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RAPID VISUAL SCREENING OF BUILDINGS

A Thesis Submitted
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Degree of

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by

Pawan Tiwari
(2K24/STE/06)

Under the Supervision of

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I, **Pawan Tiwari, 2K24/STE/06** of MTech (Structural Engineering), hereby certify that the work which is being presented in the thesis entitled "**Rapid Visual Screening of Buildings**" which is submitted by me to the **Department of Civil Engineering**, Delhi Technological University, Delhi in partial fulfilment of the requirements for the award of the degree of Master of Technology, is original and not copied from any source with proper citation. This work has not previously formed the basis for the award of the Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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ABSTRACT

Delhi, situated in Seismic Zone IV as per IS 1893:2016, faces significant seismic hazard, yet a large proportion of its building stock remains unassessed for earthquake vulnerability. This thesis presents a systematic seismic vulnerability assessment of buildings in selected localities of Delhi using the Rapid Visual Screening (RVS) methodology prescribed in FEMA P-154 (2015). The study covers two primary building typologies: Reinforced concrete (RC) framed government and residential buildings, and unreinforced brick masonry (URM) structures in informal settlements, representing the broad spectrum of Delhi's built environment.

Field investigations were carried out across three study areas — Azadpur, Akshardham, and Samaypur Badli — encompassing nine formally screened buildings subjected to both Level 1 and Level 2 RVS, supplemented by photographic RVS of informal settlement clusters near Samaypur Badli, Haiderpur Badli. Score modifiers accounting for vertical irregularity, plan irregularity, soil conditions, and code compliance were applied in accordance with the FEMA P-154 framework.

The results reveal a pronounced generational divide in seismic performance. Post-benchmark RC buildings designed and constructed after 2014 to modern code provisions achieved high Level 2 RVS scores (SL2 = 2.6 to 3.4), corresponding to very low probabilities of collapse under Maximum Considered Earthquake (MCE) shaking. In contrast, pre-code RC government buildings constructed between 1975 and 1979 exhibited substantially higher vulnerability, with Level 2 scores as low as SL2 = 0.1, translating to a failure probability of 1 in 1.25 under MCE shaking.

The photographic RVS of informal settlements identified a consistent pattern of systemic vulnerabilities including extreme rooftop overloading from unanchored water storage tanks, absence of horizontal reinforcing bands at plinth, sill, lintel, and roof levels, zero or sub-code inter-building separation distances, soft storey conditions at commercial ground floors, informal vertical additions without structural assessment, and narrow emergency access lanes of 1.0 to 3.0 metres width. These conditions collectively indicate a high probability of widespread structural failure and mass casualty risk in the event of a moderate to severe seismic event in these settlements.

The study validates the representative building approach as a resource-efficient and technically defensible method for area-wide seismic risk assessment. Given the structural homogeneity of Delhi's government building cohorts and informal settlement typologies, findings from screened representative buildings can be extended with reasonable confidence to structurally analogous buildings across entire settlement zones. Buildings 2, 7, 8, and 9 are recommended for immediate detailed structural evaluation, with Buildings 7 and 9 receiving highest priority. The thesis concludes that a significant and largely unquantified seismic risk exists in Delhi's pre-code and informal building stock, and that the RVS methodology provides a scientifically credible, scalable framework to initiate systematic seismic risk characterisation, prioritisation, and mitigation across Indian cities with comparable urban vulnerability profiles.

Keywords: Rapid Visual Screening, Seismic Vulnerability, Delhi, FEMA P-154, Unreinforced Masonry, RC Frame Buildings, Seismic Zone IV, IS 1893:2016, Informal Settlements.

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CHAPTER 1

INTRODUCTION

1.1 Background and Context

Delhi is one of the most densely populated cities in the world, and its impact on the public infrastructure is unmatched. Roads, flyovers, residential colonies, commercial complexes, utility lines and public buildings are under constant operational stress due to heavy traffic, environmental pollution, seismic activity, and aging and lack of maintenance. The urban built environment is highly vulnerable structurally in terms of structural density and lack of documentation, due to rising urbanisation and weak building code enforcement.

As per IS 1893 (Part 1): 2016, Delhi is in seismic zone IV which is considered as high seismic risk in India. Thus, buildings in Delhi must be designed and maintained to be able to withstand substantial earthquake forces. However, a large percentage of the urban fabric was constructed prior to the development of modern seismic codes and many buildings have been constructed or retrofitted without consideration of the seismic code provisions. This results in a fairly high number of seismically susceptible buildings and infrastructure elements in the city.

In this scenario, it is crucial to conduct regular structural assessment. The earthquake does not kill people, it kills when poorly designed and poorly maintained buildings collapse. Pre-seismic identification of at-risk structures is thus one of the most effective tools that is available for disaster risk reduction. Rapid Visual Screening (RVS) is a practical way to do this on a large scale, and does not require the time and resources that would be needed to conduct detailed structural analysis of each building.

1.2 The Need for Rapid Visual Screening in Delhi

Rapid Visual Screening is a non-destructive, visual-based assessment method that can be used by trained engineers to assess the seismic vulnerability of large numbers of structures efficiently and at relatively low cost. It is not a substitute for detailed structural analysis, but rather a first pass filter to identify structures that have characteristics of poor seismic performance and indicate them for detailed investigation. Delhi is a city of millions of buildings, hundreds of kilometres of roads, and a vast network of public facilities, where a systematic preliminary assessment can be done only through RVS.

The specific conditions of the study areas chosen for this investigation further emphasize the need for this methodology. All three locations have the following common features: unplanned construction, high occupancy, lack of maintenance and proximity to congested urban corridors. The structures in these areas are visibly degraded with exposed reinforcement, spalling concrete, settlement cracking and unauthorised additions that affect the structural behaviour. A systematic RVS survey can detect the most vulnerable elements and guide authorities in prioritising corrective action.

1.3 Study Area Overview

The three study areas were selected to represent distinct urban typologies within Delhi's complex metropolitan fabric. Each location presents a different combination of land use, construction vintage, occupancy patterns, and infrastructure loading, making them collectively representative of the broader range of structural vulnerability conditions found across the city.

1.3.1 Azadpur

Azadpur is one of the commercial rich areas in the northern part of the city of Delhi.It is well renowned for being home to one of the biggest wholesale fruit and vegetable markets in Asia, which causes a constant stream of buses, pedestrians, heavy trucks, freight cars, and tempos throughout the day and night. The built fabric that surrounds it is a naturally occurring high-density cluster of commercial sheds, vendor stalls, load-bearing masonry structures and

naturally extended reinforced concrete buildings that have developed around the site as a result of the concentration of commercial activity.

Most buildings in the immediate vicinity of the market and along the approach roads were constructed many years ago and often were not designed with seismic design considerations.Over time the structural layout has been changed by the addition of floors, cantilevered sections and infill walls, which significantly enhance susceptibility.A narrow lane will cause deterioration of materials because it will restrict access for emergency vehicles and natural light and ventilation.Poor drainage conditions compromises foundation soils and promotes corrosion of structural reinforcement in monsoon seasons.

The structural stock in this area is mostly of newer but code deficient buildings, with partially engineered RCC framed buildings, and also older unreinforced masonry buildings.Typical weaknesses are torsional irregularities from asymmetric plan dimensions, short column situations due to infill wall not spanning full storey height, and soft-storey situations where ground floors are set out for commercial use.The highly occupied Azadpur area had high-intensity vibrations, weak structures and high traffic flow making it one of the most risk-significant areas in the study.



Figure 1 Satellite View of Azadpur Metro Station



Figure 2 On Site View near Azadpur Metro Station

1.3.2 Akshardham

Dense urban development and institutional beauty coexist in the Akshardham region. The majority of the older reinforced concrete frame houses that make up the approach roads and adjacent colonies were built prior to the implementation of the updated seismic regulations outlined in IS 13920. Even though the area's more recent development adheres to more modern norms, most of the current stock still lacks seismic details.

Both heavy passenger traffic and tourists visiting the Akshardham Temple complex frequent the area. This increases the dynamic stresses on nearby roads and pedestrian infrastructure and exposes nearby structures to vibration. Concerns regarding pounding impacts during seismic events are raised by a number of buildings in the vicinity that exhibit obvious surface cracking, mortar deterioration, and improper separation from other structures.

Considering the zone's institutional nature, any structural failure would have greater consequences for the general population. Structures that serve tourists, such as hotels, guest houses, restaurants, and businesses, are usually populated at high densities. Such buildings' structural fragility immediately increases the

risk to human life. Therefore, this area's evaluation is especially important for public safety planning.



Figure 3 Satellite View of Akshardham Metro Station



Figure 4 On Site View near Akshardham Metro Station

1.3.3 SamaypurBadli

SamaypurBadli represents the essence of Delhi's quickly expanding outskirts. The region includes a mix of unplanned residential clusters, dense roadside business strips, transportation stations, warehouses, and industrial buildings. This zone's infrastructure has frequently expanded ahead of official planning,

leading to buildings with irregular designs, soft-story conditions, and little seismic details that were constructed on poorly examined ground. Construction methods that would be illegal in more controlled areas of the city have been made possible by the lack of official urban planning monitoring.

Additionally, the region is inside a geotechnical concern zone. Because the research region is close to the Yamuna floodplain, parts of it are underlain by soft alluvial deposits, which are prone to liquefaction in saturated conditions and amplification of seismic ground motion. The operational stress on existing structures is further increased by the transit of heavy vehicles, frequent vibrations from passing traffic, and the close proximity of industrial activity.

Out of the three research regions, SamaypurBadli has the largest concentration of non-engineered building in terms of structural vulnerability. Large openings in load-bearing masonry buildings, RCC structures with insufficient column diameters and reinforcement, and buildings with plan and vertical irregularities are also frequently seen. This location is extremely relevant for seismic vulnerability evaluation due to the combination of low structural quality, unfavourable soil conditions, and high occupancy.



Figure 5 Satellite View of Samaypur Badli Metro Station



Figure 6 On site view near Samaypur Badli Metro Station

1.4 Objectives of the Study

The main aim of this study is to evaluate seismic vulnerability of existing building stock in Delhi, falling in Seismic Zone IV as per IS 1893:2016, using methodology of Rapid Visual Screening (RVS) as prescribed by FEMA P-154 (2015). The study **centres** on two different but influential building typologies: Government/Institutional Buildings (which generally show structural regularity due to the regularity of building processes) and Brick Masonry Residential Buildings found in informal and semi-formal settlements and slum local areas.

The particular targets are the following:

1- To design and construct retrofit for selected buildings in Delhi for RVS (Level 1 and Level 2) as per FEMA P-154 considering seismic zone, soil type, structural typology, age, and irregularity observed in the building.

2- To demonstrate the feasibility and usefulness of RVS as an effective and scalable screening tool for large urban building inventories with particular focus on use of RVS as a prioritisation tool for detailed investigation.

To transfer the results of individual screened buildings to clusters of structurally similar buildings, including when a complete individual screening of all buildings is impracticable, in order to carry out an area-wide risk assessment using a representative sampling approach.

1.5 Scope and Limitations

This study does not cover in-depth structural analysis of specific buildings; instead, it is restricted to the preliminary evaluation level indicated by Rapid Visual Screening. The RVS methodology does not include destructive testing, material sampling, or instrumented monitoring; instead, it depends on professional judgment and visual observation. Before decisions are made on retrofitting or demolition, buildings that RVS has classified as potentially vulnerable must undergo additional investigation. The study does not attempt to be inclusive of all the structural stock in the three chosen metro station locations; rather, it focuses on structures in their immediate neighbourhood.

CHAPTER 2

EARTHQUAKE AND SEISMIC HAZARDS

2.1 Introduction

One of the most damaging natural disasters to human civilization is earthquakes. Every year, seismic occurrences of various intensities occur in various places of the world, resulting in infrastructure damage, financial losses, and fatalities. Because so much of India is located in seismically active zones, the country is extremely susceptible to earthquakes. Delhi is at significant risk of moderate to severe seismic events due to its location in Seismic Zone IV. This susceptibility is further increased by the predominance of non-engineered construction, population growth, and rapid urbanization.

A fundamental principle of earthquake engineering is that humans are not directly killed by earthquakes; rather, casualties are caused by the failure or collapse of badly built and neglected infrastructure. During an earthquake, buildings, bridges, flyovers, and other structures that are susceptible to seismic forces become the main source of danger. Therefore, the human and economic effects of seismic events are largely determined by the quality of construction, structural detailing, and adherence to codal regulations.

2.2 Nature and Classification of Seismic Hazards

The abrupt release of energy within the Earth's crust carried on by movement along tectonic plate borders or geological faults is what causes an earthquake. Ground motion is the result of seismic waves created by this energy release that move through the earth. The following are the main earthquake risks that affect urban infrastructure:

- The main factor causing structural damage in urban areas is ground shaking.
- Soil liquefaction: During earthquake activity, saturated loose soils temporarily lose their bearing capacity.

- Ground displacement along fault lines due to surface rupture
- Slope failures and landslides brought on by ground acceleration
- Lifeline infrastructure structural collapse and cascading failures
- Fire risks brought on by gas and electrical system failures

For the dense urban structures of Delhi, ground shaking is by far the biggest risk. The magnitude of the earthquake, the distance from the epicenter, the local soil conditions, the structural configuration of the affected building, the quality of the construction materials and workmanship, the existence of structural irregularities, and the maintenance condition of the structure over its service life are some of the interacting factors that determine the severity of damage caused by ground shaking.

2.3 Effects of Earthquakes on Structures

Due to the quick acceleration of the ground during seismic activity, structures experience both horizontal and vertical inertia forces. These forces, which are proportionate to the structure's mass, have the potential to cause stress and deformation in structural members that is substantially greater than what materials not intended for seismic loading can withstand. During earthquakes, the following damage mechanisms are most frequently seen in masonry and reinforced concrete structures.

Damage to reinforced concrete frame buildings usually consists of the following: excessive lateral sway, torsional effects in asymmetric buildings, cracking and spalling of beams and columns, failure of beam-column joints due to insufficient confinement reinforcement, storey collapse caused by soft-storey mechanisms where a weak ground floor is surrounded by stiffer upper floors, and pounding damage between adjacent structures with insufficient separation. Diagonal cracking of wall panels, failure at wall junctions, toppling of unreinforced walls, collapse of gable ends, and disintegration of improperly bonded masonry units are examples of damage to masonry buildings. For both residents and rescue workers, non-structural damage such as falling ceilings, glass partition breaking, parapet failure, and utility line rupture can be just as dangerous.

2.4 Seismic Zoning of India

According to IS 1893 (Part 1): 2016, India is divided into four seismic zones according to the likelihood of a seismic event and the expected intensity of ground motion. Table 2.1 displays the zone classification

Table 2.1: Seismic Zoning of India as per IS 1893

Seismic Zone	Zone Factor (Z)	Risk Level	Expected MSK Intensity
Zone II	0.10	Low Damage Risk	VI or less
Zone III	0.16	Moderate Damage Risk	VII
Zone IV	0.24	Severe Damage Risk	VIII
Zone V	0.36	Very Severe Damage Risk	IX and above

Delhi has a zone factor of 0.24, placing it in Seismic Zone IV. Structures in this zone must be built to withstand the earthquake forces associated with this zone factor, and reinforced concrete structures must use ductile detailing in accordance with IS 13920.

2.5 IS 1893 — Criteria for Earthquake Resistant Design

The fundamental Indian Standard for earthquake design is IS 1893 (Part 1): 2016. It details India's seismic zoning map, design horizontal seismic coefficients, response reduction factors, significance factors for various building types, soil classification, methods for calculating natural periods, dynamic analysis techniques, classification of structural irregularities, and combinations of seismic loads.

The percentage of the structure's weight that must be withstood as a lateral seismic force is represented by the design horizontal seismic coefficient Ah, which is calculated as follows:

$$Ah = (Z \times I \times Sa) / (2 \times R \times g)$$

Sa/g is the average response acceleration coefficient calculated from the response spectrum for the proper soil condition and structural natural period, Z

is the zone factor, I is the importance factor reflecting the consequence of structural failure, and R is the response reduction factor accounting for the ductility and over-strength of the structural system.

Three performance categories form the foundation of IS 1893's design philosophy: light earthquakes should not result in structural damage; moderate earthquakes may generate repairable damage but should not endanger human safety; and strong earthquakes should not induce collapse even in cases of significant damage. This progressive philosophy depends on controlled inelastic deformation, or ductility, to safeguard life, accepting that it would be economically unfeasible to build all structures to remain elastic during the maximum credible earthquake.

2.6 IS 13920 — Ductile Detailing of Reinforced Concrete Structures

One of the most significant Indian standards for the design of earthquake-resistant reinforced concrete is IS 13920: 2016. It offers thorough detailed specifications meant to guarantee that reinforced concrete structures have enough ductility to experience controlled inelastic deformation during strong earthquakes without collapsing severely. In Seismic Zones III, IV, and V, the code covers dual systems, moment-resisting frames, structural walls, and frame-wall combinations.

The basic principle of IS 13920 is that it is neither physically nor economically essential for all structural elements to remain elastic during a strong earthquake. Instead, structures should be built so that columns and junctions retain their ability to support loads while inelastic deformation is confined in meticulously specified parts, particularly beams. By using this method, the structure may absorb and release seismic energy without collapsing.

According to IS 13920's strong column–weak beam design concept, columns must be stronger in bending than the beams that frame them at every junction. This prevents the storey-level collapse process that happens when columns yield simultaneously by ensuring that plastic hinges, or zones of concentrated yielding, emerge in beams rather than columns. This need is quantified by the code as:

$$\sum Mc \geq 1.4 \sum Mb$$

Where ∑Mc is the total moment capacities of the columns at the junction and ∑Mb is the total moment capacities of the beams that frame the joint. Every beam-column joint in the structure must adhere with this requirement.

According to IS 13920, the spacing between hoops or stirrups for transverse reinforcement in specific confining regions—such as beam-column joints, the ends of beams and columns, and areas next to discontinuities—must not be greater than one-quarter of the minimum member dimension, six times the diameter of the smallest longitudinal bar, or 100 mm. These tightly spaced stirrups improve the joint region's shear resistance and ductile behaviour under cyclic seismic loading, contain the concrete core, and stop longitudinal bars from buckling.

CHAPTER 3

SEISMIC VULNERABILITY OF DELHI

3.1 Introduction

Delhi is regarded as one of India's most seismically vulnerable major cities. Its high level of exposure to earthquake damage is caused by an interaction of tectonic causes, geological circumstances, and urban growth patterns. The city is home to a wide variety of structures, from historic unreinforced masonry buildings built without formal technical input to modern high-rise buildings built in accordance with current seismic requirements. One of the most urgent issues facing Delhi's structural engineers and urban planners is bridging the massive seismic resistance gap between the best and worst of these structures by methodical evaluation and renovation.

3.2 Seismic Zone Classification

According to IS 1893 (Part 1): 2016, Delhi is categorized as Seismic Zone IV, a Severe Damage Risk Zone with a zone factor of 0.24. According to the Modified Mercalli Scale, this zone is predicted to have an earthquake intensity of VIII, which corresponds to substantial structural damage in typical buildings, partial collapse of poorly constructed structures, and extensive non-structural damage. The seismic classification criteria that apply to Delhi are compiled in Table 3.1.

Table 3.1: Seismic Classification of Delhi

Parameter	Value
Seismic Zone	Zone IV
Zone Factor (Z)	0.24
Risk Category	Severe Damage Risk
Expected Intensity (MSK Scale)	VIII
Mandatory Ductile Detailing	Required (IS 13920)

Importance Factor for Critical Structures	1.5

Due to its extremely high population density and the vital relevance of its infrastructure systems, Delhi has been designated by the Bureau of Indian Standards as one of the major urban centers that must strictly adopt seismic design codes. All new building must adhere to IS 1893 and IS 13920, and it is highly advised that existing non-compliant structures be retrofitted.

3.3 Geological and Tectonic Setting

Delhi is near one of the world's most seismically active regions – the Himalayan seismic belt. The continuous collision of the Indian and the Eurasian plates in the Himalayan region generates a huge compressional force which triggers major earthquakes along the Main Himalayan Thrust and other related fault systems. The epicenter of a large earthquake may be several hundred kilometres distant from Delhi but the seismic waves can travel long distances and produce significant ground shaking in Delhi.

More immediately, several active fault systems which are capable of producing small earthquakes directly under the City of Delhi cross or are close to the city. Delhi is surrounded by the following five fault systems which are of tectonic importance: (1) Delhi–Haridwar Ridge, (2) Delhi–Moradabad Fault, (3) Sohna Fault, (4) Mathura Fault and (5) Mahendragarh –Dehradun Fault. A moderate to large earthquake with the epicentre inside or close to the metropolitan area could result from movement along any of these faults.

3.4 Shallow-Focus Earthquakes and Their Significance

One of the most important characteristics of local seismicity in the Delhi- NCR region is the shallow depth of the focus of most of the recorded earthquakes. Based on previous seismic events in the region, local earthquakes tend to occur at depths of 5-15 km relatively little energy is lost before seismic waves reach buildings and infrastructure because shallow-focus earthquakes release seismic

energy near the ground's surface.In shallow-focus occurrences, therefore, moderate sized earthquakes can produce strong ground shaking.

In some areas having soft alluvial soils, PGA values could be between 200 cm/s2 and 450 cm/s2 if a moderate shallow earthquake of magnitude around 5.0Mw occurs within or near the Delhi area, according to scientific estimates. These accelerations can cause significant damage to unreinforced masonry buildings, poorly specified reinforced concrete structures and buildings with soft-story or plan vulnerabilities. From the past earthquakes, the city of Delhi has felt significant and sometimes high intensity ground shaking from either local or remote seismic sources, such as the Uttarkashi earthquake in 1991, the Nepal earthquake in 2015, the Chamoli earthquake in 1999 and the Delhi earthquake in 1960.

3.5 Soil Conditions and Amplification

The degree of ground shaking that occurs during earthquakes is greatly influenced by the soil characteristics in Delhi, which differ greatly throughout the city. Seismic waves are amplified in soft alluvial deposits, particularly in the floodplain of the Yamuna and environs, as compared to hard rock or dense soil. Soft soils can also increase the peak ground acceleration by 2 or more times of similar values on hard rock, in addition to increasing the primary frequency of ground motion to the natural frequencies of low to mid-rise buildings. This makes resonance induced damage more likely to occur.

In addition, areas of sandy, loose, saturated soils coupled with a shallow water table are susceptible to liquefaction during heavy ground shaking. Liquefaction can temporarily liquefy the foundations of structures, leading them to settle, tip over and even collapse, depending on how much their bearing capacity is reduced. Due to its close proximity to the Yamuna floodplain influence zone and the overwhelming majority of fill soils that are lightly compacted, the SamaypurBadli area is especially vulnerable to these effects.

3.6 Urban Vulnerability Factors Specific to Study Areas

The research areas' seismic risk is influenced by a variety of urban characteristics in addition to the geological and tectonic background. These include the building stock's age and construction vintage, the frequency of non-engineered and improperly changed structures, the degree of maintenance, the construction density and related pounding risk, land use patterns that result in high occupancy in buildings with structural flaws, and the standard of urban infrastructure, such as utility and drainage systems.

The prevalence of unreinforced masonry in older buildings, the lack of seismic separation between adjacent buildings, the widespread soft-storey condition caused by ground-floor commercial openings in otherwise load-bearing buildings, and the gradual deterioration of structural material quality as a result of poor maintenance and exposure to the chemically aggressive environment of the market area are the main vulnerability factors in Azadpur.

The main issues in the Akshardham area are the RCC frame stock's age, which significantly predates IS 13920's ductile detailing requirements; the existence of short column effects brought on by partial-height infill walls; and the high occupancy of commercial and hospitality buildings that face tourists, which raises the possibility of any structural failure.

Out of the three research locations, SamaypurBadli has the most comprehensive vulnerability profile due to non-engineered construction, unfavourable soil conditions, and a lack of institutional planning control. It is typical to see structures with irregular designs, big and poorly placed wall openings, insufficient foundations, and no reinforcement. Due to the area's industrial and transportation nature, a seismic event might potentially damage vital transportation network that serves a significant portion of outer Delhi.

CHAPTER 4

LITERATURE REVIEW

This chapter reviews key studies on Rapid Visual Screening methodologies and their application to seismic vulnerability assessment, with particular emphasis on studies relevant to Indian urban conditions and the broader development of the RVS field.

4.1 Foundational RVS Methodology — FEMA P-154

The FEMA handbook, FEMA P-154, Rapid Visual Screening of Buildings for Potential Seismic Hazards, is the basis for the standardised procedure for preliminary seismic vulnerability assessment. The methodology involves structural typology, vertical irregularity, plan irregularity, soft-storey, pounding risk, soil and foundation characteristics, construction quality and age of the building. A visual inspection is used to assign a performance score to each structure. Buildings with scores below a specific limit are suggested to be investigated in detail in the structure.

According to FEMA P-154, buildings can be grouped into various structural types: reinforced concrete moment frames, reinforced concrete shear wall structures, masonry bearing wall structures, steel moment frames, timber structures, and precast concrete structures. A base score is assigned to each typology that indicates its expected seismic behaviour and is adjusted using scores for the presence of various vulnerability indicators. The handbook puts particular emphasis on the vulnerability of older buildings built without seismic consideration and gives score penalties. It is used worldwide as a reference for preliminary seismic risk assessment and has inspired the development of adapted methodologies for many other countries, including India.

There are many examples of adapting RVS methodology in India.The RVS methodology is adapted multiple times in India.

Ravi Sinha & Alok Goyal, IIT Bombay has presented a complete national guideline for seismic vulnerability assessment in India based on FEMA 154 and ATC-21. The three-stage process (Rapid Visual Screening, Simplified Vulnerability Assessment and Detailed Vulnerability Assessment) was also customized for the building typologies, construction practices, and seismic conditions in India. The framework highlighted the high number of buildings in Indian urban settlements that were built before the codes were enacted, and their low level of engineering, coupled with the rapid process of urbanisation, had resulted in a large stock of potentially vulnerable buildings. The use of GIS mapping was suggested to allow spatial analyses and prioritisation of vulnerable zones for detailed assessment.

Anand S. Arya worked on the BMTPC guideline for Rapid Visual Screening of masonry and reinforced concrete buildings in India which enabled the adaptation of FEMA 154 procedures to cater for specific construction materials, structural typologies and construction quality variations found in Indian cities. The seismic zones, soil type, number of storeys, plan and vertical irregularities, soft-storey effect, potential for pounding, and compliance with seismic codes were taken into account. The study found that RVS was effective and practical for large-scale vulnerability screening but that the results varied greatly with the experience and training of the assessor.

Sudhir K. Jain and his co-authors have suggested a modified Indian RVS procedure for reinforced concrete frame buildings based on damage data from the 2001 Bhuj earthquake. Their approach also took into account vulnerability factors unique to Indian construction such as conditions in soft storeys, heavy overhangs, short columns due to partial height infill walls, and the impact of poor construction quality on the structure. The procedure was validated on the basis of observed earthquake damage, and had some degree of empirical support, as opposed to merely theoretical.

4.2 Applications to Delhi and Urban India

An important training module to provide training on seismic safety assessment of buildings in Delhi using RVS was prepared by the National Institute of Disaster Management (2012) that showed the high earthquake vulnerability of Delhi due to uncontrolled urbanisation and unauthorised construction. The module highlighted the example of Lalita Park building collapse in 2010 which was a non-seismic event due to poor construction quality as a typical case of structural vulnerabilities in Delhi informal building stock. It said the same weaknesses which led to this failure would be magnified under seismic conditions, with the potential for mass casualties. The module suggested the use of GIS mapping, non-destructive testing, 3D scanning and systematic training for the engineers and planners to develop institutional capacity for continuous vulnerability assessment.

Ravi Kumar and Mukesh Kumar (2025) have reviewed the applications of RVS for buildings in Delhi based on FEMA P-154 and IS 13920. Their analysis revealed that buildings constructed prior to the adoption of the new seismic codes have demonstrated significant deficiencies such as soft storey irregularities, plan irregularities, lack of reinforcement, corrosion of exposed steel and lack of maintenance. The study also examined the possibilities of emerging technologies — AI-based Classification, Drone-assisted Surveys, Mobile App-based Data Collection, GIS integration — in helping to move the future RVS campaign in Delhi forward and to improve consistency in the huge building stock.

4.3 Comparative Studies of RVS Methods

Siddharth and Ajay Kumar Sinha (2022) made a systematic comparison of International RVS methodologies such as FEMA P-154 (USA), Canadian, New Zealand, Italian, Japanese, Eurocode, UNDP, Arya, Sinha and Goyal, BMTPC procedures. These methods were reviewed in terms of seismic vulnerability parameters including load path, soft storey, weak storey, effective mass,

torsion, pounding, prior damage, seismicity level, soil type and design code compliance. The study revealed that the majority of procedures followed a three-tier assessment hierarchy and that FEMA P-154 and the New Zealand procedure provided the most generalizable procedures, while the AI-based and fuzzy logic procedures are promising for further development of RVS tools in future.

Ehsan Harirchian et al. (2020) performed a comparison between FEMA P-154 method, IITK-GSDMA (India) and EMPI (Turkey) methods and observed damage data from the earthquake in Bingöl, Turkey in 2003. The study revealed that FEMA P-154 is prone to overestimate seismic damage and the Indian IITK-GSDMA and Turkish EMPI methods are more regionally calibrated and accurate. This finding highlights the necessity of regional adaptation in the use of RVS procedures and indicates that RVS procedures developed using local earthquake damage data might yield better results for local structures in India.

Guru Prasad Sharma et al. tested RVS in school buildings in Sikkim after the 2011 earthquake, highlighting the practicality of conducting assessments in public buildings in challenging terrain and suggesting that RVS be incorporated as a mandatory requirement in school and hospital buildings that are more than 30 years old. Their work confirmed that their result from the RVS was strongly correlated with detailed analytical vulnerability assessments conducted earlier in Gujarat, Guwahati, Patna and Coimbatore

4.4 Advanced and Emerging Approaches

Shayan Shourabi and Ali Bakhshi (2025) demonstrated that deep learning-based classification of street-view building images using convolutional neural network models such as ResNet, VGG, Inception, and DenseNet can automate RVS classification with accuracy up to 95%, at approximately 17 times the speed of conventional manual screening. This development has significant implications for large-scale urban vulnerability assessment programmes where

the volume of structures to be assessed exceeds the capacity of available trained inspectors. The study emphasised that large labelled image databases and regional validation remain necessary to ensure the applicability of automated models across different construction typologies.

Chaithra Purushothama et al. evaluated the reliability of RVS procedures by comparing their vulnerability predictions with results from nonlinear numerical analysis. The study showed that while RVS provides useful and broadly consistent preliminary assessments, integrating region-specific vulnerability parameters and nonlinear analysis can substantially reduce the uncertainties inherent in empirical scoring systems. Suhail Ishack, Shankha Pratim Bhattacharya, and Damodar Maity of IIT Kharagpur introduced the concept of a Seismic Vulnerability Indicator derived from three-dimensional response spectrum analysis, finding that stiffness irregularity has a more significant effect on seismic vulnerability than mass or geometric irregularity. Their work recommends that future RVS procedures explicitly account for the severity and location of vertical irregularities to improve assessment accuracy for irregular buildings, which are particularly prevalent in India's informal urban construction stock.

CHAPTER 5

METHODOLOGY

5.1 Introduction

Existing buildings' seismic vulnerability assessment requires a systematic, structured and resource-saving method. The approach used in the present research is based on the Rapid Visual Screening (RVS) procedure as outlined in the Federal Emergency Management Agency (FEMA) publication Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook (Third Edition, 2015). This process was developed to detect, list and rank structures that could be destroyed totally or partially during a large earthquake. This process had been developed initially to recognize, name and prioritize structures which may become totally or partially destroyed during a large earthquake.

The methodology of the RVS does not require detailed structural research of individual buildings but offers a practical way for assessing buildings on a large scale. Certified screeners like civil engineers, architects, structural engineers, construction experts and experienced postgraduate students, can use their eyes to determine the likely seismic performance of a building due to their design. The basic premise of the method is that there is a statistically significant relationship between observable physical features and anticipated performance for a rare, high intensity earthquake ground motion.

The two-tier Data Collection Form system is explained in the first section and a detailed description of the Level 1 screening protocol is explored, as is the use of Score Modifiers described in Chapter 3 of FEMA P-154, the optional refinement process described in the Level 2 section with its extended Scoring Modifier framework described in Chapter 4, and the interpretation and application of RVS scores, described in Chapter 5 of the handbook. This structure is similar to the structure of the RVS procedure itself. The conceptof

the Minimum Score (S_min) is discussed in detail because it is crucial to preserve the physical meaning of computed scores.

5.2 Overview of the Rapid Visual Screening Procedure

Relevant seismic performance-related data are recorded by a skilled screener on a standardized Data Collection Form following exterior and sometimes interior (where possible) observations of a building. There is no structural computation done by the screener. Instead, a pre-calibrated scoring system is used to transform visible building characteristics to a numeric indication of probable collapse.

A series of Score Modifiers that take into consideration particular observable characteristics that are known to either improve or worsen a building's projected seismic behavior then modify this Basic Score. The Final Score is the sum of the Basic Score and the Score Modifiers relevant to the rating and is compared to a pre-determined cut-off value to determine if further in-depth analysis is required.

The Data Collection Form is slightly different for each seismicity region, due to the differing construction methods and expected ground shaking across the region.

The Final Level 1 score, S_L1, is the score on the first page of the sidewalk survey (Level 1 form). By include extra structural features that aren't always possible to evaluate from the outside alone, the second page, the optional Level 2 form, offers a more thorough evaluation. Based on the extra data gathered, a Final Level 2 score (S_L2) from the Level 2 form could be higher or lower than a S_L1 score.

5.3 Score Modifiers: Level 1 Screening

The Score Modifiers are numerical additions or subtractions to the Basic Score that represent observed characteristics of a building that can have a positive or negative effect on a building's seismic vulnerability. They will be documented on the pre-printed Building Type and Modifier portion of the FEMA scoring matrix in the Level 1 Data Collection Form by the screener. The building that

is being considered is selected by the screener and the values are circled. The Basic Score is added to any circled modifier values to get the Final Level 1 score.

All the Score Modifiers for the Level 1 form have been carefully developed based on analytical fragility analyses and earthquake performance history. Each modifier can be negative, or positive and the number represents how much the building attribute will either add or subtract to the chance of collapse. A modifier does not apply to a particular FEMA Building Type will be displayed as "N/A" on the form. The explanations for each of the Level 1 score Modifiers are below.

5.3.1 Vertical Irregularity Score Modifier (V)

The Vertical Irregularity Score Modifier, V, reduces any building that has an irregular vertical structure. Favourable conditions for vertical irregularities are where the strength, stiffness or mass of the building does not have a uniform distribution throughout the building height, but rather a significant and sudden change in one or more of these properties, causing concentration of inelastic demands during seismic excitations and increasing the potential for storey-level failure. In FEMA P-154, there are two levels of severity for vertical irregularity and they are each given a different modifier value.

When the screener determines that the vertical irregularity identified is clearly and significantly impacting the seismic performance of the building, then it is deemed to be Severe Vertical Irregularity (Vs). Common severe irregularities are lack of a strong or firm first storey, high level of geometric setback between upper and lower levels and extreme short column or captive column conditions. When the vertical irregularity is there, but is thought to be less pronounced, the Moderate Vertical Irregularity modifier (Vm) is used. For example, the Severity of the Vertical Irregularity modifier is in the range of -0.7 to -1.2 for different building types in the High seismicity region and in the range of -0.4 to -0.7 for different building types in the Moderate seismicity region. In order to avoid over conservatism, if more than one vertical irregularity is detected then only the most severe is considered at the Level 1 stage.

5.3.2 Plan Irregularity Score Modifier (P)

Plan Irregularity Score Modifier (P): This reduces the building score when the building's plan is irregular. Torsional response happens during earthquakes when the plan shape is irregular, and the building is likely to move about a vertical axis instead of move uniformly. This twisting induces seismic demand in certain structural elements, and could cause failure in those elements that may escalate to failure in other elements or the entire structure. The most frequent plan irregularities found in the Level 1 plan are those due to a diaphragm irregularity, such as a placement of an irregular wall, or a re-entrant in a plan, where two sections of the building containing a diaphragm are not parallel, and large openings in a diaphragm where the lateral-resisting elements cannot transmit the lateral forces between the sections.

The Plan Irregularity Score Modifier represents one negative score that will be applied whenever there is one identified plan irregularity in the Irregularities section on the Level 1 form. The values are dependent on FEMA Building Type and Seismicity Region. The values of the P modifier vary from about -0.5 to -1.1 for different types of buildings, depending on the building type and the type of in-plan geometric deficiency, and are applicable to the High seismicity region developed based on analytical fragility analyses and earthquake performance history. Each modifier can be negative or positive and the number represents how much the building attribute will either add or subtract to the chance of collapse. A modifier does not apply to a particular FEMA Building Type will be displayed as "N/A" on the form. The explanations for each of the Level 1 score Modifiers are below.

5.3.3 Pre-Code Score Modifier

Pre-Code Score Modifier is a penalty that is applied to the building that was designed and built before there were seismic design requirements in place and enforced by the applicable jurisdiction for that FEMA Building Type. Buildings built before the first seismic code are typically more susceptible than the average building since they were not designed to resist seismic forces from the side, and were rarely given the ductile detailing to ensure acceptable

performance under seismic loading. Using this modifier, the screener will compare the year the building was built or the year the code is known to have been in use (if it is not the same as the year it was built) to the pre-code year listed in the Quick Reference Guide created in the pre-field planning phase. If the year built is prior to the year of the building type in the jurisdiction being screened, the Pre-Code Score Modifier is circled on the Scoring Matrix. In Low seismicity regions, this modifier is not be used for buildings as the Basic Scores in the Low seismicity region are already based on the assumption that there are no seismic design requirements. The values for the Pre-Code modifier for High seismicity range from about -0.6 to -1.1 for the different FEMA Building Types.

5.3.4 Post-Benchmark Score Modifier

The Post-Benchmark Score Modifier is a bonus that will be applied to buildings designed and constructed since an important upgrade to the applicable seismic design provisions. Typically, the improvements derive from major seismic design philosophy shifts, including new ductile detailing requirements, new design standards for connections, or more conservative analysis procedures. The "benchmark" year is the year that these seismic provisions make significant improvements. The screener checks the applicability by comparing the year built or code year to the benchmark year in the Quick Reference Guide. If the building was constructed in the same year or after the benchmark year, then the Post-Benchmark Score Modifier is applied to the building. The value of this modifier is always positive and indicates the enhanced expected seismic performance of structures design to more advanced codes. One of the largest positive adjustment factors in the scoring system, the post-benchmark modifier values are generally between +1.4 and +2.4, depending on the FEMA Building Type in the High seismicity region.

5.3.5 Soil Type Score Modifiers

The Level 1 form contains two Soil Type Score Modifiers: one for Soil Type A or B (hard rock and rock), and two for Soil Type E (soft soil) one for

buildings of 3 or fewer storeys and the other for buildings of more than 3 storeys. These modifiers reflect the impact of local conditions on the intensity of ground shaking which is experienced by the building. Buildings on hard rock (Soil Types A or B) exhibit less ground shaking amplification than the average predicted by the Basic Score).As a result, the Soil Type A or B modifier is positive, indicating less seismic

demand. For low frequencies, the ground shaking in buildings built on top of soft soil (Soil Type E) is significantly higher, particularly for higher and more flexible buildings. The Soil Type E penalty increases with the building height, which is greater than three stories. Soil Types C and D are not modified since Basic Scores are adjusted for those situations. The soils in Soil Type F are liquefiable or otherwise problematic, and have no numerical modifier, but rather are identified as a geologic hazard, requiring Detailed Structural Evaluation.

5.4 Minimum Score, S_min

The main limitation of any of the additive scoring systems is that the algebraic sum of numerous modifiers could be negative. In the context of RVS process, a negative score would mean that there is a higher than 100% probability of collapse, which is physically impossible. If the multiple unfavourable score modifiers, such as a pre-code building constructed on soft soil, with a significant vertical irregularity and a significant plan irregularity, were to sum in the score, the result could be below the Basic Score in magnitude. To solve this problem, FEMA P-154 suggests using the Minimum Score, which is abbreviated as S_min. This is the minimum physically defensible Final Score for each FEMA Building Type in each Seismicity Region. It is determined based on the worst combination of soil type conditions, vertical irregularities, plan irregularities and building age (pre-code). The Minimum Score is pre-printed on the bottom line of the scoring matrix for the FEMA Building Types and seismicity areas for Level 1 Data Collection Form. The basic rule for its use is: Once you've added the Basic Score and all the circled Score Modifiers you'll know if the total is below S_min or not. If the sum is less than the Final

Level 1 Score, the sum is replaced by the Final Level 1 Score, SL1. When the raw sum is equal to or greater than S_min then SL1 is the raw sum. This will always guarantee that the final score is not less than some value that has a clear physical meaning, relating to the probability of collapse. The published values of S_min vary from 0.2 to 1.1 in the High seismicity zone depending on the type of the building, and illustrate the inherent differences in the worst-case seismic performance between the different structural systems. The Minimum Score concept is particularly important for unreinforced masonry and pre-code concrete structures as the severity of the negative modifiers is likely to yield very low or negative scores.

5.5 Determining the Final Level 1 Score and Action Decision

The ruling result of the primary screening stage is the Final Level 1 Score (SL1).It is determined on-site by the screener when adding the Basic Score to any circled Score Modifiers from the Level 1 scoring matrix to arrive at the Minimum Score for the specific FEMA Building Type. The greater of the two is called SL1.The Final Score is compared with the RVS Authority's declared cut-off score for the screening programme. The proposed default cut-off number in FEMA P-154 is 2.0, which has been defined as an acceptable level of collapse probability based on studies of the seismic performance of existing buildings during MCE ground shaking. If the Final Score is above the cut-off, the building is considered to be sufficiently seismically resistant and does not need to take further action to meet the RVS requirements. Buildings having a Final Score equal to or less than the cut-off are considered potentially seismically hazardous and are sent to a certified structural engineer with seismic design experience for a Detailed Structural Evaluation. The presence of circumstances which, even if the score computed, do not require Detailed Structural Evaluation, are recorded in the "Other Hazards" box in the Level 1 form. These are where the building gap to the adjacent building is less than 1% of the shorter building's height, the adjacent building is higher and presents a falling hazard, geologic hazards or Soil Type F, or where there is significant

visible evidence of damage or deterioration. Presence of any of these problems, irrespective of the Final Level 1 Score, requires referral for further evaluation

5.6 Level 2 Optional Screening: Extended Modifier Framework

A briefing was presented to FEMA P-154 at the Third Edition that added an optional Level 2 screening technique that would allow for a more refined and accurate assessment with very little additional screening time or resources. The conservatism required in Level 1 screening can lead to a high number of buildings being submitted for Detailed Structural Evaluation, but can also lead to overlooking a potentially hazardous building. The Level 2 technique enables a more seasoned screener to revisit such buildings, and use some extra, more specific, modifier statements to give a score more accurately reflecting the building's "real" risk. The Final Level 2 Score (SL2) is the result of the Level 2 screening. This score could be higher, lower or the same as SL1.A civil engineer, structural engineer, architect or graduate student who has background in seismic evaluation or structural design should complete the Level 2 form. The extra expertise is needed as some of the Level 2 modifier statements call for a degree of technical skill which exceeds visual assessment.

5.6.1 Adjusted Baseline Score

The Adjusted Baseline Score (S') is the score that the screener calculates prior to adding the Level 2 Score Modifiers. It is the difference between Final Level 1 Score (SL1) and the Level 1 Vertical Irregularity modifier (VL1) and the Level 1 Plan Irregularity modifier (PL1).This change is aimed at eliminating the "noisy" Level 1 irregularity modifiers and their replacement by more precise Level 2 modifiers.S' = SL1 + VL1 + PL1 is the governing equation. Note, however, that the Minimum Score is not used when determining the value of S prime; rather, the algebraic sum of the Basic Score and any Level 1 modifiers is used as the starting value.

5.6.2 Level 2 Vertical Irregularity Score Modifier (VL2)

The Vertical Irregularity assessment, Level 2, is more than a simple binary (severe/moderate) classification as is the Level 1 assessment. The Level 2 form includes a comprehensive list of specific statements for vertical irregularity with Score Modifier numbers. Each statement is checked in the building being evaluated by the screener, with the modification circled if it applies, and the statement crossed out if it does not apply or is not true. The Level 2 vertical irregularity statements cover a wide range of conditions, including: sloping site conditions causing a full-storey grade change from one side to the other; the presence of a cripple wall or open front condition in W1-type buildings; soft storey conditions defined by specific ratios of storey lateral stiffness relative to adjacent storeys; setback conditions where upper storey lateral elements cantilever beyond lower elements; and short column or pier con The sum of all available vertical irregularity modifiers is limited by a cap, VL2, which is indicated on the Level 2 form and varies by seismicity zone. This cap is to stop too many vertical penalties being applied that do not really deserve to be given.

5.6.3 Level 2 Plan Irregularity Score Modifier (PL2)

The Level 2 Plan Irregularity assessment is more detailed than the one modifier used at Level 1.Specific plan irregularity criteria for the Level 2 form include: the lateral system does not seem to be well-distributed or well-balanced in plan (torsional irregularity); one or more major vertical features of the lateral system are not orthogonal to each other (non-parallel systems); both projections from an interior corner are more than twenty-five percent of the overall plan dimension in either direction (re-entrant corner conditions).“Plan irregularity modifier” is also included in the cap for PL2 cap.

5.6.4 Additional Level 2 Score Modifiers

In addition to the larger irregularity modifiers, there are many new irregularity modifiers that are not listed in the Level 1 screening. Positive adjustment applied when the building contains at least two bays of lateral elements on each side in each direction, and the seismic force-resisting system is sufficiently redundant to provide load transfer in case of failure of some of its elements.

The Pounding modifier is a negative adjustment due to separation of less than 1 percent of the shorter building's height. A result of the out-of-phase horizontal movements of adjacent buildings, pounding can occur during an earthquake and cause serious damage in specific regions.

The Building Type Specific modifier statements are also included on the Level 2 form, and apply only to the FEMA Building Types that are applicable to them. For instance, a negative modifier is for S2-type buildings that exhibit K-bracing geometry that is susceptible to buckling and collapse at an early age. A negative modifier is related to the punching shear failure in flat plate construction in C1-type buildings. For PC1 and RM1 type buildings with roof-to-wall ties, positive modifiers are given. A positive Retrofit modifier is provided when an adequate seismic retrofit was observed or documented on drawings, to show a significantly higher seismic capacity. The Level 2 Final Score, SL2, equals the sum of the subtotal, M, of all the other Level 2 modifiers plus S', VL2, and PL2, with S_L2 being at least equal to S_min.

5.7 Interpretation and Application of RVS Scores

An important aspect to the usefulness of the procedure is the interpretation of the Final RVS Score, S, which is used for either SL1 or SL2.The final result is not an arbitrary index, but instead is based on probabilistic seismic performance theory, as per FEMA P-154.It calculates the probability of collapse of the building during the ground motion that is considered for the risk targeted Maximum Considered Earthquake (MCE_R) for the site.

5.7.1 Physical Meaning of the Final Score

The RVS is measured on a logarithmic scale.If a Final Score is S = 3, then a collapse chance of 1 in 10^3 (or 1 in 1,000) is estimated, assuming MCE_R-level ground shaking.If S = 2, then under the same conditions there is a 1 in 10^2 chance of collapse.S = 1 means that the chances of collapsing are 1 in 10, or 10%.In this sense, each unit drop in the score would cause the conditional collapse probability to be multiplied by 10, and thus the score is a meaningful

and compact representation of the relative seismic risk for a very large building portfolio.

$$\text{Probability of Failure} = 10^{-S}$$

The score considers the likelihood of partial or complete structural collapse; that is, when the gravity load-carrying system (gravity beams, gravity columns, gravity floors, and gravity shear walls) is no longer able to support the loads it carries and its own weight. This failure is characterised by major structure deformation that can be life threatening, causing the real collapse of the whole structure or parts thereof. The score does not reflect the chances of the building being damaged; it also doesn't take into account the chances of the building being habitable or functional following the earthquake.

5.7.2 Selection of the Cut-Off Score

The cut-off score is the lowest score that signals that a building may pose a potential seismic hazard, and that it should be considered for Detailed Structural Evaluation. The selection of a cut-off score is essentially a policy decision with safety and assessment/rehabilitation costs considered. The higher the cut-off value, the more buildings will be identified for further study, resulting in more costs and disruption to the community, and less chance that a truly hazardous building could be missed. A lower cut-off value will lead to a lower number of buildings to be reviewed and a higher risk of susceptible buildings being missed.

A value of 2.0 is a reasonable default using research on the acceptable level of collapse risk for existing buildings from the studies conducted by the National Bureau of Standards and more recent research under the FEMA P-695 framework that quantifies building seismic performance factors. In this criterion, buildings whose conditional collapse probability is 1% or less under MCE shaking are deemed to be acceptable. If a building does not meet this criterion, it is referred for further assessment. The cut-off value could be changed depending on the screening programme's objectives, the risk level, and available resources, as determined by the RVS Authority.

5.7.3 Role of S_{min} in Score Interpretation

The purpose of the Minimum Score, S_min, is not to prevent negative numbers from being computed. The second way from an interpretive perspective, S_min is used as a "floor" on the physical meaning of the scoring system. Due to the purpose of the Minimum Score, S_min, is not to prevent negative numbers from being computed. The second way from an interpretive perspective, S_min is used as a "floor" on the physical meaning of the scoring system. Due to the independent development of Score Modifiers, applying more than one at a time to the same structure may overestimate the overall penalty. The Minimum Score, which is determined in the combined analytical framework by considering all adverse variables, gives a more accurate lower limit on the estimated collapse probability for the worst case scenario for each building type.

If the computed score is equal to S_min, it suggests to the evaluator that the building has a mix of negative attributes that make it more vulnerable in its structural type than any other building. In practice, these buildings are almost always under 2.0 Final Score, and are obvious candidates for early Detailed Structural Evaluation. The idea of S_min enhances the interpretability of the RVS score as a meaningful indicator of risk for collapse and also ensures that the numerical stability of the scoring system independent development of Score Modifiers, applying more than one at a time to the same structure may overestimate the overall penalty. The Minimum Score, which is determined in the combined analytical framework by considering all adverse variables, gives a more accurate lower limit on the estimated collapse probability for the worst case scenario for each building type. If the computed score is equal to S_min, it suggests to the evaluator that the building has a mix of negative attributes that make it more vulnerable in its structural type than any other

building. In practice, these buildings are almost always under 2.0 Final Score, and are obvious candidates for early Detailed Structural Evaluation. The idea of S_min enhances the interpretability of the RVS score as a meaningful

indicator of risk for collapse and also ensures that the numerical stability of the scoring system.

5.8 Fieldwork Protocol Adopted in the Present Study

The process of the fieldwork involved conducting the study in alignment with the procedures described in FEMA P-154, but with some modifications based on the local regulatory framework, available pre-field data sources, and the nature of the building inventory being studied. A pre-field planning phase was done to determine the seismicity region appropriate for the study area, identify the most likely building types that would be encountered in the jurisdiction and ensure the pre-field planning guide was tailored with the appropriate pre-code and benchmark years for those building types.

The Level 1 Data Collection Form relevant to the seismicity region was used for field surveys. Approaches to each building were made on the sidewalk and all sides of the exterior. People are unwilling to allow any authority to enter their homes, hence no inside check was performed. Photographs were taken of each building. The FEMA Building Type was identified from the exterior appearance of the structural system and based on construction records, assessor's data, or building permits available.

Vertical irregularity, plan irregularity, pre-code, post-benchmark, and soil type were applied to each building, in a systematic manner. The modifiers were applied and the value added to the Basic Score and the result compared to the pre-printed S_min for the identified building type. The Final Level 1 Score was recorded and the Action Required section of the form completed to determine if Detailed Structural Evaluation was required. Buildings having a Final Score of 2.0 or lower, along with other factors that were triggering a “Other Hazard” were sent to a trained structural engineer for a detailed investigation.

5.9 Limitations of the Methodology

The RVS process offers significant benefits in terms of speed, cost, and scale, but also has inherent limitations that should be taken into account when interpreting results from any study using the RVS process. The technique is

supposed to be done from the sidewalk and many key structural components are not discernible from the exterior of the building. There are many important attributes that cannot be determined by visual inspection without access to the interior or an interior review of the structural drawing, such as ductile reinforcing details in concrete columns, the quality of beam-column connections, the presence and quality of shear keys/anchorage in precast systems, and the level of deterioration in concealed structural members. The Basic Scores and Score Modifiers are statistics averages derived from analytical research and earthquake performance history of large populations of structures. They indicate typical performance but don't show the actual distribution of performance. The building's performance may be significantly above or below the RVS score, depending on the actual construction features that differ from the average that the RVS would predict. The method is therefore explicitly presented as a preliminary screening tool to prioritise buildings for further examination and not to replace it.Moreover, the method was developed and standardized primarily for buildings in the USA and the immediate implementation of the technique for buildings in other countries such as India requires careful consideration of local building practices, regulations, and material quality standards. The present study accepts these limitations and reports the results accordingly. The present study does not measure seismic safety but uses RVS ratings as a relative indication of seismic vulnerability within the inventory of the present study.

CHAPTER 6

RESULTS AND TABLES

6.1 Building I – Case Study On G+2 Storied Moment Resisting Frame Type residential building situated in Akshardham D park Road, New Delhi

Table 6.1

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") Soil Type D (as per "FEMA 154,2015")	-
C)	Type of Building	According to construction materials and type of building, the building is classified as Concrete Moment-Resisting Frame Building (C1), as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the building was constructed in 2018 and is therefore approximately 7 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark.	-
	Basic Score	Basic score as per FEMA guidelines for C1 type of structure.	Basic score = 1.5
	Plan Irregularity	No significant plan irregularity was observed during the visual inspection. The building appears regular in plan with no re-entrant corners, excessive offsets, or torsional irregularities.	PL1=0
	Vertical Irregularity	The structure does not exhibit vertical irregularities such as soft storey, weak storey, setback, or discontinuity in vertical load resisting elements.	VL1=0
	Post Benchmark	Age of building is 9 years. Hence, a positive score modifier of Post Benchmark will be added.	Post Benchmark = 1.9
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.5 + 1.9 = 3.4	It is very high than the minimum value i.eSmin=0.3
Level 2			
G)	Baseline score, S'	S' = 3.4	-

H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity	VL2 = 0
	Plan Irregularity, PL2	No planar irregularity	PL2 = 0
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 3.4 + 0 + 0 + 0 + 0 = 3.4	S = 3.4
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-3.4 Probability of failure = 0.000398	Building has 1 in 2512 chances of being failed under MCE shaking.
K)	Conclusion	No requirement of Detailed Structural evaluation.	-

6.2 Building II – Case Study On G+2 Storied Moment Resisting Frame with masonry infill wall Type Government residential building situated in Delhi Jal board colony, near Azadpur Metro Station New Delhi

Table 6.2

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+2 Concrete Moment-Resisting Frame Building (C3) with infill walls, as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the approximate year of construction is between1975- 1979 and is therefore approximately 45-50 years old.	

E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark + Pre code.	-
	Basic Score	Basic score as per FEMA guidelines for C3 type of structure.	Basic score = 1.2
	Plan Irregularity	No significant plan irregularity could be identified based on the available exterior visual inspection.	PL1=0
	Vertical Irregularity	The building exhibits moderate vertical irregularity due to variation in façade geometry and discontinuity in elevation profile. However, no severe soft-storey or major vertical discontinuity was observed during visual inspection.	VL1=-0.4
	Pre Code	Age of building is 45-50 years. Hence, a negative score modifier of Pre code will be added.	Pre code =-0.1
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.2-0.4-0.1 = 0.6	It is very close to the minimum value i.e. Smin=0.3
Level 2			
G)	Baseline score, S’	S’ = 0.6	-
H)	Score modifiers		
	Vertical Irregularity, VL2	The structure exhibits moderate vertical irregularity due to irregular elevation geometry and discontinuity in the arrangement of vertical structural elements.	VL2 = -0.5
	Plan Irregularity, PL2	No significant plan irregularity was observed during the exterior visual inspection of the structure	PL2 = 0
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S’ - VL2 - PL2 + R1 + R2 SL2 = 0.6– 0.5 + 0 + 0 = 0.1	S = 0.1 which is lower than the minimum value defined in FEMA guidelines i.e. Smin=0.3

J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-0.1 Probability of failure = 0.794	Building has 1 in 1.25 chances of being failed under MCE shaking.
J)	Conclusion	As the RVS score is below the critical value hence the structure is recommended for detailed investigation.	Structure is vulnerable to seismic activity.

6.3 Building III – Case Study On G+4 Storied Moment Resisting Frame with masonry infill wall Type Government residential building situated in Delhi Jal board colony, near Azadpur Metro Station New Delhi

Table 6.3

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+3 Concrete Moment-Resisting Frame Building (C3) with masonry infill walls, as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the approximate year of construction is between1975- 1979 and is therefore approximately 45-50 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark + Pre code.	-
	Basic Score	Basic score as per FEMA guidelines for C3 type of structure.	Basic score = 1.2
	Plan Irregularity	No significant plan irregularity could be identified based on the available exterior visual inspection.	PL1=0
	Vertical Irregularity	The structure exhibits severe vertical irregularity due to the presence of an open ground storey, resulting in	VL1=-0.7

		possible soft-storey behaviour and discontinuity in stiffness along the building height	
	Pre Code	Age of building is 45-50 years. Hence, a negative score modifier of Pre code will be added.	Pre code =-0.1
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.2-0.7-0.1 = 0.4	It is very close to the minimum value i.eSmin=0.3
Level 2			
G)	Baseline score, S'	S' = 0.4	-
H)	Score modifiers		
	Vertical Irregularity, VL2	The structure exhibits severe vertical irregularity due to irregular elevation geometry and open storey at the base level	VL2 = -0.9
	Plan Irregularity, PL2	No significant plan irregularity was observed during the exterior visual inspection of the structure	PL2 = 0
	Retrofit, R2	Retrofitting work is on going	R2 = 1.4
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 0.4 – 0.9 + 1.4 + 0 = 0.9	S = 0.9 which is lower than the minimum value defined in FEMA guidelines i.e. Smin=0.3
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-0.9 Probability of failure = 0.125	Building has 1 in 8 chances of being failed under MCE shaking.
J)	Conclusion	No requirement of Detailed Structural evaluation.	-

6.4 Building IV – Case Study On G+3 Storied Moment Resisting Frame with masonry infill wall Type residential building situated in New Ashok Nagar, near Akshardham Metro Station, New Delhi

Table 6.4

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+3 Concrete Moment-Resisting Frame Building (C3) with masonry infill walls, as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the approximate year of construction is between2014 and is therefore approximately 12 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark + Pre code.	-
	Basic Score	Basic score as per FEMA guidelines for C3 type of structure.	Basic score = 1.2
	Plan Irregularity	No significant plan irregularity could be identified based on the available exterior visual inspection.	PL1=0
	Vertical Irregularity	No significant vertical irregularity affecting seismic performance was observed during the detailed visual inspection.	VL1=0
	Post Benchmark	Age of building is 14 years. Hence, a positive score modifier of Post Benchmark will be added.	Post Benchmark = 1.9
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.2+0+0+1.4 = 2.6	It is very high than the minimum value i.eSmin=0.3
Level 2			
G)	Baseline score, S'	S' = 2.6	-
H)	Score modifiers		

	Vertical Irregularity, VL2	No Vertical irregularity	VL2 = 0
	Plan Irregularity, PL2	No Planner irregularity	PL2 = 0
	Retrofit, R2	No retrofitting	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 2.6+0+0+0 = 2.6	S=2.6
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-2.6 Probability of failure = 0.0025	Building has 1 in 400 chances of being failed under MCE shaking.
J)	Conclusion	No requirement of Detailed Structural evaluation.	-

6.5 Building V – Case Study On G+4 Storied Moment Resisting Frame with masonry infill wall Type Residential building situated near Azadpur metro Station, New Delhi

Table 6.5

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+4 Concrete Moment-Resisting Frame Building (C3) with infill walls, as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the approximate year of construction is 2019 and is therefore approximately 7 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark + Pre code.	-

	Basic Score	Basic score as per FEMA guidelines for C3 type of structure.	Basic score = 1.2
	Plan Irregularity	No significant plan irregularity could be identified based on the available exterior visual inspection.	PL1=0
	Vertical Irregularity	The structure exhibits moderate vertical irregularity due to partial openness at the ground storey causing variation in stiffness along the height of the building.	VL1=-0.5
	Post Benchmark	Age of building is 7 years. Hence, a positive score modifier of Post Benchmark will be added.	Post Benchmark = 1.9
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.2-0.5+0+1.4 = 2.1	It is higher than the minimum value i.eSmin=0.3
Level 2			
G)	Baseline score, S'	S' = 2.1	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Detailed visual inspection indicates moderate vertical irregularity due to non-uniform distribution of stiffness and partial discontinuity in vertical structural configuration.	VL2 = -0.5
	Plan Irregularity, PL2	No Planner irregularity	PL2 = 0
	Retrofit, R2	No retrofitting	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 2.1-0.5+0+0 = 1.9	S=1.9
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-1.9 Probability of failure = 0.0125	Building has 1 in 80 chances of being failed under MCE shaking.
K)	Conclusion	No requirement of Detailed Structural evaluation.	-

6.6 Building VI – Case Study On G+3 Storied Moment Resisting Frame with masonry infill wall Type Residential building situated near Tagore Park, Model Town, New Delhi

Table 6.6

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+3 Concrete Moment-Resisting Frame Building (C3) with infill walls, as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the building was constructed in 2021 and is therefore approximately 5 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark.	-
	Basic Score	Basic score as per FEMA guidelines for C1 type of structure.	Basic score = 1.2
	Plan Irregularity	No significant plan irregularity was observed during the visual inspection. The building appears regular in plan with no re-entrant corners, excessive offsets, or torsional irregularities.	PL1=0
	Vertical Irregularity	The structure does not exhibit vertical irregularities such as soft storey, weak storey, setback, or discontinuity in vertical load resisting elements.	VL1=0
	Post Benchmark	Age of building is 5 years. Hence, a positive score modifier of Post Benchmark will be added.	Post Benchmark = 1.9
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.2 + 1.9 = 3.1	It is very high than the minimum value i.eSmin=0.3

Level 2			
G)	Baseline score, S’	S’ = 3.1	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity	VL2 = 0
	Plan Irregularity, PL2	No planar irregularity	PL2 = 0
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S’ - VL2 - PL2 + R1 + R2 SL2 = 3.1+ 0 + 0 + 0 = 3.1	S = 3.1
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-3.1 Probability of failure = 0.000794	Building has 1 in 1260 chances of being failed under MCE shaking.
K)	Conclusion	No requirement of Detailed Structural evaluation.	-

6.7 Building VII – Case Study On G+1 Storied Unreinforced Masonry residential building situated in Delhi Jal board colony, near Azadpur Metro Station New Delhi

Table 6.7

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per “IS 1893:2016”) High Seismic zone (as per “FEMA 154, 2015”)	-
B)	Type of soil	Medium Soil category (as per “IS 1893:2016”) “Soil Type D” (as per “FEMA 154,2015”)	-
C)	Type of Building	The building is a G+1 Unreinforced Masonry Building (URM), as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the building was constructed in between 1975	

		-1979 and is therefore approximately 45 to 50 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark.	-
	Basic Score	Basic score as per FEMA guidelines for URM type of structure.	Basic score = 1
	Plan Irregularity	No significant plan irregularity was observed during the visual inspection. The building appears regular in plan with no re-entrant corners, excessive offsets, or torsional irregularities.	PL1=0
	Vertical Irregularity	The structure exhibits moderate vertical irregularity due to non-uniform elevation profile and discontinuity in the vertical structural configuration.	VL1=-0.4
	Pre code	Age of building is 45-50 years, it means that the building has not been planned according to the modern seismic codes.	
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1-0.4= 0.6	It is very close to the minimum value i.e. Smin=0.3
Level 2			
G)	Baseline score, S'	S' = 0.6	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Detailed visual inspection indicates moderate vertical irregularity due to irregular wall configuration and non-uniform stiffness distribution along the height of the structure	VL2 = -0.5
	Plan Irregularity, PL2	No significant plan irregularity was identified during detailed visual inspection.	PL2 = 0
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 0.6-0.5= 0.1	S = 0.1

J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-0.1 Probability of failure = 0.794	Building has 1 in 25 chances of being failed under MCE shaking.
K)	Conclusion	Although irregularity modifiers are moderate, the structure itself appears highly vulnerable because ofold masonry construction,visible deterioration, weathering,possible weak mortar and poor seismic detailing.	So building is considered highly vulnerable to seismic event

6.8 Building VIII – Case Study On G+2 Storied Moment Resisting Frame Type Government residential building situated in Delhi Jal board colony, near Azadpur Metro Station New Delhi

Table 6.8

RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+1 Concrete Moment-Resisting Frame Building (C1), as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the building was constructed in 1975-1979 and is therefore approximately 45 to 50 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark+ Precode.	-
	Basic Score	Basic score as per FEMA guidelines for C1 type of structure.	Basic score = 1.5
	Plan Irregularity	No significant plan irregularity was observed during exterior visual inspection	PL1=0

	Vertical Irregularity	The structure exhibits moderate vertical irregularity due to non-uniform elevation configuration and variation in stiffness along the height of the building.	VL1=-0.5
	Pre Code	Based on visual inspection and apparent construction characteristics, the building is estimated to be approximately 40 years old and belongs to the pre-modern seismic code era.	Pre code = -0.4
F)	Final Level 1 Score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1.5–0.4-0.5= 0.8	It is very close to the minimum value i.eSmin=0.3
Level 2			
G)	Baseline score, S'	S' = 0.8	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Moderate vertical irregularity is present	VL2 = -0.5
	Plan Irregularity, PL2	No planar irregularity	PL2 = 0
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 Score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 0.8-0.5 = 0.3	S = 0.3
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^-0.3 Probability of failure = 0.50	Building has 1 in 2 chances of being failed under MCE shaking.
K)	Conclusion	Although the obtained RVS score is comparatively low, the building is an old structure belonging to the pre-code construction era. Due to aging, material deterioration, and lack of modern seismic detailing provisions, the structure may still exhibit considerable seismic vulnerability.	Higly Vulnerable to Seismic activity

6.9 Building IX – Case Study On G+2 Storied Unreinforced Masonry residential building situated in Slums of SamaypurBadli, New Delhi

Table 6.9

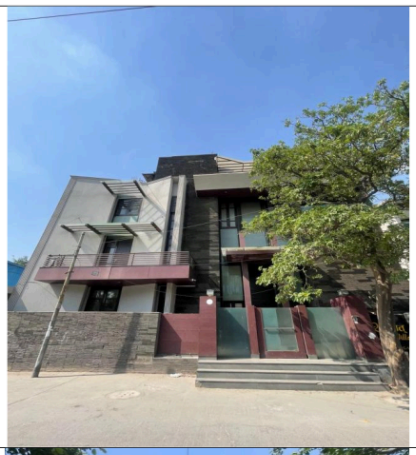
RVS	Parameter	Observation / Description	Remarks
Level 1			
A)	Seismic Zone of the Building	Zone IV (as per "IS 1893:2016") High Seismic zone (as per "FEMA 154, 2015")	-
B)	Type of soil	Medium Soil category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Type of Building	The building is a G+2 Unreinforced Masonry Building (URM), as per FEMA 154, 2015.	-
D)	Age of the Building	According to the available data, the building was constructed in 2022 and is therefore approximately 4 years old.	
E)	Formula for Level 1 Evaluation	SL1 = Basic Score + VL1 + PL1 + Post benchmark.	-
	Basic Score	Basic score as per FEMA guidelines for URM type of structure.	Basic score = 1
	Plan Irregularity	The structure exhibits plan irregularity due to asymmetric wall arrangement and irregular configuration of structural elements.	PL1=-0.4
	Vertical Irregularity	The structure exhibits moderate vertical irregularity due to discontinuity in vertical structural configuration and non-uniform stiffness distribution along the height.	VL1=-0.4
	Pre code	Although the building was constructed in 2022, the structure appears to have been constructed without proper seismic code provisions and engineered detailing. Hence, for preliminary seismic vulnerability assessment, the building may be considered to exhibit pre-code construction characteristics.	

F)	Final Level 1 score (SL1)	SL1 = Basic Score + VL1 + PL1 + Post benchmark SL1 = 1-0.4-0.4= 0.2	It is very close to the minimum value i.e. Smin=0.3
Level 2			
G)	Baseline score, S'	S' = 0.2	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Detailed visual inspection indicates moderate vertical irregularity due to discontinuous masonry configuration and variation in stiffness along the height of the structure	VL2 = -0.5
	Plan Irregularity, PL2	Detailed visual inspection indicates plan irregularity due to asymmetric arrangement of masonry walls and irregular structural configuration.	PL2 = -0.7
	Retrofit, R2	Retrofitting (not observed)	R2 = 0
I)	Final Level 2 score (SL2)	SL2 = S' - VL2 - PL2 + R1 + R2 SL2 = 0.2-0.5-0.7 = 0	S = 0
J)	Probability of failure (P)	Probability of failure = 10^-S Probability of failure = 10^0 Probability of failure = 1	Building has 100 % chances of being failed under MCE shaking.
K)	Conclusion	The building exhibits considerable seismic vulnerability due to irregular masonry configuration, lack of proper engineered seismic detailing, and non-uniform structural arrangement. Although the structure was reportedly constructed in 2022, visual inspection indicates that proper seismic code provisions and construction practices may not have been adequately followed. Moderate vertical and plan irregularities were observed during the RVS assessment, which may adversely affect the seismic performance of the structure during strong ground motion.	Building is considered highly vulnerable to seismic event

		Therefore, a detailed structural evaluation is recommended to assess the structural safety and seismic adequacy of the building	

6.10 Combined Result Table

Table 6.10

Building Number	Front View of Building	Chances of failure
1		Building has 1 in 512 chances of being failed under MCE shaking.
2		Building has 1 in 325 chances of being failed under MCE shaking

3		Building has 1 in 8 chances of being failed under MCE shaking.
4		Building has 1 in 100 chances of being failed under MCE shaking.

5		Building has 1 in 80 chances of being failed under MCE shaking.
6		Building has 1 in 260 chances of being failed under MCE shaking

7		Building has 1 in 25 chances of being failed under MCE shaking
8		Building has 1 in 2 chances of being failed under MCE shaking.

9		Building has 100 % chances of being failed under MCE shaking.

6.11 Rapid Visual Screening — Location 1

Samaypur Badli Metro Station Area | North Delhi | Seismic Zone IV (IS 1893:2016)

6.11.1 Overview and Study Area Description

The Samaypur Badli metro station area, located on the Yellow Line (Line 2) of the Delhi Metro Rail Corporation network in the northernmost reach of Delhi, forms the first study location in this Rapid Visual Screening exercise. Photographs were taken from an elevated vantage point — either the metro station platform or an adjacent elevated structure — providing both a wide panoramic view of the settlement morphology and a series of closely zoomed images capturing fine-grained structural details of individual buildings.

The wide-angle photograph (Samaypur.jpeg) reveals a densely packed residential fabric extending across the entire field of view, with virtually no open spaces, parks, or planned setbacks visible. The settlement is characterised by a mosaic of building types: multi-storey reinforced masonry blocks with flat roofs in the mid-ground, single- and double-storey informal brick structures in the foreground and scattered taller apartment blocks rising above the general roofline in the background. The dominant rooftop feature is an extraordinary concentration of white and blue plastic water storage tanks — in some sections barely a square metre of rooftop is visible without a tank occupying it — along with satellite dishes, antenna poles, and makeshift rooftop enclosures. The tree canopy, while present, is sparse relative to the density of structures, with individual trees visible at plot edges and along lane margins.

The social geography of this area is characteristic of a Delhi urban village (lal dora) that has been progressively engulfed by the expanding city, retaining its organic, unplanned character while accommodating increasingly dense habitation. Land subdivision has occurred informally over generations, resulting in an extremely fine-grained plot structure where individual plots of 25–60 square metres carry buildings of three to five storeys, creating floor-area ratios far in excess of what any formal planning regulation would permit. This extreme densification has been achieved entirely through informal construction with no structural engineering oversight.



Figure 7 Wide angle view of slums near Samaypur Badli Metro Station

6.11.2 Building Description — Physical Characteristics

Zoomed out photographs corresponding to Location provide detailed structural information. The images capture the densely packed informal slum-type construction in the immediate foreground, while zoomed in photograph focuses on an individual brick structure with a blue painted frontage, and the image showing the Meat Shop provides a street-level close-up of a typical two-storey load-bearing masonry commercial-residential building. Together, these images allow a comprehensive structural characterization of the building stock.



Figure 8 Close up view of conventional unreinforced brick masonry structures in the area

Observed Feature	Detailed Observation from Zoomed Images
Wall Material — Exposed Brick Construction	The dominant wall construction across the zoomed images is exposed, unplastered fired clay brick laid in a running bond or English bond pattern. The bricks are of inconsistent quality — some appear well-fired and dimensionally regular, while others show surface crumbling, edge erosion, and colour variation indicative of underfiring or salvaged reuse. The absence of any external plaster or render on the majority of structures means that the mortar joints are directly exposed to Delhi's extreme climate: the wet monsoon months (June–September) saturate the joint, and the dry hot season (April–June, 40–48°C) drives out moisture rapidly, causing cyclic swelling and shrinkage that progressively erodes mortar cohesion.
Wall Thickness and Structural Configuration	Wall thicknesses across the study area appear to range from half-brick (approximately 115mm) in partition and extension walls to single-brick (approximately 230mm) in main structural walls. In the taller three- to four-storey buildings visible in the picture , this wall thickness is grossly inadequate for seismic Zone IV. IS 4326:2013 recommends a

Observed Feature	Detailed Observation from Zoomed Images
	minimum wall thickness of 350mm for load-bearing masonry buildings above two storeys in Zone IV, and mandates horizontal reinforcing bands at plinth, lintel, and roof levels. None of these provisions are evident in the buildings observed. The walls act as the sole structural element — there is no RC frame visible in the slum fabric — making out-of-plane wall failure under lateral seismic forces virtually inevitable.
Rooftop Condition — Meat Shop Building	The close-up image of the Meat Shop photograph provides one of the clearest views of rooftop loading in this study. The single-storey commercial building (with a habitable upper floor) carries two large plastic water storage tanks side by side on a simple flat masonry parapet roof. These tanks, when full, represent approximately 1,000–2,000 litres of water, placing a 1,000–2,000 kg concentrated load at the top of a structure whose parapet walls are single-brick thick with no visible horizontal band at the roofline. The parapet wall itself — visible clearly in this image — is approximately 600–700mm high and built in the same unplastered brick as the main wall, with no RC coping or bond beam. This parapet would be among the first elements to topple in a seismic event, sending 300–500 kg blocks of masonry cascading onto the street below and onto the occupied entrance of the shop.
Ground-Floor Commercial Use — Soft Storey Indicator	The Meat Shop photograph also illustrates the ground-floor commercial modification pattern prevalent across this settlement. The ground floor of this building has been configured entirely as an open-fronted commercial space, with large glass panel and aluminium frame shop frontage occupying nearly the full width of the facade. This eliminates the original load-bearing wall at ground level and replaces it with a slender glazed frame that provides no

Observed Feature	Detailed Observation from Zoomed Images
	lateral resistance whatsoever. The upper brick masonry floor sits directly above this open-frame commercial frontage, creating a classic soft storey condition.
Blue Building — Structural Distress and Informal Additions	The zoomed image photograph focuses on a blue-painted two- to three-storey brick structure whose condition is among the most alarming observed in this study. The upper portion of the building shows extensive informal structural modifications: the front wall of the uppermost floor appears to have been partially removed or has partially collapsed, with exposed brick edges and a green-painted metal sheet used to close off the resulting opening. Bamboo and metal poles project from the rooftop in an unstructured arrangement, several with saffron religious flags. Wires in extreme density — at least six to eight separate wire runs — are attached to the front facade at multiple points using hooks and staples driven directly into the brickwork. The ground level shows a large blue tarpaulin sheet draped from the first floor to form a canopy over what appears to be an informal shop or storage space, supported on poles that are simply leaning against the building wall. The entire visual impression is of a building that has been continuously modified, extended, partially demolished.
Inter-Building Gaps and Shared Walls	Across all the zoomed images for this location, no discernible gap between adjacent buildings is visible at any point. Buildings share party walls or are in direct contact along their full height. In the dense slum fabric captured in photograph, the buildings form a continuous masonry mass where individual structural units are not distinguishable — the settlement functions as a single agglomerated structure rather than a collection of discrete buildings. This configuration eliminates any possibility of controlled collapse of a single unit during a

Observed Feature	Detailed Observation from Zoomed Images
	seismic event; instead, failure of one structural element will propagate through the shared wall system into adjacent structures, potentially triggering simultaneous collapse across multiple plots.
Rooftop Landscape	The dense overview image photograph reveals the rooftop landscape of the informal settlement in extraordinary detail. At least 20–30 water storage tanks are visible within a single field of view, ranging in size from 250-litre to 2,000-litre capacity, coloured white, blue, and black. Several tanks are arranged in tight clusters of three or four on a single rooftop. Corrugated iron sheet structures, makeshift brick rooms, rolled tarpaulin bundles, TV satellite dishes, bamboo drying poles with laundry, and scattered construction debris all compete for the limited rooftop space. The collective added dead load on these rooftops — water tanks, enclosures, and materials — almost certainly exceeds the live load assumptions of the original structure by a factor of two or more, reducing the available safety margin against gravity collapse to near zero before any seismic demand is considered.
Overhead Infrastructure and Wire Density	The zoomed images reveal an extraordinary density of overhead wires at every level of the building facades. In the blue building image photograph, a veritable thicket of electrical, cable TV, and data cables emerges from and terminates at points directly attached to the brick walls, with no visible conduit, junction boxes, or strain relief. Multiple cable runs cross diagonally between buildings, creating a web that ties adjacent structures together mechanically. In a seismic event, as buildings move relative to each other, these wire bundles would transmit impact and tension forces between structures — simultaneously damaging electrical installations and potentially pulling out the brick fixing

Observed Feature	Detailed Observation from Zoomed Images
	points, creating holes in already-weakened masonry walls.
Evidence of Moisture Damage and Biological Growth	Multiple surfaces in the zoomed images show green algal and moss growth at plinth level and along lower wall sections, indicating persistent moisture presence from either a high-water table, inadequate surface drainage, or both. Several lintels above shop openings in the photograph image show horizontal cracking at the mortar joint immediately below the lintel — a classic sign of differential thermal movement between the concrete lintel and the masonry wall below, which over time can cause the masonry course to separate and the lintel to become structurally ineffective. This degradation of lintel function increases the spanning demand on the masonry arch above openings, which is typically incapable of sustaining this load without cracking.
Lane Width and Emergency Access	Although no street-level view is directly available for this location, the spatial relationships visible in the wide-angle photograph confirm that inter-building lanes are extremely narrow — estimated at 1.0 to 1.5 metres in the inner settlement areas based on the proportional scale of building heights and visible lane widths. These dimensions are insufficient for any emergency vehicle access. A 108 ambulance (width approximately 2.0m) or a fire tender (width approximately 2.4m) would be physically incapable of reaching the interior of this settlement. In the event of seismic collapse, the lane corridors would be rapidly obstructed by fallen masonry, tarpaulin poles, overhead wire tangles, and debris from the parapet walls and rooftop tanks — making manual rescue the only option, across an area of potentially thousands of affected structures.

6.11.3 Seismic Vulnerability Assessment

Samaypur Badli lies within Seismic Zone IV as classified by IS 1893 (Part 1):2016, with a design basis earthquake peak ground acceleration of 0.24g and a maximum considered earthquake PGA of approximately 0.36g. Against this hazard exposure, the building stock observed presents a near-comprehensive checklist of structural vulnerabilities. The RVS matrix below summarises the key deficiency indicators, assessed against the FEMA P-154 framework adapted for Indian construction typologies:

Vulnerability Parameter	Observed Condition	Risk Level
Structural System — URM Dominant	*No RC frame; pure load-bearing brick masonry throughout*	**HIGH**
Horizontal Reinforcing Bands	*No plinth, lintel, or roof bands observed per IS 4326*	**HIGH**
Out-of-Plane Wall Failure Risk	*Single-brick walls, no tying, no ring beams*	**HIGH**
Soft / Weak Storey	*Open-front commercial ground floors; wall removal observed*	**HIGH**
Rooftop Mass — Tanks and Enclosures	*20–30 tanks visible per rooftop cluster; makeshift rooms*	**HIGH**
Parapet Wall Stability	*Unrestrained single-brick parapets with tanks at coping level*	**HIGH**
Inter-Building Pounding / Shared Walls	*Zero separation; continuous agglomerated masonry mass*	**HIGH**
Material Degradation	*Mortar erosion, efflorescence, cracked lintels, algal growth*	**HIGH**
Existing Structural Distress	*Partial wall collapse visible in blue building*	**HIGH**

Vulnerability Parameter	Observed Condition	Risk Level
Emergency / Rescue Access	*Lanes est. 1.0–1.5m; impassable to emergency vehicles*	**HIGH**
Site Amplification — Soil Conditions	*Yamuna alluvial plain; soft deposits;*	**MODERATE**
Overhead Wire Hazard	*Extreme wire density; direct wall-fixed attachments*	**MODERATE**

CRITICAL FINDING	*The Samaypur Badli settlement is assessed as HIGH seismic risk across all structural parameters. The agglomerated URM building stock, absent horizontal reinforcing bands, extreme rooftop overloading, and sub-metre emergency access combine to create one of the highest urban seismic risk profiles observed in this study. Immediate Level 2 detailed structural assessment and evacuation planning is urgently recommended.*

6.11.4 Recommendations

The following recommendations are drawn directly from the RVS findings for the Samaypur Badli study area, consistent with NDMA Guidelines for Seismic Vulnerability Assessment and the BIS IS 13935:2009 (Repair and Seismic Strengthening of Buildings):

01	Conduct an immediate Level 2 detailed structural engineering survey of all buildings above two storeys in the settlement, with priority given to structures showing visible cracking, partial collapse, heavy rooftop loading with unrestrained parapets, and open-front commercial ground floors. Buildings identified as critically deficient should be red-tagged and occupants relocated pending remediation.
02	Prohibit all further vertical additions (additional floor construction) on existing URM buildings in this zone without a prior structural assessment certifying the adequacy of the existing foundation, walls, and floor systems to carry the additional load under both gravity and seismic demand as per IS 1893:2016 and IS 456:2000.
03	Initiate a community-level programme for voluntary removal or restraint of rooftop water storage tanks on buildings with single-brick parapet walls. Where tanks must be retained, install structural steel brackets to anchor tanks to the slab rather than the parapet, and

	provide RC or steel coping beams to strengthen parapet walls against out-of-plane overturning.
04	Retrofit pilot: Install horizontal reinforcing bands (using reinforced concrete or ferrocement) at lintel and roof levels on a selected cluster of URM buildings as a demonstration project, following the provisions of IS 4326:2013 and NDMA retrofitting guidelines. Monitor performance and use as a template for a wider settlement-level retrofitting programme funded through the Delhi Urban Shelter Improvement Board (DUSIB) or equivalent municipal body.
05	Develop a site-specific seismic microzonation stu 60 for the Samaypur Badli locality, including borehole investigations, standard penetration tests (SPT), and shear wave velocity measurements (MASW or SCPT), to accurately characterise site amplification factors and liquefaction susceptibility. Incorporate findings into a revised local seismic hazard map for use in structural design and urban planning decisions.
06	Prepare and disseminate an earthquake emergency response plan specific to this settlement, including identification of assembly points, evacuation routes (to the extent possible given the lane geometry), and coordination protocols with Delhi Fire Services, NDRF, and the nearest trauma hospitals. Conduct regular community earthquake drills involving local Resident Welfare Associations (RWAs) and neighbourhood groups.

6.12 Rapid Visual Screening — Location 2

Haiderpur Badli Metro Station Area | Side A (Western View) | Delhi — Seismic Zone IV

6.12.1 Overview and Study Area Description

The first study area under the Haiderpur Badli corridor occupies the western approach of the metro station, photographed from the elevated DMRC viaduct. This elevated vantage point allowed for both a wide-angle panoramic capture of the overall settlement morphology and a sharp telephoto zoom into the building facades immediately below and beyond the viaduct's edge. The settlement is part of a larger unplanned residential agglomeration that has grown incrementally over three to four decades along the northern extension of Delhi, classified under the Master Plan of Delhi 2041 as an urban village transitioning to mixed-use residential land use.

The wide-angle photograph reveals a sprawling low-to-mid rise urban fabric extending towards a visible horizon blurred by Delhi's characteristic haze and particulate-laden air. The skyline is punctuated by scattered cellular antenna towers, a handful of recently constructed multi-storey apartment blocks in the middle distance, and the dense canopy of mature trees interspersed across the settlement — a reminder that this area was, until two decades ago, substantially greener. A large white commercial/institutional building dominates the mid-background, representing the formal planned construction that coexists uneasily alongside the organically grown residential fabric in the foreground.



Figure 9 Wide Angle View of Site at Haiderpur Badli Metro Station

6.12.2 Zoomed-In Building Description — Physical Characteristics

The telephoto photograph corresponding to Location provides a sharply resolved close-up view of a cluster of 3 to 5 storey buildings. The following observations are derived directly from this image:



Figure 10 Close Up View of the Location

Observed Feature	Detailed Observation from Zoomed Images
Wall Construction	Walls are constructed in fired clay brick with cement-sand mortar. The dominant finish is cement plaster applied externally, painted in white, light grey, and pale pink tones — typical of Delhi's informal residential stock built between the 1980s and 2000s. Where plaster has spalled or peeled, the underlying brickwork is visible, showing irregular bond patterns and non-uniform mortar joint widths (estimated 10–20mm), indicating inconsistent workmanship. Several sections show efflorescence — white salt deposits leaching through plaster — evidence of persistent moisture ingress and potential mortar degradation.
Structural Frame	RC columns are visible at corners and along the mid-span of some buildings, though their dimensions appear to be approximately 230mm × 230mm or smaller — significantly below the minimum recommended for Zone IV. Beams are thin and flush with the floor slab in most cases, indicating a flat slab or very shallow beam system. No visible haunching, corbelling, or beam depth increase at column junctions, which would be indicative of moment-resisting design. The overall visual impression is of a gravity-only design with no lateral load consideration.
Floor Slabs	Flat RC slabs at each floor level, estimated at 100–120mm thickness based on visible slab edge at balconies and sunshades. This thickness is marginal even for gravity loads in 3+ storey buildings and provides minimal diaphragm stiffness for lateral load redistribution during seismic shaking.
Balconies and Chhajjas	Each floor features cantilever balconies approximately 800–1000mm in projection, with railings made of MS angle-iron grilles welded in place. The slab-balcony junction

Observed Feature	Detailed Observation from Zoomed Images
	shows no visible beam or thickening — the cantilever appears to be a direct extension of the floor slab, a condition that relies entirely on the top-face reinforcement at the root section. Multiple chhajjas (sunshades) of 300–500mm projection overhang each window and door opening, adding distributed load and eccentricity. These elements are among the first to fail in an earthquake, producing dangerous falling debris.
Openings — Windows and Doors	Each floor exhibits a dense array of window and door openings, in some cases comprising over 50% of the wall area on the facade. The wall piers between openings are as narrow as 250–350mm, providing extremely limited shear resistance. No visible lintel beams spanning across multiple openings at the same level — each opening appears to be individually lintel-spanned, leaving no continuous horizontal band to arrest crack propagation.
Rooftop Loading	Rooftops carry white plastic overhead water storage tanks (likely 500L–1000L), satellite dishes, antenna poles, and in some cases small brick/metal enclosures for rooftop service rooms. Two or three tanks are visible per building, concentrated near parapet walls. Tanks at capacity represent 500–1000 kg point loads at the highest and seismically most sensitive elevation of the structure.
Vertical Additions	At least two buildings in the zoomed image show exposed RC columns with cut rebar projecting above the current roof slab level — the unmistakable sign of planned additional floors. These additions are being made without any visible scaffolding or engineering supervision. The columns below were almost certainly not designed for the additional load, and no retrofitting of the lower structural members is evident.

Observed Feature	Detailed Observation from Zoomed Images
Inter-building Gaps	Adjacent buildings are in direct contact or separated by gaps of less than 150mm in most cases — far below the minimum separation distance required by IS 4326 (Earthquake-Resistant Construction). This proximity guarantees building pounding during seismic shaking, where differential lateral displacements cause adjacent structures to hammer each other, leading to corner crushing, slab puncture, and cascading progressive collapse.
Surface Cracking	Diagonal and stair-step crack patterns are faintly visible on two or three building facades in the zoomed image. Diagonal cracks radiating from window corners are indicative of shear stress concentration — a classic indicator of inadequate lateral wall reinforcement. Stair-step cracks following mortar joints suggest differential settlement in the foundation, pointing to soil-bearing inconsistencies across the plot.

6.12.3 Seismic Vulnerability Assessment

Delhi is classified under Seismic Zone IV per IS 1893:2016, placing it in the 'High Damage Risk Zone' with a design basis earthquake (DBE) peak ground acceleration of 0.24g. Against this hazard level, the buildings observed on Side A of the Haiderpur Badli corridor present multiple overlapping structural deficiencies that place them firmly in the high-priority category for seismic vulnerability:

Vulnerability Parameter	Observed Condition	Risk Level
Lateral Load-Resisting System	*No dedicated LLRS; relies on infill walls*	**HIGH**
Soft Storey / Weak Storey	*Open/commercial ground floors observed*	**HIGH**

Vulnerability Parameter	Observed Condition	Risk Level
Building Pounding Risk	*Zero or sub-code separation between buildings*	**HIGH**
Column Size and Detailing	*Undersized columns; non-ductile detailing suspected*	**HIGH**
Out-of-Plane Wall Failure	*No ring beams or horizontal bands observed*	**HIGH**
Rooftop Mass Concentration	*Multiple tanks + enclosures at roof level*	**MODERATE**
Cantilever Element Stability	*Balconies and chhajjas without seismic detail*	**MODERATE**
Site Amplification (Soil)	*Yamuna alluvial plains — soft soil*	**MODERATE**
Emergency Access	*Narrow approach roads, partially obstructable*	**MODERATE**
Material Degradation	*Efflorescence, spalling plaster, crack evidence*	**MODERATE**

KEY FINDING

Buildings on Side A of the Haiderpur Badli western approach are assessed as MODERATE-TO-HIGH seismic risk under IS 1893:2016 Zone IV provisions. A minimum of Level 2 detailed structural assessment is recommended before any further vertical construction is permitted.

6.12.4 Recommendations

01	Conduct Level 2 detailed structural engineering assessment for all buildings above 2 storeys in both study zones, prioritising structures showing visible cracking, partial collapse, or heavy rooftop loading.
02	Immediately halt and review all ongoing vertical additions (exposed rebar columns above existing rooftops) pending structural assessment of the existing structural system's capacity to bear additional loads.
03	Implement seismic retrofitting pilot programmes in both zones, with column jacketing for RC frames (Location 2) and installation of horizontal reinforcing bands and wall stitching for URM buildings (Location 3) as priority interventions.
04	Coordinate with Delhi Jal Board and BSES/Tata Power for seismic vulnerability assessment of the water pipeline and HT transmission infrastructure running through or adjacent to the location , and develop emergency isolation protocols.
05	Include both study zones in Delhi's Earthquake Risk Mitigation Programme under the NDMA National Disaster Management Plan, with community-level awareness, hazard mapping, and emergency response route planning as parallel non-structural mitigation measures.

6.13 RAPID VISUAL SCREENING (RVS) REPORT

Haiderpur Badi Metro Station Area | North-West Delhi | Seismic Zone IV (IS 1893:2016)

6.13.1 Study Area Overview

Photographs for this RVS exercise were taken from the elevated viaduct of Haiderpur Badi Metro Station. The wide-angle photographcaptures the overall settlement morphology extending south from the metro line. The zoomed photograph focuses on a representative cluster of three- to four-storey residential buildings in the immediate foreground of the settlement and forms the primary basis for structural assessment in this report.



Figure 11 Wide Angle View at Haiderpur Badli Metro Station

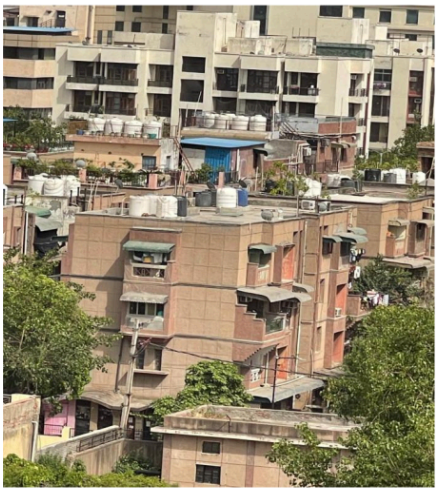


Figure 12 Close up View of Clustered Structures

The wide-angle view (Figure 1) establishes the macro-urban context: a dense, predominantly low-rise (2–5 storey) informal and semi-formal residential fabric with heavy tree cover, broken by a drainage nullah running roughly east–west, and a single taller (~12–14 storey) commercial building visible in the mid-background. The sky shows a pronounced haze layer consistent with Delhi's pre-monsoon smog conditions. The trackside marker confirms the photograph was taken from an elevated metro structure.

The zoomed view (Figure 2) resolves the structural details of a representative 4-storey building in the foreground and allows direct observation of wall finish, fenestration, rooftop condition, service installations, and the character of adjacent structures. All RVS observations in Sections 3–5 are grounded exclusively in what is directly visible in these two photographs.

6.13.2 Settlement Morphology — Wide View Observations

Parameter	Observation from Wide View
Building Height Range	Predominantly 2–4 storeys across the foreground and middle distance. A single taller commercial/hotel tower (~12–14 storeys, white glazed facade) is visible in the background. No buildings of equivalent height are visible elsewhere in the residential fabric, indicating an isolated formal development surrounded by informal low-rise stock.
Roof Type and Rooftop Features	Flat reinforced concrete or masonry roofs throughout the residential fabric. White plastic water storage tanks are visible on numerous rooftops across the mid-ground. Several rooftops carry satellite dishes and antenna poles. No pitched or sloped roofs are visible in the informal fabric.

Plot Density and Open Space	The settlement is densely packed with minimal visible open space between structures. Tree canopy provides some visual separation but does not indicate actual structural setbacks. A single open corridor — likely the drainage nullah — runs through the lower portion of the frame, providing the only significant gap in the built fabric.
Drainage / Water Body	A linear open drain or nullah is clearly visible in the lower-middle of the wide-angle frame, running roughly parallel to the metro viaduct. Its banks appear vegetated and unenclosed. This water body introduces potential for high groundwater levels and soft alluvial soil conditions immediately adjacent to the residential fabric.
Street and Lane Geometry	No individual street widths are measurable from this vantage point. The pattern of tree placement and building edges suggests that interior lanes within the residential cluster are narrow (estimated < 3 m) and not aligned to any formal grid. Slightly wider roads are visible at the periphery near the commercial frontage.
Building Age Mix	The wide view shows two visually distinguishable generations of construction: an older informal fabric of 2–3 storey brick buildings in the foreground-left (muted earth tones, irregular fenestration), and a slightly newer generation of 3–4 storey tiled/plastered buildings in the foreground-centre and right (including the primary study building). The commercial tower in the background represents a third, formally constructed typology.

6.13.3 Primary Structure — Detailed Observations

The zoomed photograph (Figure 2) provides sufficient resolution to assess the following structural and non-structural characteristics of the primary 4-storey building and its immediate neighbours. All observations are drawn directly from visible evidence in the image.

Feature	Detailed Observation
Number of Storeys	The primary building in the foreground is 4 storeys above grade. Ground floor is partially obscured by tree canopy; floors 2, 3, and 4 are clearly visible. A rooftop parapet with rooftop additions constitutes a fifth level.

	The building directly behind and to the right appears to be 3–4 storeys, and the taller modern apartment block in the upper background is approximately 8–10 storeys.
Wall Construction and Finish	The facade of the primary building is finished with stone cladding or ceramic tile in a beige/sandstone colour applied to the external face of brick masonry — a common practice in Delhi's semi-formal residential construction. This tile finish conceals the underlying brick and mortar joints from visual inspection, preventing direct assessment of joint quality or mortar integrity. The tile finish itself appears intact on the main facade with no visible spalling, delamination, or cracking at tile joints at the resolution of this photograph.
Structural System Inference	No reinforced concrete frame elements (columns or beams) are visible projecting from or expressed on the facade. The regular grid of windows without visible beam-column joints, the relatively thin wall sections at upper floors, and the construction typology typical of this settlement era strongly suggest an unreinforced or nominally reinforced load-bearing brick masonry system. It cannot be confirmed from the photograph whether any ring beams or horizontal RC bands are present within the wall thickness.
Window and Opening Configuration	Each visible floor carries 4–5 windows across the facade width, with openings of approximately 1.0–1.2 m width. Window-to-wall ratio appears moderate (~35–45% of facade area). Openings are topped with what appear to be arched or flat brick lintels concealed beneath the tile finish. On floor 3 (left bay), a window has been partially infilled with brickwork — visible as a different-texture patch in the tile surface — reducing daylighting and possibly indicating a prior structural modification. Green metal awnings (approximately 400 mm projection) are fitted to all windows on floors 2 and 3.
Window AC Units	At least 4 window-mounted air conditioning units are visible on the main facade — one on floor 2 left, one on floor 2 right, one on floor 3, and one on the right-side return facade. Each AC installation requires a penetration through the wall or window frame. In load-bearing masonry, repeated wall penetrations for AC sleeves weaken the bearing section, particularly when

	multiple units are installed in the same vertical bay. The units also add approximately 30–60 kg of facade-mounted mass each, which contributes to out-of-plane inertial demand on the wall during shaking.
Rooftop — Water Storage Tanks	The rooftop of the primary building carries at least 8 water storage tanks visible in the zoomed image: approximately 4–5 white cylindrical tanks (estimated 500–1000 L each), 2 blue cylindrical tanks (~500 L), and 1–2 black tanks (~500 L). Tanks are arranged in two informal clusters — one on the left portion of the roof and one on the right. When fully charged, this tank array represents an estimated aggregate load of 5,000–9,000 kg of water mass concentrated at roof level, in addition to the tank self-weight. The tanks appear to rest directly on the roof slab with no visible bracketing or anchoring to a parapet or structural element.
Rooftop — Blue Sheet Room	A makeshift room structure with a blue corrugated metal sheet roof is visible on the rooftop, positioned between the two tank clusters. The structure appears to be enclosed on at least two sides with brick or block masonry walls and is roofed with corrugated GI or colour-coated metal sheet. This addition is informal and was almost certainly constructed without structural assessment of the underlying roof slab's capacity. It adds both dead load (estimated 500–1,500 kg depending on extent) and a raised mass at the highest point of the building, increasing overturning demand.
Rooftop — Satellite Dishes and Poles	At least 2 satellite dish antennas are visible on the rooftop — one on the left parapet and one mid-roof. Additionally, several vertical metal poles (likely antenna masts or clothesline supports) project upward from the rooftop parapet. These elements individually represent negligible structural load but are attached to the parapet wall by bolted or wedge-anchored brackets, creating point loads and potential crack initiators at bracket penetrations in the masonry parapet.
Parapet Wall	The rooftop parapet is visible above the top floor slab. It appears to be of single-brick construction (~115 mm nominal thickness) and approximately 700–900 mm in height, based on the proportional scale of the tanks resting against it. No reinforced concrete coping beam or ring beam is visible at the parapet top. This parapet wall — loaded by water tanks resting against or near it,

	and not tied to the roof slab — represents the highest-probability failure element in any seismic or wind event.
Overhead Wires and Electrical Attachments	Three to four overhead wire runs are visible crossing diagonally in front of the primary building's facade, attached at points on the external wall surface. Additional wire drops are visible on the right-side return facade. The attachment points appear to be hooks or brackets driven into the tile cladding and underlying masonry. The wire density is moderate compared to older, unplastered informal construction visible in the background, but sufficient to create inter-building mechanical coupling and localised wall damage at attachment points during seismic shaking.
Inter-Building Gap and Adjacency	On the right side of the primary building, a narrow gap of approximately 0.3–0.5 m is visible between it and the adjacent structure of similar height. This gap is too narrow to act as a functional separation under seismic pounding — relative displacement during a Zone IV event can reach 25–50 mm, which would cause repeated impact (pounding) between the facades, shedding tile cladding and potentially fracturing the underlying brick wall at the contact zone. On the left side, the primary building appears to directly share a party wall with the adjacent structure, with no visible gap.
Adjacent Background Structures	Directly behind the primary building are two distinct built typologies visible in the zoomed image: (a) an older 2–3 storey unplastered brick masonry building with smaller windows, irregular construction, and rooftop tanks — consistent with a lal dora village structure — and (b) a taller, more recently constructed 8–10 storey apartment block with regular fenestration, plastered or painted facade, and balconies. The contrast between these three generations of construction within a single field of view illustrates the layered densification of this area over several decades.
Vegetation and Ground Level	Mature trees are visible at the base of the primary building and between buildings, indicating sufficient open ground at plot level for root growth and suggesting the ground floor is at or near natural grade. The tree canopy partially obscures the ground and first

	floors, preventing direct assessment of ground-floor wall condition, plinth treatment, or damp-proofing.

6.13.4 RVS Vulnerability Matrix

The following matrix assesses seismic vulnerability parameters against the FEMA P-154 Rapid Visual Screening framework as adapted for Indian construction typologies per IS 1893:2016 (Zone IV, PGA 0.24g DBE / 0.36g MCE). Assessments are based exclusively on photographic evidence; parameters not directly observable are noted accordingly.

Vulnerability Parameter	Evidence from Photographs	Risk Rating
Structural System	No RC frame elements visible. Regular brick masonry facade with tile cladding. Consistent with URM or nominally reinforced load-bearing masonry (NRLBM) — the most seismically vulnerable typology in Zone IV.	**HIGH**
Horizontal Reinforcing Bands	Tile cladding conceals wall section — band presence cannot be confirmed or denied. IS 4326:2013 mandates bands at plinth, sill, lintel and roof levels for URM above 2 storeys in Zone IV. Absence is the norm in this construction era and typology.	**HIGH (assumed absent)**
Rooftop Dead Load — Water Tanks	8 tanks visible (white, blue, black), estimated aggregate 5,000–9,000 kg when full. Concentrated at roof level, raising centre of mass and amplifying overturning demand. No visible anchoring to slab or structural element.	**HIGH**
Parapet Wall Stability	Single-brick parapet (~115 mm), height ~700–900 mm,	**HIGH**

	unrestrained at top. Tanks positioned in proximity. Out-of-plane overturning of parapet under seismic or wind inertia is highly probable.	
Informal Rooftop Addition	Blue-sheet roofed room structure constructed on roof slab without visible engineering basis. Adds dead load and raised mass. Roof slab capacity to carry this addition is unverified.	**HIGH**
Wall Penetrations — AC Units	4+ window AC units installed, each requiring wall sleeve penetration. In URM, repeated penetrations in a vertical bay reduce net bearing area and introduce crack initiation points under lateral loading.	**MODERATE**
Opening Infill / Modification	One window on floor 3 (left bay) shows visible infill of original opening with different-texture masonry. Indicates prior structural modification — nature and structural implication unknown without internal inspection.	**MODERATE**
Inter-Building Pounding Risk	Gap on right side ~0.3–0.5 m — insufficient to prevent pounding in a Zone IV event (expected relative displacement 25–50 mm). Party wall on left side eliminates any separation. Pounding will cause tile shedding and facade cracking.	**MODERATE**
Overhead Wire / Mechanical Coupling	3–4 wire runs attached to facade. Moderate density relative to older informal stock. Creates inter-building mechanical coupling and	**MODERATE**

	localised pull-out damage at attachment points during differential movement.	
Soft / Weak Storey	Ground floor obscured by tree canopy — cannot be assessed from photograph. Commercial ground-floor modification is common in this typology and area but is not directly evidenced here.	**NOT OBSERVED**
Existing Structural Distress	No visible cracking, spalling, or out-of-plumb condition observed on the primary building facade at this photographic resolution. Tile cladding may conceal underlying cracking.	**LOW (as visible)**
Site / Soil Conditions	Open nullah/drain visible in Figure 1 indicates proximity to soft alluvial deposits. No geotechnical data available. Potential for ground motion amplification and localised settlement. Vs30 estimated 150–250 m/s (NEHRP Class D/E).	**MODERATE**
Emergency / Rescue Access	Interior lane widths estimated < 3 m from wide view. Insufficient for standard fire tender (2.4 m width + door swing) in built-up condition. Post-earthquake debris from parapets and tanks would further obstruct access.	**HIGH**

OVERALL RVS FINDING	*The primary study building at Haiderpur Badi is assessed as HIGH overall seismic risk. The dominant vulnerabilities are extreme rooftop overloading (8 water tanks + informal rooftop room), an unrestrained single-brick parapet wall, and a probable URM structural system with no visible horizontal reinforcing bands. A*

Level 2 detailed structural assessment is recommended before any further vertical additions or rooftop loading is permitted.

6.13.5 Recommendations

01	Commission a Level 2 detailed structural survey of the primary building and its immediate neighbours. Given that the tile cladding conceals the wall construction entirely, an internal inspection is required to determine whether horizontal reinforcing bands are present at plinth, sill, lintel, and roof levels as required by IS 4326:2013 for URM buildings above 2 storeys in Zone IV.
02	Reduce rooftop mass immediately. The 8-tank assembly represents an estimated 5,000–9,000 kg of elevated water mass on a building of unconfirmed structural capacity. Tanks should be relocated off the parapet edge, anchored to the roof slab by structural steel cradles, and the number consolidated where household demand permits.
03	Restrain or remove the informal blue-sheet rooftop room. Unless the roof slab has been structurally assessed and confirmed adequate to carry the additional load under seismic demand (IS 1893:2016 and IS 456:2000), this addition constitutes an unquantified risk to the building's seismic performance and should be removed or formally assessed.
04	Install a reinforced concrete coping beam along the full length of the parapet wall, tied back to the roof slab with dowel bars at 600 mm centres. This single intervention significantly reduces the probability of parapet collapse — the most likely source of street-level casualties in a moderate seismic event.
05	Investigate the partially infilled window opening on floor 3. Determine whether the infill replaced a load-bearing element or modified the structural load path, and confirm that the infill is properly bonded and does not create a plane of weakness in the wall panel.

CHAPTER 7

SUMMARY AND CONCLUSION

7.1 Overview

This thesis proposes seismic vulnerability assessment of buildings in Delhi, which is located in Seismic zone IV under IS 1893:2016 by adopting the methodology of Rapid Visual Screening (RVS) as prescribed in FEMA P-154 (2015). The explosive growth of the city of Delhi in the last five decades has created a huge and diverse building mass spectrum from formally engineered government buildings to organically growing informal settlements and slum housing. Much of this stock has been created before the advent of modern seismic codes and with no engineering supervision and is being increased by ad hoc additions. In this context, the present study is a systematic field based seismic vulnerability assessment of two typologies representing the government/institutional buildings (RC – reinforced concrete) and the informal settlement residential buildings (URM – unreinforced brick masonry).

7.2 RVS of Government and Residential Buildings

The entire two-level RVS was performed on a total of nine government and residential buildings. All the buildings selected are RC framed structures and the government buildings of Delhi have a general design template, construction schedule and structural layout. The consistency of the data allows findings obtained from a detailed RVS of one typical building in a class to be extended, with reasonable confidence to other structurally similar government buildings of the same vintage and typology — providing the city-wide inventory assessment goal.When the goal is to achieve a city-wide inventory assessment, findings from a detailed RVS of one representative building in a class can be extended to other structurally similar buildings in the same class with reasonable confidence, which is both practically efficient and technically defensible. The buildings screenings showed a significant generation gap in

seismic performance. Post-2014 buildings (Buildings 1, 4 and 6) built to the modern seismic code provisions gave high RVS scores ranging from SL2 = 2.6 to SL2 = 3.4. The corresponding probabilities of failure under MCE shaking were extremely low — 1 in 2,512 for Building 1 (SL2 = 3.4), 1 in 400 for Building 4 (SL2 = 2.6), and 1 in 1,260 for Building 6 (SL2 = 3.1). These buildings are not considered under FEMA 154 detailed structural evaluation. The older government buildings, built between 1975 and 1979, before the introduction of modern Indian seismic codes, had substantially higher levels of vulnerability, in contrast. The probability of failure of Building 2 (G+2, C3 type, SL2 = 0.1) and Building 3 (G+3, C3 type with open ground storey, SL2 = 0.9 after R2 = 1.4 ongoing retrofitting credit) were 1 in 1.25 and 1 in 8 respectively. Under MCE shaking, the probability of return for Building 8 (C1 type, SL2 = 0.3) was 1 in 2. The most common vulnerability drivers found in older government buildings were pre-code construction (modifiers ranging from -0.1 to -0.4), lack of retrofitting provisions (modifiers of -0.4 to -0.9), and vertical irregularities such as soft/weak storey and irregular elevation geometry (modifiers of -0.4 to -0.9). Fortunately, Building 3 was screened as being in an active retrofitting phase (R2 = +1.4), and this was added to making the building a marginally acceptable score. This is a good example of the effectiveness of retrofitting interventions, and emphasises the role of continuing programmes for pre-code government structures. The findings of the RVS from the assessed buildings are used as a reference template for the government building stock in a large urban inventory, which is not practically feasible to make such detailed evaluations and is not economically viable. Buildings 2 and 8 scored at or below the critical threshold and therefore are recommended for detailed investigation. The results from the examples screened can be extrapolated to prioritise the larger population of other government buildings of similar age, typology (C3, pre-code) and configuration across Delhi.

7.3 RVS of Informal settlements and Brick Masonry Housing

The second major component of this study, was the study of unreinforced brick masonry buildings in informal settlements, urban villages and slum localities in North and North-West Delhi around the Samaypur Badli, Haiderpur Badli, and Haiderpur Badi metro station catchment areas. These settlements are mainly constructed out of brick. They are the most vulnerable part of the urban fabric of the city of Delhi, because they are built without engineering drawings and structural supervision, and are often extended upwards without an evaluation of existing structural capacity. The brick masonry housing stock results were always disappointing for RVS. The two URM buildings with the lowest scores in the entire study were the two buildings that were formally screened (Buildings 7 and 9). Building 7 (G+1, URM, built c.1975-79) achieved SL2 = 0.1, which equates to a failure probability of 1 in 1.25, that is, collapse is very likely with MCE shaking. We found in this study that Building 9 (G+2, URM, constructed 2022) had a probability of failure of 100% (SL2 = 0), which is the most critical result. Though recently constructed, Building 9 was found to have plan and vertical irregularity, absence of any seismic detailing, and was found to be constructed without following IS 4326:2013 provisions for masonry construction in seismic zones. This outcome exemplifies an ongoing issue: a building's age is no indication of structural safety if it is not designed according to seismic code. The qualitative photographic RVS supported and helped to clarify these quantitative findings with regard to the informal settlements. The Samaypur Badli settlement was evaluated to be the highest seismic risk profile in all parameters observed in this study and in particular, it has been found to have continuous URM construction, lack horizontal reinforcing bands, extreme rooftop overloading from water storage tanks (20–30 tanks per rooftop cluster), no inter-building separation, and narrow lanes (1.0–1.5 metres). The conditions are similar in Haiderpur Badli and Haiderpur Badi, where both the older informal URM buildings and the newer, but under-detailed RC-framed buildings exist side by side in close physical proximity, causing further pounding and cascade collapse risks. Individually screening each building in an informal settlement of perhaps thousands of structures is not practically possible in a realistic time and

resource envelope, so the RVS approach taken here concentrates on a representative sample of buildings – one or two buildings of each predominant structural typology per settlement area. The results of these representative buildings are then extended to the overall population of structurally similar buildings for the same settlement. This is warranted because the informal settlements in Delhi are highly homogeneous in terms of the construction materials used, lack engineering control, the height of the buildings, the floor plan etc. and the indicators of vulnerability are prevalent on many buildings and across the settlement fabric. This conclusion of near-certain seismic failure for a representative URM building in Samaypur Badli can therefore be directly extended to the hundreds of structurally similar buildings around it.

7.4 Broader Urban Context and Observations

A consistent set of recurring structural vulnerabilities across the study locations was uncovered during the photo and field evaluations, and this set of vulnerabilities further added to the risk identified in numerical RVS scores. Examples of these include: heavy water storage tanks on roof levels supported by an unrestrained single brick parapet wall; lack of horizontal reinforcement bands at plinth, lintel and roof levels as required by IS 4326:2013; lack of formal vertical reinforcement of existing structures at the interfaces of informal vertical additions; lack of horizontal reinforcement around overhead wires and cables, causing a classic soft storey condition; high concentrations of overhead wires and cables, causing mechanical connection of buildings without any structural verification; and persistent degradation caused by moisture ingress and efflorescence from the mortar of the various levels of the wall. The width of the lanes across the study sites varies between 1.0 and 3.0 metres, which is too narrow to allow for an emergency approach in most of the settlements in the interior, making the mass casualty risk situation worse during a seismic event.

7.5 Conclusion

First, the age and typology of buildings continue to be the leading seismic vulnerability predictors in the building stock of Delhi. The pre-code RC-framed buildings with vertical irregularity and URM buildings of all ages are the highest-risk groups, and should be targeted for detailed structural investigation and retrofitting. Second, the lack of seismic code compliance in newly-built informal buildings (for example, Building 9) reveals that regulatory enforcement is continuing to contribute to the production of new seismic risk even in this decade. Urgent action is needed from urban planning and building regulation authorities. Thirdly, this research confirms the conceptual and practical usefulness of the representative building approach for area-wide seismic risk assessment. Economically and technically impractical and unnecessary to detail evaluate every individual building in a large urban settlement. Because government buildings were designed with standardised building templates and overseen by building inspectors, there is enough structural similarity among buildings within each generational cohort (pre-code vs. post-benchmark) for results from the representative buildings screened to be extrapolated to the class of government buildings as a whole. In the same way, the brick informal settlements of Delhi are highly uniform in structure; the materials, configurations, omissions, and lack of engineering along with hundreds of buildings within the same community are repeated. The critical vulnerability indicators identified in the RVS of Buildings 7 and 9 and the photographic RVS of Samaypur Badli and Haiderpur Badli, can therefore be considered as representative of the informal URM building stock of these and structurally analogous informal settlements in North and North-West Delhi. Fourthly, the qualitative dimension of the photographic RVS part of this study, consisting of photographs and interpretations, has added a qualitative layer to the numerical scores that supports and contextualises them. The evidence of rooftop overloading, lack of horizontal reinforcing bands, no separation between buildings, soft storey conditions on the ground floors of open-plan commercial buildings, and lack of accessible emergency lanes to buildings across the study settlements portrays a systemic vulnerability that is more than the sum of its individual building parts. Based on the RVS results, it is

recommended that Buildings 2, 7, 8 and 9 be immediately evaluated by a detailed structural engineering assessment, with the highest priority placed on Buildings 7 and 9, as these have been found to have a near zero or zero RVS. Building 3 is in a retrofitting process and should be completed and independently verified with its programme. All Government buildings built before 1980 across Delhi of C3 and URM typologies should be assessed and prioritised based on the assessed buildings for phased RVS screening. Samaypur Badli and Haiderpur Badi informal URM settlement fabric should be prioritized for community level seismic risk mitigation measures such as pilot programmes for retrofitting, rooftop tank restraint measures, strengthening parapets and developing earthquake emergency preparedness planning. Finally, it is concluded that there is a significant and largely unquantified seismic risk posed by the informal and pre-code building stock in Delhi and that the RVS methodology provides a scientifically credible, resource-efficient and practically scalable approach to commence a systematic seismic risk characterisation, prioritisation and mitigation of that informal and pre-code building stock. The results provided herein are meant to be a contribution towards the body of evidence for seismic risk policy in Delhi and as a practical template for comparable RVS-based assessments in other Indian cities facing similar urban seismic vulnerability problems.

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