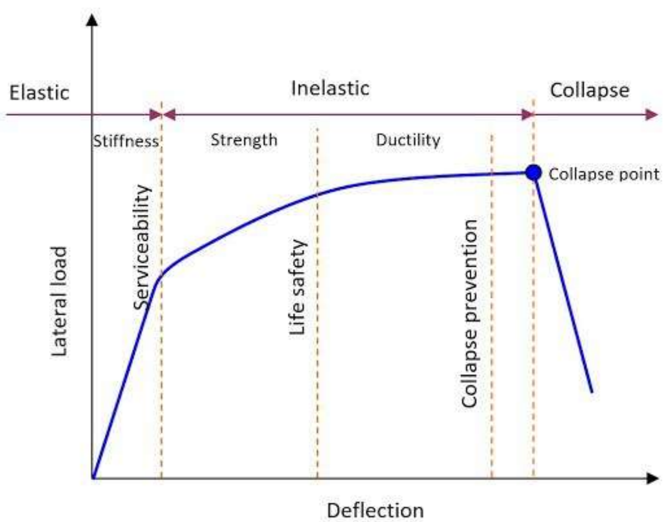

Figure 5: Lateral Load vs. Deflection

2. LITERATURE REVIEW

2.1. Introduction

A comprehensive study of research papers is conducted over a period of approximately 15 years, with the study object in mind. The various standard research journals are studies based on the building's seismic vulnerability and its causes. When reviewing the research-based papers on Seismic Vulnerability, the authors' good amount of information and conclusions are an excellent help in our research.

(1) Drian Fredrick C. Dyaa and Andres Winston C. Oretaaa 2015

- According to this research paper, the main reason for soft story buildings being more vulnerable to earthquakes is the localization of seismic forces.
- Though the total demand on the building is reduced as a result of the increased height, uneven demands on the building's areas result in a local hazard.
- The forces are concentrated on the segment of the building with the lowest stiffness, which is where the soft story is located. This can be seen in the evolution of the plastic hinges, the story drift of the buildings, and the design. These seismic parameters demonstrate seismic demand localization. The building's risk has increased due to increased hazards of specific types.

(2) Terala Srikanth, Ramancharla and Pradeep Kumar 2010

- Rapid Visual Screening (RVS) was performed on 16000 buildings in the cities of Gandhidham and Adipur. The preliminary findings reveal a wide range of construction practises, with RCC and masonry structures dominating. The RVS scores of these structures indicate that, in general, the buildings are of low quality, and that further evaluation and strengthening of the buildings is recommended.
- Gujarat is located in one of the world's most seismically active zones, and future earthquakes of moderate to great magnitude cannot be ruled out. In this regard, a comprehensive study of Gujarat's seismic risk assessment was conducted. Gujarat's government chose Gandhidham and Adipur as pilot cities.
- A Rapid Visual Survey was carried out on 16000 buildings in Gandhidham and Adipur. Based on the low scores, the area is potentially vulnerable to future earthquakes. It is also suggested that preliminary and detailed analyses be performed on 300 buildings in order to calibrate RVS scores.

(3) Angelo Masi 2003

- The seismic vulnerability of some existing Reinforced Concrete buildings designed only for vertical loads has been assessed. Nonlinear dynamic analyses with artificial and natural accelerograms are used to calculate the seismic response.
- There are three types of frames studied: bare frames, regularly infilled frames, and pilotis frames.
- The results show that the pilotis buildings are highly vulnerable: they are classified as class B on the European Macro seismic Scale of 1998. (EMS98).
- On the contrary, regularly infilled buildings have a low vulnerability (EMS98 class D): collapse in this case is considered unlikely even with strong earthquakes. Buildings without infills exhibit intermediate seismic behaviour, with vulnerability ranging between classes B and C.

(4) Babita Tamta and Vikram Kaintura 2021

- The study identifies poor construction quality, a lack of maintenance, and noncompliance with safety standards as the primary reasons for the surveyed buildings' increased vulnerability. According to Chamoli data, a total of 2120 masonry buildings (about 25% of those surveyed) have a high probability of Grade 5 damage and a very high probability of Grade 4 damage, whereas 533 buildings (about 19% of those surveyed) have a high probability of Grade 4 damage and a very high probability of Grade 3 damage in the event of earthquake shaking of Intensity VIII or greater on the MSK scale. Rapid visual screening (RVS) can be used effectively to assess the vulnerability of a large number of buildings while requiring little computational effort.

According to the study, only 18.38 per cent of the surveyed masonry units fall into Grade 1 and Grade 2 (Table 3), which are considered safe in a seismic event. A large proportion of the surveyed masonry building units (81.61 per cent) are thus likely to sustain major damage in a seismic event, which is a serious issue that requires immediate correction. 9.05 per cent of the masonry building units surveyed have Grade 5 structural damage or total or near total collapse. Furthermore, 47.09 per cent fall in Grade 4, indicating severe structural failure of the roof and floor. The study emphasises the serious issue of noncompliance with seismic safety codes and negligence of established engineering norms.

(5) Moustafa Moufid Kassem, Fadzli Mohamed Nazri, Ehsan and Noroozinejad Farsangi 2020

- The authors attempted to present the most common empirical and analytical methodologies in a concise manner in order to encourage researchers and practising engineers to use it as a comprehensive guide and reference for their future work.

(6) Amirhosein Shabani, Mahdi Kioumarsi and Maria Zucconi 2021

- This study examined simplified analytical methods for assessing the seismic vulnerability of unreinforced masonry (URM) buildings, beginning with their classification into three major groups: collapse mechanism-based, capacity spectrum-based, and fully displacement-based methods. Finally, consideration was given to the corresponding software packages that were created to aid in the assessment process.

(7) Shunsuke Otani 2000

- A brief overview of the development of seismic vulnerability evaluation standards for reinforced concrete buildings in Japan is provided. Damage statistics show that even after damaging earthquakes around the world, severe damage was observed in a relatively small percentage of existing buildings. To identify such vulnerable buildings among the existing building stock, a simple screening procedure is required. Following a discussion of the principles of seismic vulnerability assessment using a simple single-degree-of-freedom system, applications to multi-degree-of-freedom systems and irregularly configured structures are discussed. A general procedure consistent with Japan's current design provisions is introduced.

(8) M. Panahi, F. Rezaie, and S. A. Meshkani 2013

- The current study's goal is to assess the seismic vulnerability of school buildings in Tehran using the analytic hierarchy process (AHP) and a geographic information system (GIS). The peak ground acceleration, slope, and soil liquefaction layers were used to create a geotechnical map for this purpose. Furthermore, the structural materials, age of construction, quality, and seismic resonance coefficient layers were identified as major factors influencing the structural vulnerability of school buildings.

- The AHP method was then used to assess the priority rank and weight of each criterion's criteria (layers) and alternatives (classes) via pairwise comparison at all levels. Finally, the geotechnical and structural spatial layers were superimposed to create a seismic vulnerability map of school buildings in California.

(9) A. Formisano, F. M. Mazzolani and G. Florio, R. Landolfo 2010

- The work focuses on the development, validation, and large-scale application of a quick methodology for seismic vulnerability assessment of historical masonry aggregates typical of Italian town centres.
- The proposed procedure was first established by conducting parametric analyses on a masonry structural unit representative of the municipality of Sessa Aurunca. Then, within an investigation area of the historical centre of Torre del Greco, a town in the district of Naples, a masonry building block was initially selected and numerically analysed for form validation.
- Finally, the proposed methodology was applied to the entire surveyed area of Torre del Greco, allowing for the creation of a damage map of the built up in relation to a reference point.

(10) J.A. Razak, Shuib bin Rambat, Zhongchao Shi and Saiful Amri bin Mazlan 2021

- Sabah is vulnerable to seismic activity because of its location, which is near the boundaries of three major active tectonic plates: the Eurasian, India-Australia, and Philippine-Pacific plates. The 6.0 Mw earthquake that struck Ranau, Sabah, on June 15, 2015, and killed 18 people, all of whom were Mount Kinabalu climbers, raised many concerns, most notably the need for a seismic vulnerability assessment for this region.
- To map seismic vulnerability in Ranau, Sabah, this study used frequency ratio (FR)-index of entropy (IoE) and a combination of (FR-IoE) with an analytical hierarchy process (AHP). The success rate and prediction rate for the areas under the relative operating characteristic (ROC) curves were 0.853; 0.856 for the FR-IoE model and 0.863; 0.906 for the (FR-IoE) AHP, respectively.

(11) L. Gerardo F. Salazar and Tiago Miguel Ferreira 2020

- Seismic risk is determined by the sum of multiple components produced by a specific seismic intensity, which include seismic hazard, structural vulnerability, and asset exposure at a specified zone.

- By relegating ordinary dwellings to a second plane, most methods and strategies used to assess the vulnerability of historic structures are specialised in buildings of higher importance, either public or private. As a result, the purpose of this paper is to present a seismic vulnerability assessment based on a limited urban area of Mexico City's Historic Downtown, resulting in the analysis of 166 historic buildings. The area's seismic vulnerability was assessed using a simplified seismic vulnerability assessment method that included both qualitative and quantitative parameters. The results were integrated into a Geographic Information System (GIS) tool, which allowed to map vulnerability and damage scenarios for different earthquake intensities, to better manage and analyse the human and economic exposure.

(12) Nicola Chieffo, Marius Mosoarca, Antonio Formisano, Iasmina Apostol 2018

- The level of earthquake hazard, building vulnerability, and level of exposure are all factors in assessing seismic risk in built-up areas. Large-scale vulnerability assessment is a well-known topic for the protection of historical buildings and the mitigation of the effects of natural phenomena on built-up areas. Timisoara will be the European Cultural Capital in 2020, so knowing the number of unusable and collapsed buildings in the event of an earthquake is critical for planning appropriate future intervention strategies from structural and urban perspectives. Based on these assumptions, the proposed research is being carried out in collaboration with the University of Naples "Federico II," with the primary goal of focusing on the seismic vulnerability assessment of buildings.
- To begin, the typological vulnerability classes of buildings have been defined using the RISK-UE method in order to classify them from both a typological and structural standpoint. Following that, a vulnerability form appropriate for masonry aggregates was filled out for the study area buildings, and typological fragility functions were derived for them in order to identify the most vulnerable constructions.
- Finally, parametric analysis was performed by varying the seismic magnitude and site-source distance to estimate seismic loss under earthquakes.

(13) Mohsen Alizadeh, Mazlan Hashim, Esmaeil Alizadeh, Himan Shahabi, Mohammad Reza Karami, Amin Beiranvand Pour, Biswajeet Pradhan and Hassan Zabihi 2018

- The research was done in the study to assess the seismic vulnerability of residential houses in an urban region using the Multi-Criteria Decision-Making model, which included the analytic hierarchy process (AHP) and geographical information system (GIS). Tabriz, located near the North Tabriz Fault (NTF) in northwestern Iran, was chosen as a case study. The NTF is a major seismogenic fault in Iran's northwestern region. First, a geotechnical map was created using parameters such as distance to fault, slope percentage, and geology layers. Furthermore, structural construction materials, building materials, building block size, building quality, and building floors were identified as key factors influencing the structural vulnerability of residential buildings.
- Following that, the AHP technique was used to measure the priority ranking, criteria weight (layers), and alternatives (classes) of each criterion at all levels using pair-wise comparison. Finally, the layers of geotechnical and spatial structures were superimposed to create a seismic vulnerability map of buildings in Tabriz's residential area. According to the findings, the south and southeast areas of Tabriz city have low to moderate vulnerability, while some areas in the north-eastern area have severe vulnerability. Finally, the proposed approach provides a practical and effective evaluation of the Seismic Vulnerability Assessment.

(14) G. Castellazzi, C. Gentilini, and L. Nobile 2013

- This paper presents an analysis of the seismic vulnerability of a church structure through the study of three collapse mechanisms of its facade. The analysis was performed using nonlinear finite element models and in accordance with Italian standards for monumental and historical masonry buildings. Some macro elements have been investigated using results from limit analysis and nonlinear finite element analysis, with a focus on those that interact with the facade.
- The obtained results demonstrated the primary role of the interlocking effect of lateral walls on facade behaviour, as well as the role of the church's conservation status, cracking pattern, and previous damage state. Analyses have provided basic information about the structural behaviour of the church under seismic loads, highlighting that some of the mechanisms studied do not correspond to safe conditions. As a result, appropriate retrofitting actions can be designed.

(15) Ehsan Harirchian, Kirti Jadhav, Kifaytullah Mohammad , Seyed Ehsan Aghakouchaki Hosseini and Tom Lahmer 2020

- The demand for occupancy has rapidly increased the construction rate, while inadequate structure design has made structures more vulnerable. Buildings built prior to the development of seismic codes are more vulnerable to earthquake vibrations. The structural collapse results in economic losses as well as human life losses. The use of various theoretical methods to analyse structural behaviour is costly and time-consuming.
- As a result, for future developments, it is necessary to implement a rapid vulnerability assessment method to check structural performances. As previously stated, the procedure is known as Rapid Visual Screening (RVS). This method was developed to identify, inventory, and screen potentially hazardous structures. When poor construction quality fails to provide some of the required parameters, the RVS process fails as a result, and multiple-criteria decision-making (MCDM) methods for seismic vulnerability assessment open a new door to dealing with such a situation. The various RVS parameters can be taken into account in MCDM. In several fields, MCDM evaluates multiple conflicting criteria in decision making. The purpose of this paper was to bridge the gap between RVS and MCDM. Furthermore, to define the relationship between these techniques, methodologies from Indian, Turkish, and Federal Emergency Management Agency (FEMA) codes have been implemented. The effects of structural seismic vulnerability have been observed and compared.

3. Conclusion

From the study we have found the following point:

(1) The main reason for soft story buildings being more vulnerable to earthquakes is the localization of seismic forces.
(2) The forces are concentrated on the segment of the building with the lowest stiffness.
(3) The seismic vulnerable existing Reinforced Concrete buildings are designed only for vertical loads and not for horizontal (EQ load or Wind Load).
(4) The results show that the pilotis buildings are highly vulnerable: they are classified as class B on the European Macroseismic Scale of 1998. (EMS98).
(5) On the contrary, regularly infilled buildings have a low vulnerability (EMS98 class D): collapse in this case is considered unlikely even with strong earthquakes. Buildings without infills exhibit intermediate seismic behaviour, with vulnerability ranging between classes B and C.

(6) simplified analytical methods for assessing the seismic vulnerability of unreinforced masonry (URM) buildings, beginning with their classification into three major groups: collapse mechanism-based, capacity spectrum-based, and fully displacement-based methods.
(7) The primary role of the interlocking effect of lateral walls on facade behaviour, as well as the role of the conservation status, cracking pattern, and previous damage state. Analyses have provided basic information about the structural behaviour of the building under seismic loads, highlighting that some of the mechanisms studied do not correspond to safe conditions. As a result, appropriate retrofitting actions can be designed.
(8) The study identifies poor construction quality, a lack of maintenance, and non-compliance with safety standards as the primary reasons for the surveyed buildings' increased vulnerability. Rapid visual screening (RVS) can be used effectively to assess the vulnerability of a large number of buildings while requiring little computational effort.

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