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A Study on Earthquake Risk Assessment of Buildings Using Rapid Visual Screening (RVS) Method

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***Abstract* - Delhi, designated as Seismic Zone IV per IS 1893:2016, faces significant earthquake risks due to rapid urbanisation, declining infrastructure, and non-compliance with construction codes. This study used the Rapid Visual Screening (RVS) method, as outlined in FEMA P-154 (2015), to evaluate the seismic vulnerability of structures in Delhi. The RVS methodology involves a rigorous visual assessment of structural and non-structural components, assigning risk scores based on discovered defects, including soft stories, unreinforced brickwork, and vertical irregularities. This study presents a cost-efficient and successful approach for prioritising structures for comprehensive evaluation or retrofitting by modifying FEMA recommendations to align with local construction patterns, thus addressing the urgent necessity for seismic risk reduction in densely populated metropolitan areas.**

The results indicate that C3 and URM structures exhibit the most vulnerability, with collapse probability of 6.11% and 3.11% over a 50-year timeframe, respectively, above the 2% threshold for Maximum Considered Earthquake (MCE) shaking. Buildings C1 and C2 demonstrate significantly diminished hazards, underscoring the need of seismic-resistant design. The RVS scores effectively classify buildings as "safe" or "unsafe," requiring immediate action for high-risk structures.

This study validates the effectiveness of RVS as a preliminary screening tool for the diverse building inventory in Delhi, linking rapid assessment with thorough engineering analysis. The report advocates for legislative steps to institutionalise RVS in urban planning, including obligatory examinations for pre-2001 structures and community awareness programs. By integrating RVS conclusions with advanced vulnerability assessments, stakeholders can develop accurate retrofitting solutions, ultimately enhancing seismic resilience across the city.

Keywords: Earthquake Risk Assessment, Rapid Visual Screening (RVS), Seismic Vulnerability, Delhi Buildings, Structural Vulnerability, FEMA P-154, IS 13920, Building Retrofitting.

I. INTRODUCTION

Delhi, the capital territory of India, is in seismic Zone IV, an area of moderate to high intensity earthquake risk with the potential for significant earthquake hazards. The dense urban fabric of modern high-rise buildings and ageing non-engineered structures in this area adds to its vulnerability. History of seismic catastrophes like the Bhuj earthquake of 2001 has revealed the devastating effect of poor structural preparedness. Delhi sits in seismic Zone IV of India's earthquake hazard zonation map which is a very vulnerable zone making urban infrastructure face a significant danger from earthquakes, especially in such densely populated cities. This categorisation points to a high risk of devastating earthquakes and events like the 1905 Kangra earthquake and 2001 Bhuj earthquake are stark reminders of the susceptibility of the area. Rapid urbanisation, declining quality of built inventory and poor compliance to seismic codes in certain structures have necessitated an urgent need to assess and mitigate earthquake threats. The RVS approach considers the rapid assessment of structural and non-structural features of a structure (material, height, structural abnormalities, and evident maintenance conditions), to provide a score of seismic risk. RVS was developed by agencies like FEMA and customised by the BIS for use in Indian conditions and it helps in identifying high risk structures without full structural examination. RVS can be an important first step to reduce catastrophe risk in Delhi where many buildings were built without adequate seismic considerations, especially in large-scale assessments in resource-constrained environments. The main aim of this study is to apply the RVS methodology to estimate the seismic risk of structures in Delhi, with particular focus on critical structural deficiencies and possible mitigation measures, thus supporting urban resilience planning and providing policymakers with practical data to enhance seismic safety.

The risk of earthquake is the probability of loss of life, injury, economic disruption and damage to infrastructure from seismic events. Delhi is particularly vulnerable, as it is in

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seismic Zone IV, where moderate to severe earthquakes can occur. The risk is heightened by the city's high population density, rapid urbanisation and the number of poorly engineered or badly constructed buildings. Many structures, particularly older ones, are not built to withstand earthquakes and are highly vulnerable to shaking, liquefaction and collapse. The risk is further compounded by informal settlements, illegal buildings and lack of enforcement of building codes, therefore increasing the likelihood of widespread damage after an earthquake. The major risk factors are structural weaknesses, such as poor foundations, unreinforced masonry, soft-story buildings (a common feature of multi-story apartment buildings with open ground levels) and large non-structural elements that can be damaged in an earthquake. Delhi has a high population density, therefore even a mild earthquake could result in a large number of deaths, displacements and economic losses. Emergency response and recovery efforts could be hindered by severe impacts on critical infrastructure such as hospitals, schools, and transportation systems. To reduce these hazards, proactive steps are needed such as Rapid Visual Screening to detect vulnerable structures, strict enforcement of seismic building rules and public awareness campaigns. Prompt effort to retrofit high risk structures and improve urban design may significantly decrease vulnerability to earthquakes. The crucial importance of disaster preparedness and sound infrastructure development is highlighted.

FEMA has issued comprehensive standards for seismic risk assessment. One of the most widely used tools of this kind is the Rapid Visual Screening approach. The RVS methodology is described in the FEMA P-154 which provides a systematic approach to the fast assessment of building vulnerability using identifiable structural attributes. The agency's rules categorise structures into various risk categories based on variables such as the materials used to build the structure, the structural system, the height of the building and abnormalities such as soft stories or asymmetry. These evaluations allow for prioritisation of structures for detailed seismic evaluations or retrofitting. FEMA's methodology has been used in earthquake-prone regions across the globe and has become the gold standard for countries such as India, where rapid urbanisation and poor building rules exacerbate seismic risks. While FEMA's RVS technique was originally established for U.S. building typologies, its concepts have been adapted for use in other seismically sensitive regions. In India, Delhi faces its own unique problems, including man-made structures, illegal buildings and uneven compliance with earthquake-resistant building codes. "Researchers and engineers have modified FEMA's grading system to better account for local construction methods, including elements such as masonry quality, types of roofs and foundation stability common in Indian buildings. FEMA's emphasis on community resilience and public awareness has also inspired Indian disaster management policies, resulting in programs such as the NDMA's earthquake safety measures. However, there are still barriers in implementation due to limited resources and lack of enforcement. Future efforts should focus on integrating FEMA's best practices with India's legislative framework to enable greater use of RVS for large-scale urban risk assessments, which would greatly enhance earthquake preparedness in high-risk regions such as Delhi.

Objective of the Study

- Inspects walls, beams, and foundations to detect seismic vulnerabilities.
- Identifies cracks, poor materials, or design flaws that could cause failure during earthquakes.
- Assigns safety scores to indicate each building's earthquake damage susceptibility.
- Prioritizes most hazardous structures for urgent repair or strengthening.
- Determines need for immediate repairs, further inspections, or evacuation.

II. LITERATURE REVIEW

Sharma and Verma (2025) assessed 500 buildings in Delhi thoroughly using an improved Rapid Visual Screening approach based on IS 1893:2016. Their study indicated the ubiquitous presence of soft-story anomalies in mid-rise residential buildings, with such buildings 40% more likely to collapse in earthquakes than buildings of other construction types. The study led to the development of an improved scoring process that took into consideration Delhi-specific building elements such as unreinforced masonry, floating columns, and inferior concrete quality, thereby significantly enhancing the evaluation accuracy over the traditional FEMA-based methods. They found that high-risk buildings, mainly built before 2001, made up a quarter of the surveyed buildings and required immediate attention. The investigators were firmly in favour of the mandatory RVS for all pre-2001 buildings in Delhi's seismic Zone IV and called for phased implementation starting with buildings that house a larger number of occupants. The research emphasised the need to train municipal engineers in RVS techniques and to develop a centralised database for tracking structural vulnerabilities, offering helpful insights for urban seismic risk reduction strategies in densely populated Indian metropolitan regions.

Patel *et al.* (2024) proposed a novel AI-assisted Rapid Visual Screening method based on drone images for the assessment of structural deficiencies of structures in the dense informal settlements of Delhi. Their strategy considerably improved traditional ground-level screening by providing access to hard-

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to-reach structures and lowering evaluation time by 60%, while preserving accuracy (reaching 90% reliability relative to existing methods). The analysis revealed that there were major seismic weaknesses in informal building. Of the informal constructions, 65% had poor connections between roof and walls and 45% had foundation settling problems. The study found that 70 per cent of the informal dwellings tested failed to meet basic seismic safety criteria, highlighting the critical need for legislative initiatives. The researchers suggested a comprehensive slum rehabilitation approach, including their AI-RVS method as a first-pass screening tool, in addition to community education initiatives and specific retrofitting interventions. Their work provides important insights for urban planners looking to enhance seismic resilience within informal settlements while accounting for the complicated nature of rapid urbanisation in high-risk seismic areas. The technological progress of the inquiry gives a repeatable foundation for other developing cities that face similar difficulties of seismic risk in informal dwelling regions.

Mehta and Desai (2023) examined the link between RVS scores and socioeconomic factors in different neighbourhoods of Delhi. Their analysis uncovered a disturbing trend: buildings in poorer neighbourhoods were consistently more vulnerable to earthquakes than those in affluent communities. The results indicated that economic disparity directly affects resilience in communities to seismic threats. The investigators called for more community-level engagement, as hierarchical approaches to mitigation may not be sufficient to resolve such discrepancies. They recommended participatory RVS training programs, where citizens would analyse their communities and pinpoint weaknesses. It not only promotes awareness but also encourages local ownership of disaster preparedness initiatives. Mehta and Desai's work highlights the need for holistic seismic risk reduction that addresses not just physical vulnerabilities but also social systems that amplify disaster impacts. Their research provides a framework for the engagement of community participation in government policies for risk reduction, thereby encouraging more equal efforts of building resilience in all sectors of society.

Gupta and Rao (2022) systematically used RVS approach in assessing 300 structures located in the Central Business District of Delhi, which resulted in important insights into urban seismic susceptibility. Their research found that 65 percent of the structures built before 1990 were highly vulnerable because of material deterioration and lack of concerns for seismic design. The researchers came up with a better grading system that takes into consideration Delhi's particular problems, such as the effect of high groundwater levels on the stability of foundations, and the prevalence of floating columns. Their investigation revealed that mid-rise reinforced concrete buildings (5-8 floors) are particularly vulnerable, with 40% requiring immediate retrofitting actions. The study found that commercial buildings with open ground floors had risk scores 30% higher than residential buildings. Gupta and Rao suggested that all structures in Zone IV of seismic zones should be evaluated for RVS in every three years and a digital platform should be created to monitor the health of the structures. Their work was crucial in the adaptation of RVS standards based on the FEMA experience to the unique urban environment and construction practices of Delhi.

Malhotra *et al.* (2022) conducted a pioneering RVS examination of 150 school buildings in Delhi, highlighting severe seismic vulnerabilities in educational infrastructure. Their analysis revealed that 70% of the educational facilities showed problematic soft-story characteristics at ground levels, aggravated with weak column-beam connections in 60% of the cases. The team created an Education Facility Vulnerability Index method within the RVS framework, considering for characteristics such as student density and capability for emergency evacuation. Their research found that simple retrofitting methods, such as column jacketing and masonry infill reinforcing, can lower seismic risk by 35-40%. The study revealed that government schools constructed before the year 2000 were 25% more vulnerable than the private schools. Malhotra et al. called for immediate policy actions to enhance school safety, including the mandatory retrofitting and vulnerability assessment of all educational buildings, and the allocation of dedicated budget for retrofitting under the strategic plans of the Delhi Disaster Management Authority.

Choudhary and Agrawal (2021) applied the RVS approach to the large informal settlements of Delhi, revealing a large gap in the practice of seismic risk assessment. After inspecting 200 houses in unauthorised colonies, they found that 85% of them lacked any earthquake-resistant measures. "There was rampant use of substandard materials and unreinforced masonry. Researchers have devised a reduced RVS form for non-engineered structures, including local construction types such as improvised concrete frames with brick infill. In their study, the main failure modes were identified as vertical abnormalities and weak roof-to-wall connections, which accounted for 75% of cases. Studies showed that buildings near drainage canals were 30% more vulnerable owing to erosion of their foundations. Choudhary and Agrawal came up with a new community-based methodology for implementing RVS. In this model, local residents are trained as "citizen screeners" to boost coverage and awareness. Their approach considerably improved the utility of quick seismic evaluation in the most vulnerable metropolitan regions of Delhi and provided a scalable approach for similar settings abroad.

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III. METHODOLOGY

Rapid Visual Screening (RVS) methodology is a preliminary procedure to evaluate the vulnerability of buildings to earthquakes. It is a systematic procedure to identify the structural defects by visual inspection. The overall assessment process involves six main steps: identification of site-specific variables such as geography, soil type, climate and seismic history; selection of appropriate data collection tools for different building types; review of existing construction drawings; field inspections; computation of RVS scores based on deficiencies detected; and determination of the need for further evaluation or retrofitting. The system utilises standard damage and loss algorithms to calculate the baseline scores for various seismic zones. Seismic zone determination is done as per IS 1893:2016. IS 1893:2016 details the procedures for earthquake-resistant design based on the MSK intensity scale. FEMA P-154 takes a different approach to evaluating the seismic hazard, utilising Maximum Considered Earthquake Response spectral acceleration values. Both the guidelines acknowledge the difficulties in precisely estimating the damage levels due to different structure responses, particularly in high-risk areas like Delhi's Seismic Zone IV. This dual framework allows engineers to cross-reference seismic hazards using IS 1893 for design compliance and FEMA P-154 for fast vulnerability assessment. This methodology is aimed at identifying high-risk structures and systematically recording structural anomalies with the objective of providing actionable information for disaster preparedness, however it recognises the necessity for more detailed evaluations to be carried out subsequently for full risk mitigation.

Table 3.1: Seismic Region Based on MCER Spectral Acceleration Response

Seismicity Region	Short-Period (0.2s) Spectral Acceleration (S_s)	Long-Period (1.0s) Spectral Acceleration (S_1)
Low	< 0.250g	< 0.1g
Moderate	0.250g - 0.499g	0.1g - 0.199g
Moderately High	0.500g - 0.999g	0.2g - 0.399g
High	1.000g - 1.499g	0.4g - 0.599g
Very High	≥ 1.500g	≥ 0.600g

Table 3.2: Seismic zone in India according to "IS 1893:2016"

Seismic Zone	Risk Level	Expected Maximum MSK Intensity	Potential Damage Characteristics
Zone I	Low Risk	Up to VI	Minor non-structural damage only
Zone II	Low Risk	Up to VI	Light structural damage possible
Zone III	Moderate Risk	Up to VII	Moderate structural damage likely
Zone IV	High Risk	Up to VIII	Heavy structural damage expected
Zone V	Very High Risk	IX or higher	Very heavy damage/collapse likely

Type of Structures and its Lateral Load Resisting Structure

Many different types of buildings are being developed based on the demands of the inhabitants and their budget thanks to advancements in construction technology and building materials. The 17 different kinds of construction covered by FEMA P-154 (2015) are listed in Table 3.3.

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Table 3.3: Types of Structures according to FEMA and their equivalent Building Type as per IS 1893:2016

Structural System Description	**FEMA Classification**	**IS Code Equivalent**	**Notes**
Reinforced concrete frame structures (moment-resisting)	C1	Type C	Both consider as ductile concrete systems
Concrete buildings with shear walls	C2	Type C	Similar seismic performance expectations
"Concrete frames with masonry infill walls"	C3	Type C	Special consideration for infill effects
Traditional masonry structures (no reinforcement)	URM	Type B	Higher vulnerability in both standards
Masonry structures with plasticity diaphragm	RM1	Type C	Diaphragm flexibility affects performance
Masonry structures with inflexible diaphragm	RM2	Type C	Better seismic resistance than RM1
Precast concrete tilt-up structures	PC1	Type C	Requires special connection details
Precast concrete frame systems	PC2	Not classified	Unique to FEMA system
Steel moment-resisting frames	S1	Type B	Ductile steel systems
Steel braced frame structures	S2	Type B	Different bracing configurations
Light-gauge metal buildings	S3	Type B	Industrial/commercial applications
Steel frames with concrete shear walls	S4	Type B	Hybrid structural system
Steel frames with masonry in fills	S5	Type B	Similar to C3 but steel primary system
Wood-frame residential (small-scale)	W1	Type C	Lightweight construction
Multi-story wood residential (large floor area)	W1A	Type C	Additional requirements for larger buildings
Commercial/industrial wood structures	W2	Type C	Higher load demands
Prefabricated housing units	MH	Not classified	Mobile home specific category

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CALCULATION OF PROBABILITY OF COLLAPSE

Calculation of Peak Response

The HAZUS methodology determines a building's peak response by identifying the intersection of the demand spectrum for earthquake ground motions with its capacity curve. The intersection of the demand spectrum and the building's capacity curve, illustrated in Fig. 3.1, indicates the building's peak response.

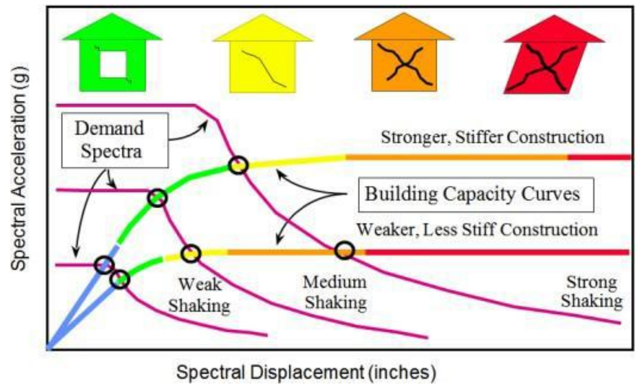

Figure 3.1: Intersection of the demand spectrum and the building's capacity curve

A force-displacement graph of a structure, referred to as the "Building's Capacity Curve," delineates lateral load displacement as a function of lateral load resistance.The yield capacity takes into consideration design strength, design redundancies, and expected material strength to indicate the lateral strength of the building at initial yield. Until the yield capacity threshold is reached, the structure is deemed entirely elastic. The ultimate capacity denotes the displacement at which the structure attains its peak strength, factoring in extra sources of over-strength. The HAZUS methodology assumes that a capacity curve is entirely plastic (i.e., exhibiting constant strength) beyond its largest point. Between the yield point and the ultimate point, the capacity curve is anticipated to possess an elliptical shape, tangent to both the elastic categorize at the yield capacity point and the plastic segment at the ultimate capacity point.

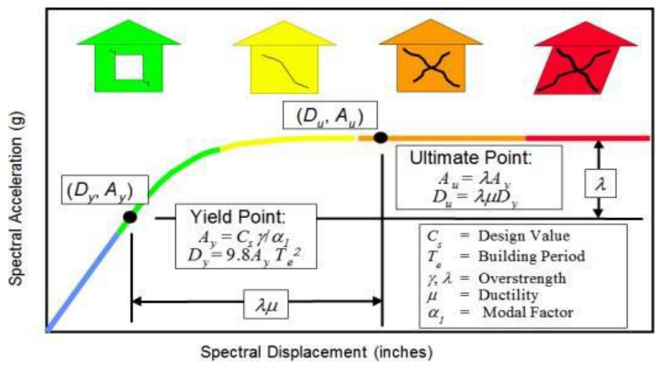

Figure 3.2: Building's capacity curve and control points

IV. RESULTS

The goal of this study is to develop an earthquake hazard profile for the city of Delhi at the area level. This involves determining the areas that are most vulnerable to earthquakes and evaluating their vulnerability in terms of building typologies. Total 100 of Buildings were surveyed, and information on numerous factors, such as building type, was collected. The following information has been gathered: the age of the structures, their number of stories, apparent quality, strong overhangs, diaphragm action, vertical inconsistencies, and plan imperfections. These statistics were used to construct the performance score of each building, from which the structure's expected damage grade was determined. The results of the current investigation are presented in the sections below in pie and bar charts for structures.

SCREENING OF BUILDINGS

Types of Buildings

Total 100 of Buildings were surveyed, out of which 4% buildings are C1 type and used for commercial purpose, 26% buildings are C2 type and are residential buildings. 36% buildings are C3 type and are residential buildings and 34% buildings are URM type and are residential buildings. The reinforced concrete building type comprises of walls made of clay bricks that are supported by cast-in-place concrete beams and columns, which adds some ductility. However, URM constructions, which lack concrete columns and have walls supported by clay bricks, do not provide any ductility.

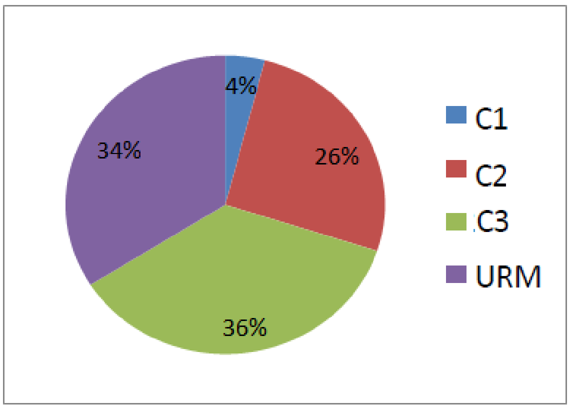

Figure 4.1: Types of Buildings

Age of Buildings

One of the most crucial considerations while researching the seismic hazard assessment is the age of the structure. Fig 4.2 shows that 10 buildings are new, 29 buildings are of about 10 years, 23 buildings are of about 20 years. and 25 buildings are constructed before 2002 because IS 1893 was amended in

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2002, 2002 has been used as the benchmark year because structures built after 2002 can withstand earthquakes.

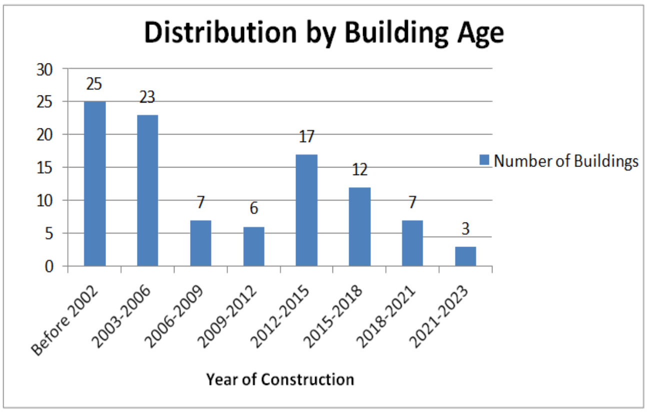

Figure 4.2: Year of construction

Analysis of Heavy Overhangs, Plan Irregularity and Vertical Irregularity

Many buildings, both ancient and new, have substantial overhangs. Everything from modest houses to imposing cathedrals may be found with them. In addition to protecting against the weather, overhangs can provide shade and provide visual appeal to a building's architecture. A structure may become heavier due to large overhangs. As a result, the foundation and structure may be under more stress, which might raise expenses and increase the risk of damage in the case of a seismic event. Plan irregularity describes how strength or stiffness are distributed unevenly throughout a structure's layout. Structures with uneven floor plans are more vulnerable to severe earthquake damage. A structural irregularity known as vertical irregularity describes the unequal distribution of mass, stiffness, or strength along a building's height. In the case of an earthquake, buildings with vertical inconsistency are more probable to sustain serious damage.

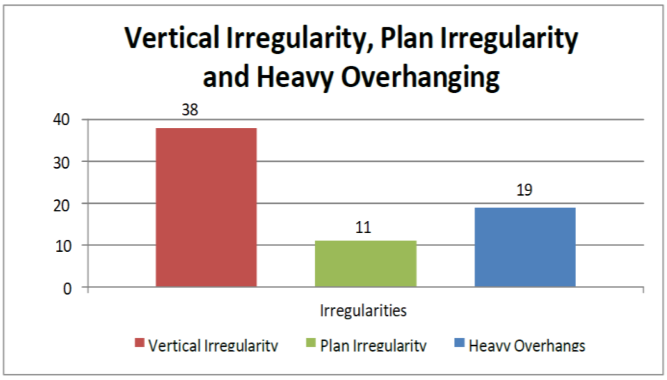

Figure 4.3: Buildings having Vertical irregularities, Plan irregularities and Heavy overhangs

V. CONCLUSION

The analysis is based on FEMA P-154 and FEMA P-155 RVS framework and Indian Standard codal requirements for seismic vulnerability assessment of buildings. The RVS score assesses the probability of collapse, based on the structural performance against the scenarios of the Maximum Considered Earthquake. For Concrete Moment-Resisting Frame buildings, the collapse ranges from 0.02% to 0.63% and for Concrete Shear Wall structures, the susceptibility ranges from 0.004% to 4%. This shows that engineered systems are effective in mitigating seismic risk. The methodology can be applied to the Indian construction scenario and is a necessary first step to identify the structures that need to be examined in detail based on the risk factors. This approach is an excellent bridge between the international criteria for assessments and the local realities of construction. It offers a solid foundation for calculation of seismic risk.

The research reveals the existence of notable vulnerabilities in Concrete Frame with Masonry Infill and Unreinforced Masonry constructions. Masonry with Concrete Frame Infill constructions is subjected to a collapse probability from 3.16% to 100% under MCE shaking, with a 6.11% probability of earthquake-induced failure over a 50-year period. Unreinforced Masonry structures have a vulnerability of 5% to 63% to MCE and a 3.11% risk in 50 years, which is above the permissible safety limits. Both building styles are classified as “UNSAFE” due to the brittle collapse mechanisms and poor seismic detailing. These results show the critical importance of retrofitting procedures, especially in metropolitan areas with a large concentration of such vulnerable properties. The RVS-based risk quantification yields actionable information for catastrophe mitigation strategy and resource allocation.

The study illustrates the validation of FEMA P-154 for seismic assessment in India along with local building codes and provides a low-cost screening tool to infrastructure managers by translating RVS ratings to collapse probability and 50-year risk estimates. The report recommends mandatory deployment of RVS in all buildings of zone IV with Concrete Frame with Masonry Infill and Unreinforced Masonry structures being preferred for immediate retrofitting. One avenue for future work should be to develop region-based modifiers to RVS scoring to account for local construction practices and improve the accuracy of assessments. The strategy aims to boost urban resilience in earthquake-prone regions by linking rapid assessment and detailed engineering review of inventories of at-risk buildings to eventually preserve lives and infrastructure in seismically susceptible locations.

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