M.Tech (Structural Engineering) PRATEEK DUBEY(2K23/STE/25) MAY 2025

Development of a Generalised Method for Seismic Retrofitting of Masonry Structures

A Dissertation Submitted
in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

PRATEEK DUBEY

(2K23/STE/25)

Under the supervision of

Prof. ALOK VERMA

Department of Civil Engineering Delhi

College of Engineering

Department of Civil Engineering
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Bawana Road, Delhi- 110042

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CANDIDATE'S DECLARATION

I, **Prateek Dubey**, M. Tech (Structural Engineering) student, having **Roll no: 2K23/STE/25**, hereby certify that the work which is being presented in the dissertation entitled "**Development of a Generalised Method for Seismic Retrofitting of Masonry Structures**" in the partial fulfilment of the requirements of the award of the Degree **Master of Technology in Structural Engineering**, submitted in the **Department of Civil Engineering, Delhi Technological University** is an authentic record of my work carried out under the supervision of **Prof. Alok Verma**, Professor, Department of Civil Engineering, Delhi Technological University, Delhi

The matter present in this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

(PRATEEK DUBEY)

This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

(Prof. ALOK VERMA)

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Development of a Generalised Method for Seismic Retrofitting of Masonry Structures**" which is submitted by **PRATEEK DUBEY**, **2K23/STE/25**. **Department of Civil Engineering**, **Delhi Technological University**, Delhi in partial fulfilment of the requirement for the award of the **degree of Master of Technology**, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Countersigned

31.5.25

Place: Delhi

Prof. ALOK VERMA
(SUPERVISOR)

Date: 30/5/25

ABSTRACT

The URM represent a large portion of buildings around the world. Masonry in construction is being widely used in the country, around 60% of the country amounts to 70% of the masonry construction. The masonry has wide advantages but also have some disadvantages i.e. brittle failure, sudden collapse of the structure in a moderate to strong earthquakes can devastate complete cities or villages resulting in massive death toll and can cause extensive loss.

To address contemporary requirements, there are established standards, guidelines, and methodologies that guide the selection of appropriate materials and techniques for both repairing and seismically strengthening buildings damaged by earthquakes. These frameworks also provide recommendations for the design and construction of earthquake-resistant structures, encompassing various construction types such as masonry construction with rectangular masonry units, timber-framed buildings, and structures featuring prefabricated flooring or roofing systems.

The method includes the procedure of reconnaissance of structures, visual inspection, collecting data, taking measurements, further the information is fed into the designed module which determines the whether structure is safe/unsafe and depending upon the suitable measures are suggested.

The technique described may be useful for all types of masonry buildings and constructions. The proposed method may prove to be effective and efficient in terms of time and cost. Buildings in zone II does not requires special seismic resisting features but the important buildings may be considered for upgrading seismic resistance. Applicable for buildings in seismic zones III to V and are based on damaging seismic intensities VII and more on M.S.K. intensities scales.

The objectives are Education Imparting, helping Practicing Engineers/Consultants, can be registered/patented to govt. of India from where it can be accessed to mass application, understanding of code, Pre-earthquake behavior assessment, Useful for surveyor to be used by Insurance company,

Designers get help for pre – construction, Cost – estimation, Retrofitting cost. Seismic retrofitting of masonry buildings plays a crucial role in reducing the vulnerability of existing structures to earthquake damage**.** Many of these buildings, especially those made from unreinforced masonry (URM), were not designed with seismic resistance in mind and often lack the flexibility needed to withstand seismic forces. As such, they are particularly susceptible during earthquakes. To address these risks, engineers have developed a range of strengthening methods. These include applying surface reinforcements like shotcrete or fiber-reinforced polymers, using post-tensioning techniques, adding reinforced concrete elements for confinement, and employing advanced systems such as base isolation and energy dissipation devices.

These strategies aim to improve the structural behaviour of masonry walls in both in-plane and out-of-plane directions, enhance the connections between walls and floors, and reinforce overall building stability. For heritage or architecturally significant structures, special attention is given to minimizing visual and physical alterations. Comparative evaluations of retrofitting approaches suggest that certain techniques—such as the centre core method and surface reinforcement—offer notable improvements in seismic resistance. These methods vary in terms of cost, complexity, and impact on the existing structure, allowing for flexible application depending on specific project needs. In addition to structural benefits, recent studies highlight the broader value of seismic retrofitting, showing that it can lead to considerable reductions in expected damages, economic losses, and fatalities. This is especially relevant for public-use buildings like schools. Consequently, retrofitting masonry structures has become a key component of disaster risk reduction and heritage conservation strategies in seismically active areas.

ACKNOWLEDGEMENT

I am deeply grateful to my mentor, **Prof. Alok Verma**, whose expert guidance and unwavering support have been instrumental throughout this research journey. His profound knowledge and insightful advice have significantly enriched my work, and I sincerely appreciate the time and effort he invested in mentoring me.

I also extend my heartfelt thanks to Dr. Pratinidhi, Pranjal Gupta for their constructive feedback and valuable suggestions. Their perspectives have been crucial in refining my thesis, and I am thankful for their willingness to share their expertise.

My sincere appreciation goes to my family and friends, whose encouragement and support have been a constant source of strength. Their belief in me kept me motivated and focused during challenging times, and I am truly thankful for their presence in my life.

Lastly, I express my gratitude to Delhi Technological University for providing the resources and an environment conducive to research. The opportunities and support offered have been pivotal in the successful completion of this project, and I am eager to share the outcomes of my work.

Sincerely,

Prateek Dubey

M.Tech (Structural Engineering)

Roll No – 2K23/STE/25

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LIST OF ABBREVIATIONS

GSDMA- Gujrat State Disaster Management Authority

PGA- Peak Ground Acceleration

URM – Unreinforced Masonry

EERI- Earthquake Engineering Research Institute

IAEE- International Association for Earthquake Engineering

IRCC- Industrial Research and Consultancy Center

EDM- Electrical Discharge Machining Technology

NCCBM-National Council for Cement and Building Materials

SHM- Structural Health Monitoring

NDT-Non-Destructive Testing

MDT- Minor Destructive Testing

FRP- Fiber Reinforced Polymer

TRM – Textile Reinforced Mortar

FRCM – Fiber Reinforced Cementitious Matrix System

CFRP- Carbon Fiber Reinforced Polymer

UAV -Unmanned Aerial Vehicle

NIED – National Research Institute for Earth Science and Disaster Prevention

ASTM- American Society for Testing and Materials

PP- Polypropylene Strings

CLT - Cross Laminated Timber Panels

ADAS- Added Damping Stiffness System

R-RMS- Retrofitted Reinforced Masonry Structures

SAP 2000- Structural Analysis Programming

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Many existing buildings do not meet current seismic design standards and are therefore at risk of experiencing severe damage or even collapse during a major earthquake. The primary goal of seismic evaluation is to determine the structural capacity of buildings that are either vulnerable to earthquakes or have already sustained seismic damage, in order to decide on their suitability for future use. This evaluation also helps in identifying the level of intervention necessary for structures that are found to be deficient in seismic performance. Seismic evaluation techniques for existing buildings are generally categorized into two main types: **qualitative methods** and **analytical methods**. Qualitative approaches rely on available background information such as architectural and structural drawings, historical performance of similar buildings during past earthquakes, visual inspections, and non-destructive test results. Examples of qualitative methods include the Field Evaluation Method, Rapid Visual Screening, and the ATC-14 guidelines. On the other hand, analytical methods involve a more detailed assessment based on structural capacity and ductility, using available design documents. These techniques include the Capacity-to-Demand (C/D) ratio method, screening procedures, pushover analysis, and nonlinear inelastic analysis. However, in many cases, building drawings are either incomplete or unavailable. Additionally, the complex nature of analytical methods often makes them impractical for use by field engineers, particularly in the context of current conditions in India. Given these constraints, it is essential that evaluation procedures be straightforward and efficient, allowing for broad application in assessing seismic risk across large numbers of buildings. Consequently, qualitative methods are more commonly adopted for practical field assessments. The main objective of qualitative evaluations is to help engineers identify structural vulnerabilities that could lead to component or system failure. Traditionally, such assessments are conducted through visual inspection, complemented by some material testing. In recent years, advancements in non-destructive testing techniques have provided effective tools for quickly assessing structural damage and deterioration. This chapter outlines a general methodology for evaluating buildings based on condition assessment, visual inspection, and selective non-destructive testing. This approach is intended to serve as a practical guide to support decision-making, rather than as a definitive evaluation standard.

Components of Seismic Evaluation Methodology

Evaluating a building for seismic performance is a complex process that demands comprehensive knowledge of structural systems, damage mechanisms, material properties, and construction practices. The methodology for this evaluation is typically divided into three primary components:

Condition Assessment

This step involves collecting detailed information about the structure. It includes reviewing architectural and structural plans, examining the performance of similar buildings during past seismic events, and conducting a preliminary assessment of the building's strength, drift, materials, and structural elements. This approach, largely influenced by the ATC-14 guidelines, is mainly applied to existing buildings that have not sustained damage.

Visual Inspection or Field Survey

This component is based on observing physical damage or distress in the building. While visual inspection is particularly valuable for structures that have experienced damage, it can also be applied to undamaged buildings to identify potential vulnerabilities.

Non-Destructive Evaluation (NDE)

NDE techniques are used to quickly estimate material strength, assess the extent of deterioration, and identify issues that are not easily visible. These methods also help determine reinforcement details and may be used to recreate structural drawings when original documentation is unavailable.

Condition Assessment for Seismic Evaluation

The goal of a condition assessment is to gather relevant data on the structure and evaluate its likely behaviour under seismic loads. This helps in making informed decisions about the building's safety and retrofitting needs. Additional information may be incorporated depending on the project requirements.

Data Collection and Information Gathering

Data collection is a crucial step in the seismic assessment of an existing structure. The information typically falls into three categories:

Building Information

- Architectural, structural, and construction drawings
- Seismic vulnerability factors such as number of floors, construction year, and total floor area
- Soil investigation reports and structural design documents Seismic hazard characteristics of the building location

Construction Details

- Identification of systems resisting gravity and lateral loads
- Records of maintenance, renovations, or structural modifications
- On-site surveys to document the current condition of the building

Structural Characteristics

- Material properties
- Structural configuration, including irregularities (vertical/horizontal), torsional effects, and short columns
- Detailing practices such as seismic reinforcement and confinement
- Foundation system
- Non-structural elements affecting overall performance

Masonry has long been one of the most time-honoured and widely used construction materials in India, especially in residential buildings. Typically, these structures are built in an informal manner by local masons, often without significant involvement from trained engineers or professionals. As a result, such buildings are classified as non-engineered constructions. Commonly used materials in this type of construction include fieldstone, fired bricks, concrete blocks, adobe, rammed earth, timber, or a mix of locally sourced traditional materials. Given India's extensive history with seismic activity and its longstanding construction traditions, one would expect that earthquake-resilient techniques would be an integral part of these structures. However, experience has shown otherwise. The failure of non-engineered buildings has been the leading cause of widespread destruction and fatalities during past earthquakes. Unfortunately, despite repeated natural warnings, the importance of incorporating earthquake-resistant features in these structures has not been adequately recognized or implemented. This may be due to a lack of awareness about such techniques, or scepticism regarding their effectiveness.

Criteria for Earthquake-Resistant Design

Historical earthquake events have exposed several vulnerabilities in masonry buildings. These include poor structural integration, weak connections between walls, roofs, and foundations, insufficient resistance to lateral forces, and the brittle nature of traditional mortars. Other contributing factors are the rigidity of masonry walls, limited ductility, and high structural weight. To enhance the seismic performance of such buildings, it is essential to incorporate specific earthquake-resistant (ER) features. These features are aimed at improving both strength and flexibility. Indian Standards such as IS: 4326 and IS: 13828 provide detailed guidelines on these improvements. IS: 4326 (1993) outlines the selection of materials and special design considerations for various types of earthquake-resistant buildings, including those using masonry, timber, and prefabricated components. IS: 13828 (1993) offers recommendations specifically for low-strength masonry buildings made of brick and stone. Earthen structures are addressed in IS: 13927 (1993).

The main goals behind these guidelines include:

- Ensuring structural unity and cohesion
- Strengthening connections between structural elements
- Improving the ability to resist bending forces perpendicular to walls
- Reinforcing weak sections with materials like steel, wood, or reinforced concrete
- Enhancing the quality of mortar and construction practices through better bonding techniques.

To enhance the structural integrity of non-engineered buildings, horizontal bands (or bond beams) should be incorporated at crucial levels, along with vertical reinforcement bars positioned at wall corners and intersections. These horizontal bands create a structural frame that helps transfer earthquake-induced horizontal forces from the floors to the load-bearing walls, thereby connecting and integrating the structural components for improved overall performance. The placement and naming of these bands depend on their location in the building, they may be referred to as plinth, sill, lintel, roof, or gable bands. Their reinforcement specifications can be found in standards such as IS 4326, IS 13927. When combined with vertical reinforcement, these elements enhance the strength, ductility, and energy absorption capacity of masonry walls. The extent and type of reinforcement depend on the building material and the seismic risk of the location. Descriptions of the various strengthening elements are as follows:

- **Plinth Band**: Located at the plinth level above the foundation, this band helps to accommodate differential settlement, especially in areas with weak or inconsistent soil.

- **Gable Band**: Positioned at the top of gable masonry beneath the roof purlins, this band connects with the roof band at the eaves and prevents the gable wall from collapsing outward under seismic loads.

- **Roof Band**: Installed directly under the roof or floor slab, this band enhances the horizontal stiffness of the floor diaphragm. It is not necessary where rigid floor systems are already present.

- **Lintel Band**: Applied at the lintel height across all internal and external structural walls (excluding partitions), this band enhances the building's lateral load resistance and helps prevent out-of-plane wall failure. Including lintel bands in partition walls can also improve their stability.

- **Sill Band**: Positioned at the window sill level, this band decreases the effective height of masonry between openings, which helps reduce shear cracking. Although not yet mandated by building codes, it can contribute to better wall behaviour under lateral loads.

  - **Vertical Reinforcement**: Steel bars (typically 10–12 mm diameter) or bamboo are placed vertically at key junctions such as corners and window or door jambs. These reinforcements should anchor into the foundation and extend through lintel bands and floor slabs to ensure adequate tensile strength. In stone masonry, a pipe casing is used to form a cavity around the vertical bar, which is then filled with a 1:2:4 concrete mix as the masonry is built up in layers.

  The aftermath of an earthquake often results in significant destruction due to the unexpected and intense ground shaking, leading to extensive damage in numerous buildings—ranging from minor to partial or complete collapse. Such structural failures frequently result in severe loss of life and high casualty rates. Understandably, survivors may be reluctant to reoccupy these buildings without reassurance of their safety against potential future seismic events. Studies indicate that many earthquake-affected buildings can be safely reused if they undergo seismic retrofitting, which enhances their resistance to future earthquakes. This approach is typically more cost-effective and quicker to implement compared to demolishing and rebuilding structures, making it a practical solution to both economic and immediate housing challenges. Even in cases of significant structural damage, retrofitting is often less expensive than reconstruction. As a result, seismic retrofitting has emerged as a crucial strategy for reducing earthquake risks, particularly in regions prone to seismic activity. Although terms such as repair, strengthening, retrofitting, remodelling, rehabilitation, and reconstruction are often used interchangeably, they carry subtle differences and lack a universally agreed-upon distinction. A general interpretation of these terms is often presented in summary tables for clarity. Seismic retrofitting becomes necessary in two key situations:

(1) buildings that have already sustained earthquake damage, and
(2) buildings that are structurally vulnerable and at risk, even if they haven't yet been subjected to a major earthquake.

Engineers tasked with retrofitting earthquake-damaged structures face several challenges. These include the absence of standardized retrofitting procedures, limited data and experience regarding the long-term performance of retrofitted buildings, and lack of agreement on suitable methods across a wide array of variables—such as building types, material conditions, damage types and severity, and whether specific damaged elements are viable for retrofitting. To address these challenges, it is essential to compile a detailed inventory of feasible and practical retrofitting techniques, tailored to various structural and damage scenarios.

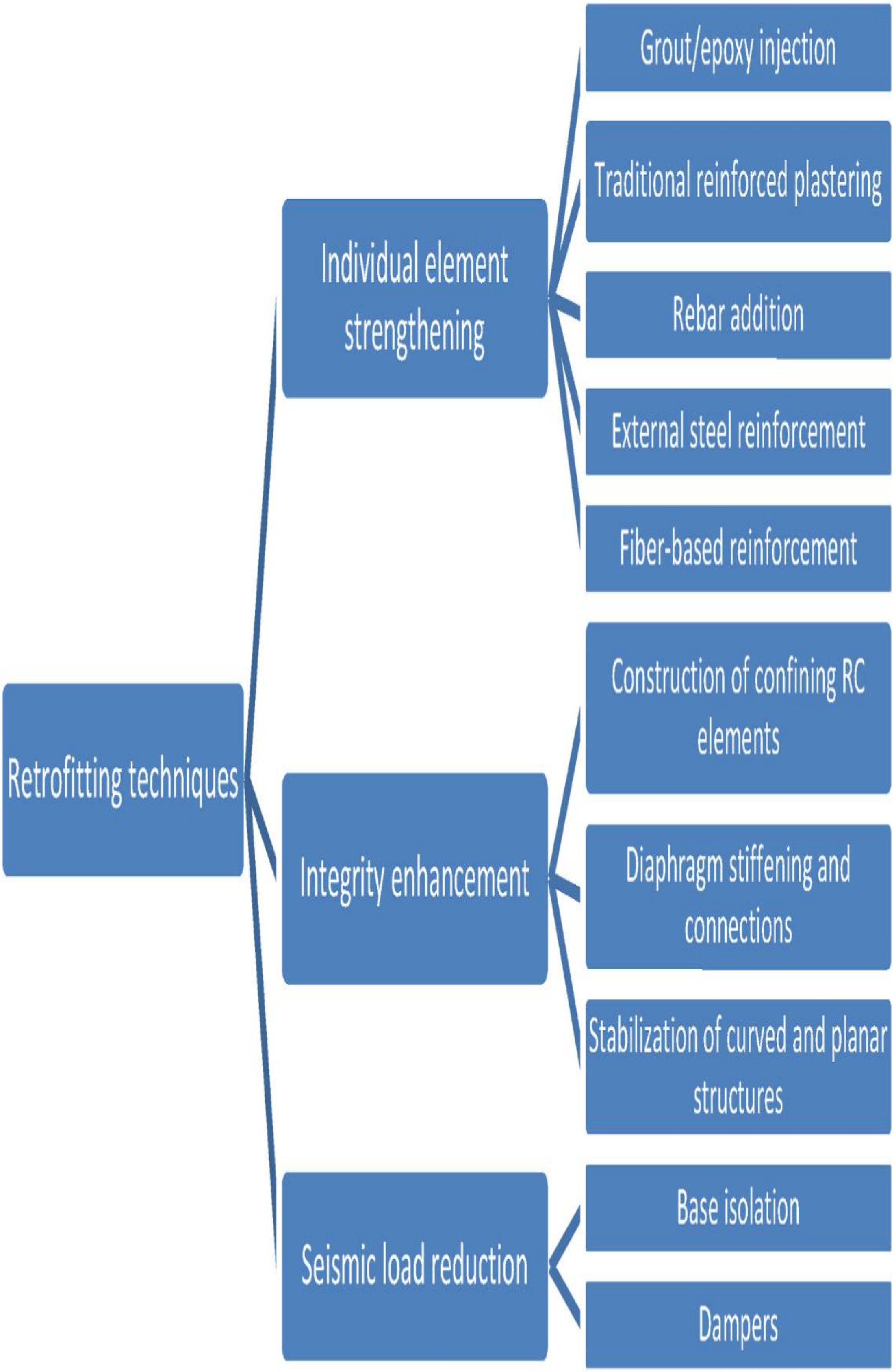

Figure 0.1.1 Retrifitting Techniques

Masonry structures are among the most widely used forms of construction for residential buildings across the globe. In India, they are extensively adopted in rural, urban, and hilly areas due to their adaptability to varying environmental conditions. As a result, over 90% of the population resides in such buildings. Despite their widespread use and popularity, masonry constructions are not without shortcomings—particularly when it comes to seismic performance. Earthquake events in India have highlighted the vulnerability of masonry buildings, which often suffer extensive damage due to their limited seismic resistance. In comparison to reinforced concrete or steel structures, masonry buildings have shown to be more susceptible to seismic forces. One of the contributing factors to this vulnerability is the inadequate seismic design commonly seen in such constructions.

Adhering to the earthquake-resistant measures outlined in the Indian Standards (IS) codes can significantly reduce the risks associated with seismic events. However, a major challenge lies in addressing the existing stock of buildings that were either poorly designed or have already sustained damage from previous earthquakes. These structures continue to pose a risk and present a complex problem for earthquake engineers who are actively seeking effective solutions to mitigate future damage.

One viable approach is the retrofitting of existing buildings, which involves enhancing the seismic capacity of structures that are either deficient by design or have been weakened by past earthquakes. Retrofitting is a challenging yet crucial task, especially considering the large number of seismically vulnerable buildings and the economic and practical difficulties in rebuilding damaged structures immediately after a disaster. Timely retrofitting in accordance with current seismic codes can help ensure that these buildings remain safe and usable in future seismic events.

Although earlier efforts in retrofitting did not yield highly promising results, recent research suggests that with proper techniques, the seismic resilience of retrofitted structures can match that of newly constructed earthquake-resistant buildings. A wide range of both conventional and innovative retrofitting techniques are being explored and implemented to achieve this goal.

1.2 Failure Mode of Masonry Buildings

The appropriate choice of retrofitting techniques for masonry structures depends largely on the specific failure mechanisms observed in each case. Numerous failure patterns have been documented by reconnaissance teams and reported in various research publications. While construction methods, building locations, and structural configurations of masonry buildings differ across regions, the damage induced by seismic events tends to exhibit consistent characteristics. Among the most prevalent failure types in masonry structures are out-of-plane and in-plane failures. **Out-of-plane** failure occurs in walls oriented perpendicular to the direction of seismic waves, where the walls bend outward, often resulting in vertical cracks at the corners or mid-span. Conversely, **in-plane failure** affects walls aligned parallel to the direction of seismic motion, where shear and bending forces lead to horizontal and diagonal cracking patterns. Additional forms of masonry failure include diaphragm failure, pounding between adjacent structures, failure at connection points, and damage to non-structural elements (AGARWAL,P 2014, y,Pp-.

Out-of- plane failure

Insufficient anchorage between the wall and the roof diaphragm, combined with the inherently low tensile strength of both masonry and mortar, often leads to out-of-plane wall failures in unreinforced masonry structures, which are particularly susceptible to such damage. When subjected to lateral forces, the resulting flexural stresses can surpass the masonry’s tensile capacity, causing cracks and eventual collapse. Additionally, long-span diaphragms can contribute to excessive horizontal bending, further increasing the risk of structural failure.

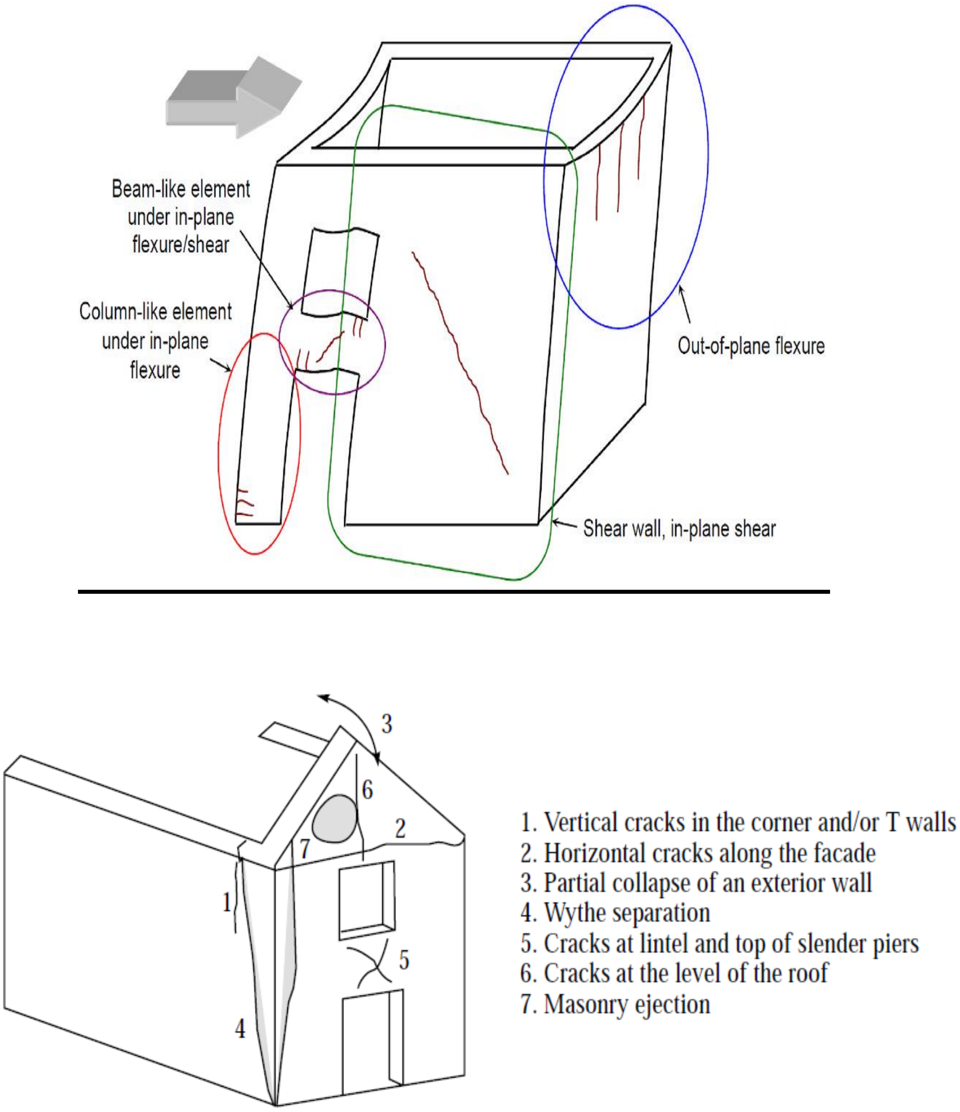

Figure 1.0.2 Out-of Plane Failure

In-plane failure

In unreinforced masonry buildings, in-plane wall failures—caused by excessive bending or shear—are quite common, often identified by the appearance of double diagonal (X-shaped) shear cracks. This distinctive cracking pattern, especially prevalent under cyclic loading, reveals that the walls are unable to resist repeated reversals of load, which can ultimately lead to collapse. However, since earthquake ground motions typically last only a short time, walls usually experience just one or two significant load reversals, so complete collapse is rare. Fortunately, even as these shear cracks become severe, the wall generally retains its ability to support vertical loads. Diagonal tension cracks, or "X" cracks, tend to develop mainly in short wall segments (piers), while slender piers may exhibit rocking at their top and bottom ends. Such damage is usually more pronounced in the lower stories of a building.

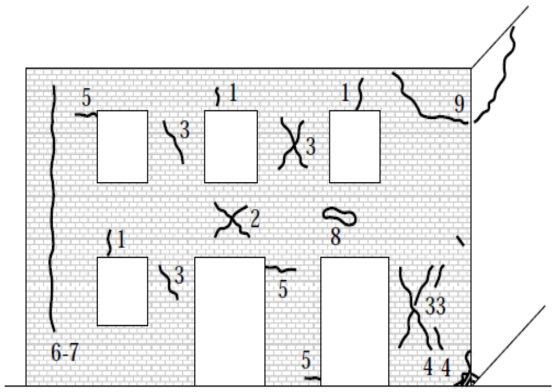

Figure 1.0.3 In Plane Failure

Diaphragm Failure

Diaphragm failure is an uncommon occurrence during seismic activity, and even when damage occurs, the structure's ability to support vertical loads typically remains intact. A critical issue arises when inadequate tension anchoring allows diaphragm forces to push against walls, creating a cantilever-like behavior at the wall base. Damage at wall corners often stems from two factors: in-plane rotation at diaphragm edges and insufficient shear transfer between diaphragms and load-bearing walls. As shown in Figure, excessive diaphragm flexibility can lead to wall failure—a problem virtually absent in retrofitted structures and rare in anchored buildings. However, in strengthened buildings, separation issues often concentrate near the diaphragm's central axis rather than at its edges.

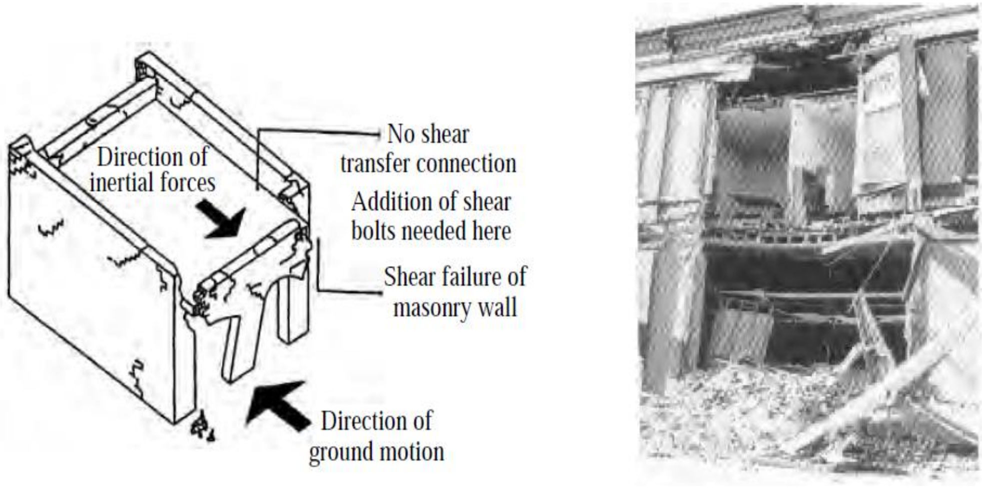

Figure 1.0.4 Diaphragm Failure

Failure of Connections

Seismic inertial forces generated throughout a building are transmitted to horizontal diaphragms via structural connections. These diaphragms then distribute the forces to the vertical structural elements, which ultimately channel them down to the foundation. Therefore, it is crucial to have robust connections that can effectively transfer in-plane shear from the diaphragms to the vertical members while also supporting out-of-plane forces. If these connections are inadequate, diagonal cracks often develop at the wall corners, leading to the separation and potential collapse of these areas (see Figure). This type of failure is further exacerbated by weakly reinforced openings near wall edges and by floors that are not securely tied to the exterior walls.

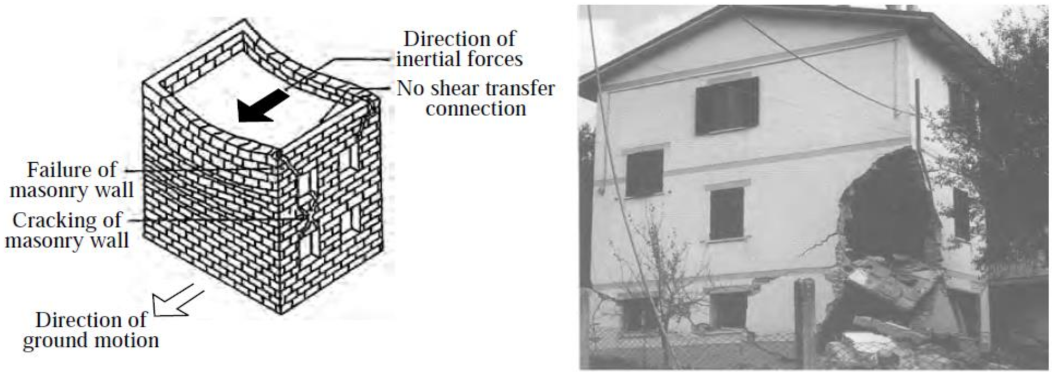

Figure 1.0.5 Failure of Connections

Non-Structural Component Failure

In masonry buildings, non-structural elements such as **parapet walls**, **partition walls**, **staircases**, **water tanks**, **canopie**s, and other projections can be particularly vulnerable during seismic events. If these components are not properly restrained, they tend to act as cantilevers. As a result, they often experience amplified motion compared to the ground itself, making them more susceptible to damage or failure.

Pounding

This type of failure occurs when the roof levels of two adjacent buildings and vertical brick work face flush with one another, the pounding action causes structural distress due to out-of-plane vibrations.

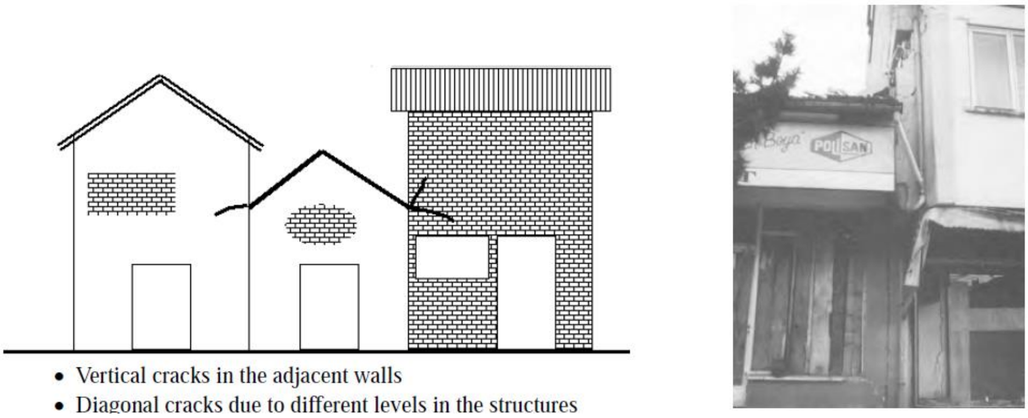

Figure 1.0.6 Pounding

Repair – Reconstruction or renewal of any part of a damaged or deteriorated building to provide same level of strength and ductility, which the building had, prior to damage.

Rehabilitation – Strengthening of a building to its initial strength/ original service level.

Retrofitting – upgradation of seismic resistance of a damaged building up to the level of present-day codes by using appropriate technique, so that it becomes safer under future earthquake occurrence.

It requires neither **demolition** nor **removal of debris**, which are integral parts of reconstruction and which cost, It means **making small changes** to only **some components** of existing buildings, It is **five times cheaper** and faster than reconstruction, Conveniences created in the house are not lost, Can be done in phases in **incremental manner** and, hence is more manageable in terms of resources and time, It is the greenest option for reducing vulnerability, It can help save valuable heritage of vernacular architecture, It can ensure long term safety against future hazards for most number of people with least amount of money and time, with minimum hardship.

The National Institute of Disaster Management (NIDM) plays a pivotal role in enhancing India's disaster preparedness by focusing on capacity building, human resource development, and strategic policy guidance. Its overarching mission is to foster a disaster-resilient society through education, training, and awareness initiatives. NIDM is mandated to lead national efforts in disaster risk reduction. The institute promotes a proactive approach to disaster risk by embedding a culture of preparedness across all sectors. Key responsibilities include the design and implementation of training programs and human resource development strategies. NIDM also contributes to policy development at both national and state levels. The institute raises awareness on managing multiple hazards and enhancing response capabilities. It serves as the headquarters for the **SAARC Disaster Management Centre**, promoting regional collaboration.

1.3 OBJECTIVE OF THE STUDY

- To develop a generalised method for seismic retrofitting of Masonry Structures.
- To suggest retrofitting measures
- The assessment of Pre-Earthquake behaviour
- Designers to get Pre- construction Aid
- To help in understanding the true meaning of IS code

1.4 OVERVIEW OF THESIS

Chapter 1 – deals with description about an introduction to the topic, its application and significance.

Chapter 2 – discusses some of the literature and previous work on retrofitting and applications

Chapter 3 – discusses the methodology followed along with the quantitative, application work carried out.

Chapter 4 – discusses the result and discussion related to the use of method developed

Chapter 5 – deals with the conclusion of present study

FORM [1]

RAPID VISUAL SCREENING OF MASONRY BUILDINGS FOR SEISMIC HAZARDS

Seismic Zone II Ordinary Building

Photograph

Sketch Plan with Length and Breadth

1.1 Building Name: ____________________

1.2 Use: ____________________

1.3 Address: ____________ Pin ____________

1.4 Other Identifiers: ____________________

1.5 No. of Stories ________ **1.6** Year Built ________

1.7 Total Covered Area; all floors (sq.m) ____________

1.8 Ground Coverage (Sq.m): ____________

1.9 Soil Type: ________ **1.10** Foundation Type ______

1.11 Roof Type: ________ **1.12** Floor Type ________

1.13 Structural Components: ____________

1.13.1 Wall Type: BB* ☐ Earthen ☐ UCR* ☐ CCB* ☐

1.13.2 Thickness of wall ________ **1.13.3** Slab thickness __

1.13.4 Mortar Type: Mud ☐ Lime ☐ Cement ☐

1.13.5 Vert. R/F bars: Corners ☐ T-junctions ☐ Jambs ☐

1.13.6 Seismic bands: Plinth ☐ Lintel ☐ Eaves ☐ Gable ☐

*BB — Burnt Brick, *UCR — Uncoursed Random Rubble
*CCB: Cement Concrete Block

2.0 OCCUPANCY	3.0 SPECIAL HAZARD	4.0 FALLING HAZARD
2.1 ***mportant buildings*:** Hospitals, Schools, monumental structures; emergency buildings like telephone exchange, television, radio stations, railway stations, fire stations, large community halls like cinemas, assembly halls and subway stations, power stations, Important Industrial establishments, VIP residences and Residences of Important Emergency person. **Any building having more than 100 Occupants may be treated as **Important**.* **2.2** ***Ordinary buildings*:** Other buildings having occupants <100	**3.1** High Water Table (within 1m) and if sandy soil, then liquefiable site indicated. Yes No **3.2** Land Slide Prone Site Yes No **3.3** Severe Vertical Irregularity Yes No **3.4** Severe Plan Irregularity Yes No	**4.1** Chimneys **4.2** Parapets **4.3** Cladding **4.4** Others

5.0 Probable Damageability in Few/Many Buildings

Building Type	**5.1 Masonry Building**			
Damage-ability in Zone II	**A /A+**	**B/B+**	**C/C+**	**D**
	G2/G1	**G1/–**	**–/–**	**–/–**

Note: +sign indicates higher strength hence somewhat lower damage expected as stated. Also average damage in one building type in the area may be lower by one grade point than the probable damageability indicated.

Surveyor will identify the Building Type; encircle it, also the corresponding damage grade.

RECOMMENDED ACTION:

- ☐ Ensure adequate maintenance.
- ☐ If any Special Hazard 3.0 found, re- evaluate possible retrofitting.

Surveyor's sign: ____________________

Name: ____________________

Executive Engineer's Sign: ____________

Date of Survey: ____________________

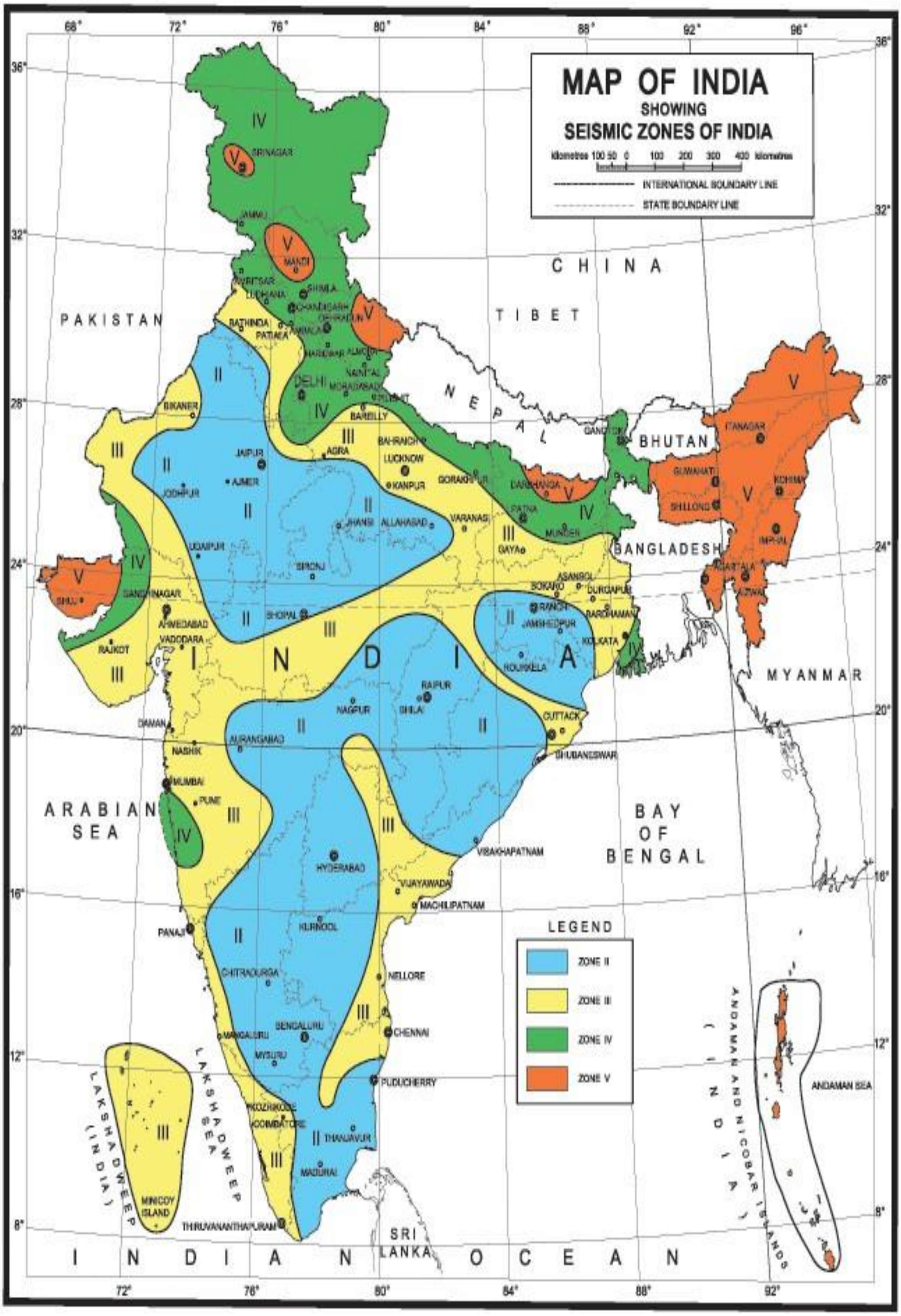

Figure 1.8 Map showing Seismic Zones of India

The relief and reconstruction efforts following the Gujarat earthquake underscored significant areas for improvement in disaster preparedness and response. Several critical insights emerged from this experience:

- Enhancing search and rescue operations requires modern tools and specialized training for emergency responders.
- There is a need for ongoing surveillance using seismic instruments and better predictive systems for natural hazards like floods and cyclones.
- Disaster management strategies should be regularly assessed and updated to incorporate lessons from recent events and to address emerging risks.
- Clearly defined command and coordination structures are essential at every administrative level to ensure efficient response efforts.
- Creating and maintaining a digital resource inventory can support rapid deployment during emergencies.
- Defining the responsibilities of the police, paramilitary forces, and the military within disaster response frameworks is crucial for coordination.
- Pre-positioning critical supplies and equipment in accessible locations can significantly reduce response time during a crisis.
- Control centres at both district and sub-district (taluka) levels require modernization to improve their operational effectiveness.
- Structured training programs for all personnel involved in disaster management are necessary to build readiness and capability.
- Increasing public awareness and encouraging community involvement are fundamental to building resilience and effective local response.

(from catalogue of 2015)

Figure1.8 A Site of Liquefaction

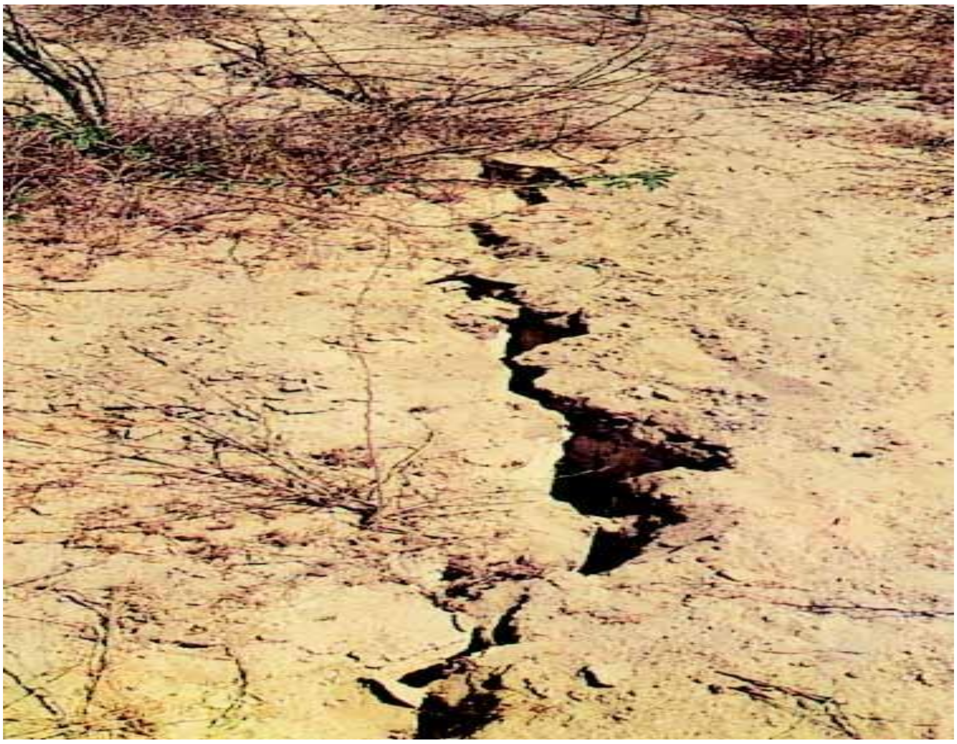

Figure 1.9 Elongated Fractures in the cultivated fields of Vondh Village

Figure 1.10 Highway to Bhuj

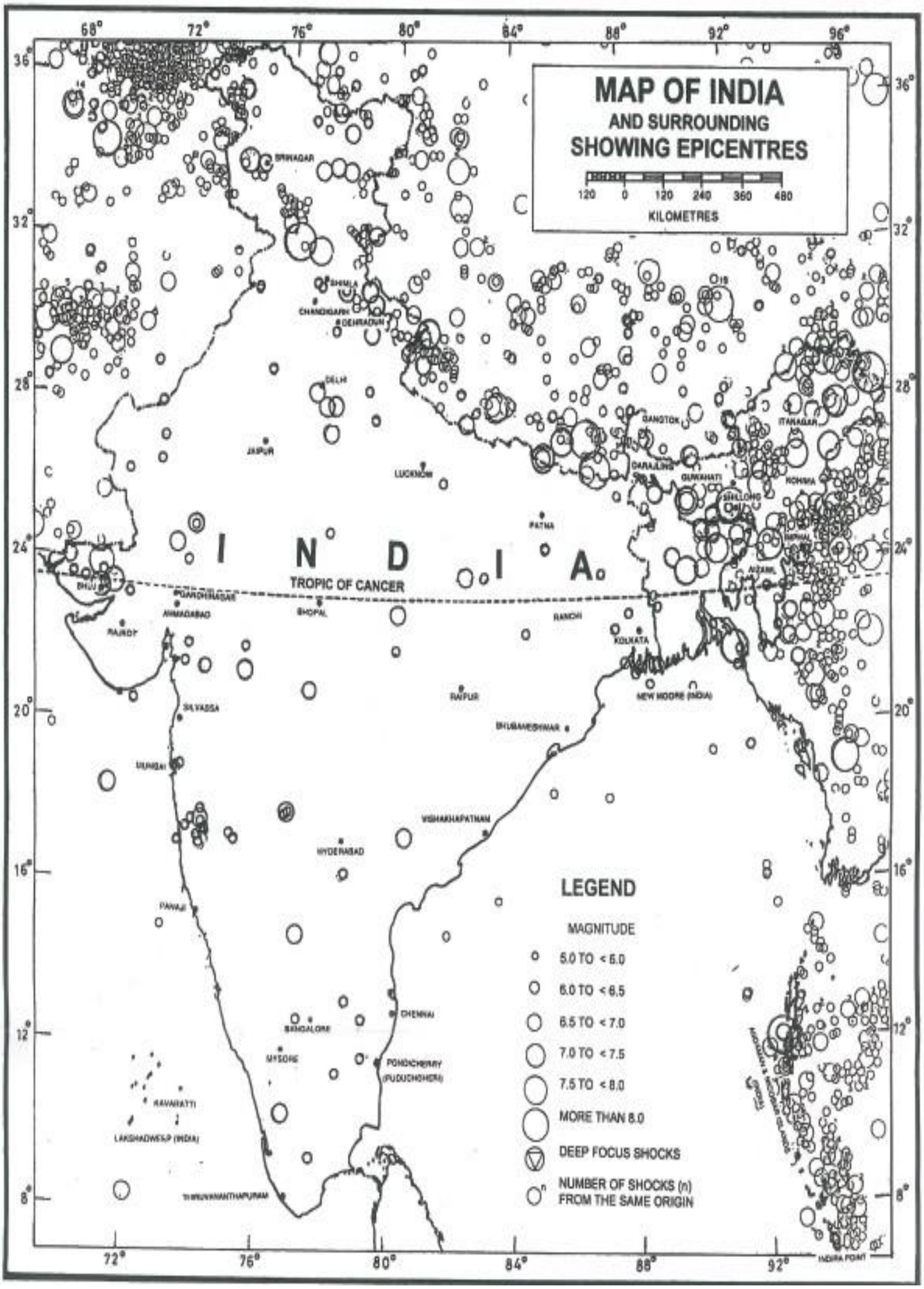

Figure1.11 Map of India showing Epicenters

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

India has historically experienced a significant number of earthquakes. Areas such as the Himalayan-Naga Lushai zone, the Indo-Gangetic plains, Western India, and the Kutch and Kathiawar regions have been sites of some of the world's most catastrophic seismic events. This history of seismic activity highlighted the urgent need for improved earthquake-resistant design and construction standards, especially given the scale of ongoing development and mass construction projects. In response, the standard IS 1893:1962, "Criteria for Earthquake Resistant Design of Structures," was established and later updated in 1966, 1970, 1975, 1984, and 2002. These revisions addressed critical considerations such as seismic zoning, fundamental seismic coefficients, and related parameters. Additionally, IS 13935 introduced several key advancements: the use of non-shrink grouts and fiber-reinforced plastics for repair, restoration, and strengthening work; procedures for assessing the vulnerability of existing masonry buildings to earthquake damage; guidelines for evaluating and implementing retrofitting measures; requirements for seismic reinforcement around door and window openings; and the integration of rapid visual screening (RVS) methods, including standardized survey forms for masonry structures to assess seismic risk. Complementing IS 1893, the standard IS 4326, "Code of Practice for Earthquake Resistant Design and Construction of Buildings," was introduced in 1967 and revised in 1976 and 1993. The 1976 version included specific recommendations for low-strength brick and stone masonry structures, which were not addressed in IS 13828:1993, "Guidelines for Improving Earthquake Resistance of Low Strength Masonry Buildings." Recommendations in these codes focus on limiting the size and placement of openings, incorporating steel reinforcement in horizontal bands and vertical supports at wall corners and openings, and are grounded in calculations that consider steel design coefficients and the ductility of steel reinforcement.

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2.2 LITERATURE STUDY

Cemil Akcay et al (2016) [1]**-** This paper focuses on assessment of historical masonry structures form point of seismic resistance. The complete process was depicted using a case study which is restored within scope of laboratory and numerical analysis in the form of FINITE ELEMENT METHOD. In the first stage plaster analysis and mechanical tests were conducted and in the second stage building's 3d model was developed and the members adequate in strength was determined using numerical analysis. Final stage includes restoration applications based on the above stages. Structural components like volta slab, interior walls, exterior façade walls and door/windows are strengthened by a different technique.

K L Walla et al (2002) [2]**-** This paper discusses the lessons learnt from Gujrat earthquake and emphasizes the need to improve building practices and lessons. The earthquake was registered on 6.9 Richter scale on 26 January 2001. There was significant damage to infrastructure one million homes, 215255 houses were completely destroyed, 2 district hospitals were affected along with death toll was 13000. Investigation reports highlight inadequate supervision and adherence to building standards 90% of houses were outengineered. Building permitting processes are lax, especially towns like Bhuj. Lack of structural engineering to unsafe construction practices. Thus, Criticism of regulatory authorities and construction practices has been widespread. Numerous Indian institutions focus on earthquake-resistant design and construction. Bureau of Indian Standards (BIS) has published several codes for earthquake-resistant buildings. Deficient construction practices are linked to reduced supervision and participation by engineers. Engineers need to be more proactive in advocating for better building standards. Knowledge dissemination and enforcement of building codes are essential for earthquake safety. Retrofitting existing buildings and emergency planning should be prioritized. Leadership from various sectors is necessary to integrate seismic safety into public policy. Countries like New Zealand have developed disaster recovery plans and emergency management procedures.

Ayoub Keshmiry et al (2024) [3]**-** Over recent decades, reinforced masonry has gained recognition as a reliable and economical building material, especially in regions susceptible to earthquakes, due to its advantageous cost–benefit ratio. In contrast, unreinforced masonry materials often exhibit nonlinear behavior under stress because of their inherently low tensile strength. As these materials degrade, their capacity to withstand loads and deformations diminishes, leading to a phenomenon known as material softening. The development of internal cracks and the progressive accumulation of damage are typical failure mechanisms in quasi-brittle materials. Research by Abbass et al. demonstrated that applying graphene/polyurethane nanocomposite coatings can significantly improve both the mechanical properties and environmental durability of natural fibers used in masonry retrofitting. Their studies reported increases of 120% in tensile strength and 163% in elastic modulus. Meanwhile, Brinkmann and Wiehle focused on creating a practical method to evaluate how varying moisture levels affect the mechanical performance of unstabilized earth masonry. Their results revealed a direct linear relationship between compressive strength, modulus of elasticity, and relative humidity. Damage within a structure can be described as alterations to its geometry or material composition, which may compromise both its current state and future functionality. From 2000 to 2023, there has been a notable surge in research dedicated to the assessment of masonry structures, as indicated by data from Scopus. Nonetheless, other essential aspects such as repair and strengthening within masonry maintenance programs have not received the same level of scholarly attention. Common method of NDT and MDT for masonry structures are Flat Jack Testing, Flat Jack-shear compression test, Ground Penetrating Radar, Ultra Sonic Pulse Velocity, Impact echo testing, Thermography, Impulse Radar Testing.

Reza Amiraslanzadeh et al (2012) [4]**-** This document explores and evaluates various seismic retrofitting techniques for masonry brick walls, highlighting their respective advantages, disadvantages, and constraints. It identifies the most appropriate methods for both historical and traditional brick masonry structures, with consideration given to cost-effectiveness and overall performance. Among the techniques analyzed, the center core method and surface treatment emerge as the most effective—enhancing in-plane and out-of-plane responses, respectively. The center core technique is particularly beneficial for heritage buildings due to its minimal impact on the structure's appearance and integrity. In contrast, surface treatment is well-suited for conventional buildings because it is affordable and does not require skilled labor. The majority of human deaths in such structures are because of out-of-plane corruption of URM. Experiments have proved that the buildings retrofitted through bamboo-band could withstand twice large input energy as compared to those which are non-retrofitted. Application of FRP in URM increase both in-plane and out-plane strength. Under static cycle load test also the FRP has increased/ The lateral strength by a factor of 1.7 to 5.9. FRP also improves shear strength of wall by a factor of 1.3 to 2.9. Post-tensioning can increase lateral strength of URM by a factor of 2. The method of confinement increases the lateral resistance of wall by factor of 1.2 for high aspect ratio wall lateral resistance of wall increase by factor of 1.5. Confinement improves the lateral deformation and energy dissipation by more than 50%. Injection method does not affect the surface of the wall but improves the compressive and shear strength of wall by improving its initial stiffness. Epoxy resin is typically used for injecting and sealing small cracks that are less than 2 mm wide. In contrast, cement-based grout is more suitable for addressing larger cracks, voids, and unfilled collar joints in multi-wythe masonry walls. This type of grout injection can restore up to approximately 80% of the original compressive strength of unretrofitted masonry. Moreover, research by Hamid et al. showed that cement-based grout significantly enhances the shear bond strength at the interfaces of multi-wythe stone walls, with improvements ranging from 25 to 40 times. Additionally, the lateral resistance of the retrofitted walls was found to increase by a factor of 2 to 4 compared to unretrofitted walls. As high masses of URM are a considerable problem, thus those retrofitting methods are adopted which adds less mass to the structures.

P.D. Gkournelos et al (2022) [5]**-** The document highlights that older masonry structures, due to their age and increased vulnerability, require more extensive structural retrofitting compared to newer buildings constructed with advanced materials. The paper categorizes retrofitting techniques into three main groups. The first group focuses on methods that enhance the cyclic performance of individual structural components. The second group encompasses strategies designed to improve the overall structural integrity of the entire building. The third category includes approaches that utilize specialized devices to reduce internal forces generated by seismic activity. In many developed nations, a significant portion of the building stock has surpassed its intended lifespan. For instance, in Europe, approximately 80% of buildings were constructed before the 1990s, and 40% date back to before the 1960s, making them over half a century old. This aging infrastructure contributes substantially to environmental challenges, as buildings in the European Union account for 40% of total energy consumption and 36% of CO_2 emissions.. Multi-leaf walls, often found in older structures, require effective connections to ensure structural integrity. Strengthening techniques for these walls can significantly enhance their load capacity and ductility. Traditional connections using diatones may be inadequate, necessitating additional measures. Experimental studies show that grout injection combined with steel tying improves the combined response of masonry leaves. Transverse steel connectors can double the axial load capacity of multi-leaf wall. Here surface reinforcement involves applying a new layer of material to the exterior of masonry walls to enhance their tensile strength. This method is widely used and can significantly improve the structural performance of masonry elements. Steel mesh embedded in cementitious mortar is a common reinforcement method. Shotcrete can cover large areas quickly and improve both in-plane and out-of-plane resistance. The thickness of the reinforcing layer can be adjusted to fine-tune the degree of strengthening.

Qiao Qiyun et al (2025) [6]**-** The enhancement and rehabilitation of masonry structures affected by seismic activity have drawn considerable interest in recent years. This study introduces a retrofitting technique that employs a combination of steel and polymer mortar, specifically designed for masonry buildings damaged during earthquakes. To evaluate the method’s effectiveness, shaking table tests were performed on a half-scale, two-story reinforced masonry structure (RMS), as well as on a retrofitted version (R-RMS) strengthened using the proposed technique. Key seismic performance indicators—such as dynamic behaviour, acceleration responses, inter-story drift, and strain—were measured and analysed. The findings indicate that the steel and polymer mortar retrofit notably enhances both the load-bearing capacity and seismic resilience of damaged masonry structures, while also restricting the spread of plastic deformation. Furthermore, the lateral stiffness of the retrofitted model showed a marked improvement. The natural frequencies in the X and Y directions for the R-RMS model increased by 257.35% and 177.78%, respectively. The acceleration amplification factor (AAF) in the second story rose by 69.67% in the X-direction and 62.21% in the Y-direction. Additionally, the inter-story drift of the first story increased by 76.61% and 87.30% in the X and Y directions, respectively. Under rare seismic conditions, the first story experienced significantly less damage compared to both the retrofitted RMS and the second story of the R-RMS, indicating improved structural integrity. The study details the materials used in constructing the RMS and R-RMS models, as well as the setup for the shaking table tests, ensuring accurate representation of real-world conditions. The RMS model utilized clay bricks and mixed mortar with compressive strength of 19.23 MPa and 2.57 MPa respectively. The polymer mortar employed in the R-RMS model had a compressive strength of 37.57 MPa, significantly higher than the ordinary mortar's 10.97 MPa. The shaking table, with a capacity of 300KN, applied various seismic ground motions, including the 1940 EL Centro and 1952 Taft records. The total mass of model was approximately 25.5 tons, with a gravity load representing 61.2% of the full-scale structure.

Simon Petrovcic et al (2025) [8] **-** This research presents an in-depth analysis of the seismic susceptibility of unreinforced masonry (URM) residential buildings erected in Slovenia from 1945 to 1963. The study focuses on more than 400 buildings located in Ljubljana, which were classified into 24 unique categories based on their architectural design, height, and structural characteristics. The evaluation indicated that none of these buildings meet the seismic safety requirements specified in Eurocode 8. Two retrofitting approaches utilizing Fiber Reinforced Cementitious Matrix (FRCM) were analysed: a selective method targeting critical structural elements, and a comprehensive method reinforcing all load-bearing walls. Both strategies improved seismic performance; however, full compliance with Eurocode 8 was not achieved. Selective retrofitting demonstrated higher efficiency in certain scenarios. In the aftermath of World War II, rapid urbanization and housing demands led to the construction of multi-story residential buildings across southeastern Europe, including Slovenia. Many of these structures were built under early Yugoslav building codes, which lacked adequate seismic considerations. The 1963 Skopje earthquake highlighted these deficiencies, prompting the introduction of stricter seismic design provisions. The assessment methodology integrated Geographic Information System (GIS) databases, historical construction data, and advanced numerical modeling. Four representative building typologies were selected for detailed analysis using the 3Muri software, which employs the equivalent frame modeling approach to simulate the seismic behavior of URM structures. FRCM was chosen as the preferred retrofitting technique due to its compatibility with historic masonry substrates and its ability to enhance structural capacity without compromising architectural integrity. The material's properties, including improved fire resistance and minimal application thickness, make it suitable for retrofitting heritage buildings. The effectiveness of FRCM strengthening was analyzed, revealing varying efficiency across building typologies and retrofitting scenarios. A new metric (η) was defined to assess the impact of retrofitting measures relative to the wall area utilized. All building types showed significant increases in η when moving from URM to selective retrofitting (RET). The RET-AW scenario generally resulted in lower η values, indicating that selective strengthening may be more efficient. Seismic hazard curves illustrated the performance of Buildings S and R under various seismic intensities. Both buildings showed improvements but did not meet the 475-year return period target for the Significant Damage (SD) limit state, highlighting the challenges in achieving modern seismic standards. The study evaluates the effectiveness of FRCM retrofitting strategies, revealing that selective retrofitting is generally more efficient than comprehensive retrofitting. This approach is particularly beneficial for buildings with complex geometries and directional weaknesses. FRCM was chosen for its compatibility with historic masonry structures. Selective retrofitting (RET) showed higher efficiency than comprehensive retrofitting (RET-AW).

2.3 RESEARCH GAP

- High cost and need for advanced technology in some retrofitting methods.
- Limited research attention on repair and strengthening methods compared to assessment methods.
- Challenges in SHM due to limited data, financial constraints, and environmental impacts.
- Practical application of SHM is challenging and requires continuous research.
- Complexity in selecting repair and retrofitting methods due to structure-dependent factors.
- Need to translate insights into practical solutions.
- Gaps in knowledge and technology for sustainable retrofitting methods.
- Urgent need to explore retrofitting strategies for resilience against environmental stressors.
- Lack of knowledge about the seismic response of masonry structures.
- Need for interdisciplinary cooperation in analysis and evaluation.
- Gap in effective methods for seismic retrofitting of historical buildings

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The data collection was a quite interesting and proactive work. It was a very learning, lesson giving task to interact with variety of people, initially the people were reluctant, teaching them the importance of earthquake measures, retrofitting and how to minimize the effect in case of adversities. The dataset covers a variety of locations and variety of structures as well. Dimension parameter such as Length, Breadth, Height, Size of door, Size of window, setback distances, thickness of wall etc. are taken. The rigorous method was developed which will save a lot of time and effort ultimately leading to the optimum usage of resources. This process will analyses and compares with the standard guidelines of the IS code on Items of masonry, Requirement as per IS 4326 for Building Category and as a result provides the best suited retrofitting measures for the structure.

3.2 PROCEDURE

The method adopts a quantitative approach, utilizing Microsoft Excel as the primary tool for data collection, organization, analysis, and visualization. The selection of Excel is based on its versatility, accessibility, and robust functionality for handling structured data.

Data were collected from surveys, secondary data. The raw data were entered into Excel spreadsheets with proper structuring, including clear labels, data validation, and consistent formatting. A survey was conducted in which data of around 50 structures were taken. Collected data was entered manually into Excel using a predefined template to ensure consistency and avoid entry errors. Features such as Drop-down lists and data validation rules were applied to minimize errors during data input.

Data were organized using the Excel features for separate sheets for raw data. Raw data were stored in different sheets, while another set of sheets contained cleaned and pre-processed data. Missing values were addressed using mean imputation or removed depending on the cases including cleaned data, and analysis. Named ranges for easier reference in formulas. Filters and conditional formatting to highlight trends or issues. Excel functions and tools were employed for various levels of analysis. **Descriptive statistics**: COUNTIF, **Data cleaning**: IFERROR, TRIM, CLEAN, SUBSTITUTE, **Pivot tables:** for summarizing data by categories. The accuracy of the analysis were cross-checked and reviewed manually. Tables were validated by comparing them against known benchmarks and using secondary tools (manual calculations). Data integrity checks were done using Excel's error-checking tools and conditional formatting.

3.3 INPUT PARAMETERS FOR THE TABLE

Table 3.1 Provisions in IS 4326 and Actions for Retrofitting

SI No	Item of Masonry	Requirement as per IS 4326 for Building Category				Action for Retrofitting
		B	C	D	E	
1	Mortar	CLS-1:2:9	CS-1:6	CLS-1:1:6	CS-1:4	Change of mortar not feasible. Hollowness may be filled by grouting or walls may be strengthened by ferro-cement plating or fibre-wrapping
2	Door, Window opening:$b_5$min	0.0	230mm	450mm	450mm	Increase by build-up or reinforce with belt
	(b1+b2+b3)/l,Max:					Attain the limit by closing/ narrowing an opening or reinforce the opening by seismic belting
	One storey	.6	.55	.5	.5	
	two storey	.5	.46	.42	.42	
	three storey	.42	.37	.33	.33	
	four storey	.42	.37	.33	4 storey building not allowed in zone V	
	$b_4$min	340 mm	450 mm	560 mm	560 mm	Increase by build-up or reinforce with belt

3	Length of wall between cross wall	_	Maximum Length =35 x thickness or 8 m whichever less			If length more, provide plaster or buttress
4	Height of wall from floor to ceiling	_	Maximum = 15 times thickness or 4 m whichever is less			If height more, add plaster to increase effective thickness
5	Random-Rubble walls	‘Through’ or Header stones, one each in 0.72 m^2 surface area of wall . Long stones at corners of walls, in each wall in every alternate course.				If not provided, install RC headers in holes made by removing stone
6	Horizontal Seismic Band: Plinth Level	Needed if soft (Type III) soil at base				Provide seismic belt, if plinth height>=90 cm
	Door window lintel level	Needed in all cases with varying reinforcement and thickness specified in each case				Provide seismic belt of equivalent strength on both sides of walls
	Ceiling or eave level	Need in sloping roofs or floor or roofs of prefab, materials needed in case of pitched roof				Repeat
	Gable or ridge wall	Needed in case of pitched roofs				Repeat
	Window sill level or dowels	Not required buildings only	Not required	Required in 3 and 4 storeyed	Required in all buildings	Repeat
7	Vertical bar at each corner and T-junction of wall	Needed in only 4 storey building	Needed in 3 and 4 storey building	Needed in all buildings	Needed in all buildings(4 storeys not permitted)	Install equivalent bars or vertical belts at corner and T junctions
8	Vertical bar at jambs of doors and windows	Not needed	Repeat	Repeat	Repeat	Install equivalent seismic belts around the opening

Source: (First Revision)," BIS, 2009.

Table 3.2 Provisions for Roof and Floor in IS 4326 and Actions for Retrofitting

SI No	Item of Roof/Floor	Requirement as per IS 4326 and Action for Building Category				Retrofitting Action, if Code provision not satisfied
		B	C	D	E	
1	Roof/floor with prefabricated/pre-cast elements	Tie beam all around		All round tie beam and RC screed		Provide RC steel and seismic belt or band around
2	Roof/floor with wooden joists, various covering elements(brick, reeds, etc) and earth fill	- All round seismic band and integration of units as a rigid horizontal diaphragm				Provide seismic belt around, inter connect beam ends through wooden planks and diagonal x -ties
3	Sloping roofs with sheet or tile coverings	- i) Horizontal x bracing at level of ties of the trusses - ii) X-bracing in the planes of the rafters and purlins				Install the x-bracing, anchor trusses into the walls and rafters into seismic belt at eave.
4	Jack arch roof/floor	- Connect the steel joists by horizontal ties at intervals to prevent spreading and cracking of the arches. Provide seismic belt all around				Install steel flats as by welding them to the steel joists and provide seismic belt.
RC screed- RC screed consists of minimum 14 mm concrete reinforcement with 6 mm dia bars @ 100 mm c/c both ways(single layer), covering the whole roof/floor.						

Source: (First Revision)," BIS, 2009.

Table 3.3 Recommended Mortar Mixes

SI No	Building Category	As given in IS 1905	Grade of Mortar	Mix Proportions (By Loose Volume)			Minimum Compressive Strength at 28 Days N/mm^2
				Cement	Lime	Sand	
1	**E**	2(a)	H2	1	C/4 or B	4	7.5
		2(b)	-	1	C/4 or B	4 ½	6
2	**D**	3(a)	M1	1	-	5	5
		3(b)	-	1	C or B	6	3
3	**C**	4(a)	M2	1	-	6	3
		4(b)	-	1	2B	9	2
4	**B**	5(a)	M3	1	-	7	1.5
		5(b)	-	1	3B	12	1.5

Source: (First Revision)," BIS, 2009.

Table 3.4 Masonry Load Bearing Wall Buildings

SI No	Building Type	Description
1	A	Rubble (Field stone) in mud mortar or without mortar usually with sloping wooden roof Mud walls, Adobe walls of two storeys UCR masonry without adequate through stones Masonry with rounded (undress) stones
2	A+	Adobe (unburnt block or brick) walls of single masonry Rammed earth/Pise construction
3	B	Semi dressed, rubble, brought to courses, with through stones and long corner stone unreinforced brick walls with country type wooden roofs, unreinforced CC block wall constructed in mud mortar or weak lime mortar. Earthen Walls (Adobe, Rammed earth) with horizontal wooden elements.
4	B+	Unreinforced brick masonry in mud mortar with vertical wooden posts or horizontal wooden elements or seismic band (IS 13828). Unreinforced brick masonry in lime mortar.
5	C	Unreinforced masonry walls built from fully dressed (Ashlar) stone masonry or CC block or burn brick using good lime or cement mortar, either having RC floor/roof or sloping roof having eave level horizontal bracing system or seismic band. AS at B(a) with horizontal seismic bands (IS 13828).
6	C+	Like C(a) type but having horizontal bands at lintel level of doors and windows
7	D	Masonry construction as at C(a) but reinforced with bands and vertical reinforcement, etc or confined masonry using horizontal and vertical reinforcing walls
NOTE- In rural areas, there are huts or shacks made from bio-mass and metal sheets etc. Their vulnerability to earthquake is very low .		

Source: (First Revision)," BIS, 2009.

Table 3.5 Damageability Grades of Masonry Buildings

SI No	Types of Building	Zone II (MSK VI or less)	Zone III (MSK VII)	Zone IV (MSK VIII)	Zone V (MSK IX or More)
1	A And A+	Many of grade 1 Few of Grade 2 (rest no damage)	Many of grade 3 Few of Grade 4 (rest of grade 2 or 1)	Many of grade 4 Few of Grade 5 (rest of grade 3,2)	Many of grade 5 (rest of grade 4)
2	B And B+	Few of Grade 1 (rest no damage)	Many of grade 2 Few of Grade 3 (rest of grade 1)	Many of grade 3 Few of Grade 4 (rest of grade 2)	Many of grade 4 Few of Grade 5 (rest of grade 3)
3	C And C+	Few of Grade 1 (rest no damage)	Many of grade 1 Few of Grade 2 (rest of grade 1)	Many of grade 2 Few of Grade 3 (rest of grade 1)	Many of grade 3 Few of Grade 4 (rest of grade 2)
4	D	_	Few of Grade 1	Few of Grade 2	Many of grade 2 Few of Grade 33 (rest of grade 1)

Source: (First Revision)," BIS, 2009.

Table 3.6 Grades of Damageability of Masonry Buildings

Grade 1 Negligible to slight damage (no structural damage, slight non-structural damage)
a) Structural hair line cracks in very few walls. b)Non-structural Fall of small pieces of plaster only. Fall of loose stones from upper parts of building in very few cases
Grade 2 Moderate damage (slight structural damage, moderate non-structural damage)
a) Structural Cracks in many walls, thin cracks in RC slabs and A.C. sheets. b) Non structural Fall of fairly large pieces of plaster, partial collapse of smoke chimneys on roofs. Damage to parapets, chajjas. Roof tiles disturbed in about 10 percent of the area. Minor damage in under structure of sloping roofs.
Grade 3 Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
a) Structural Large and extensive cracks in most walls. Wide spreading of coloumn and piers. b)Non-Structural Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
Grade 4 Very heavy damage(heavy structural damage, very heavy non-structural damage)
Structural Serious failure of walls(gaps in walls), inner walls collapse; partial structure failure of roofs and floors.
Grade 5 Destruction (very heavy structural damage)
Total or near total collapse of the building

Source: (First Revision)," BIS, 2009

CHAPTER 4

RESULTS AND DISCUSSIONS

Table 4.1 Field Survey and Data Collection

Figure4.1 Field Survey and Data Collection

Table 4.2 CASE A

Figure 4.2 Manik chowk, jhansi

Manik chowk, jhansi			
	Seismic Zone	II	
	Building use	Ordinary	
	Building category	B: Table no 2 IS 13935	
	Soil Type	Type I (Rock)	
	Foundation type	Isolated	
	Mortars	C:L:S – 1:2:9	
	Type of masonry	confined masonry	
	Masonry as per Load bearing	A: Rubble (Field stone) in mud mortar or without mortar usually with sloping wooden roof Mud walls, Adobe walls of two storeys UCR masonry without adequate through stones Masonry with rounded (undress) stones	
	Dimensions	B1=.8m, B2=.5m, B3=.3m, B4=.5m ,B5= 1.5m, L=8m, H= 3m	

	Damageability	G2 : a) Structural Cracks in many walls, thin cracks in RC slabs and A.C. sheets. b) Non structural Fall of fairly large pieces of plaster, partial collapse of smoke chimneys on roofs. Damage to parapets, chajjas. Roof tiles disturbed in about 10 percent of the area. Minor damage in under structure of sloping roofs.	
	No of floors	3	
	Falling hazard	No	
	Special hazard	No	
	Item of roof/floor	Pre-fabricated or Pre-cast roof	

Retrofitting Measures -:

1) b4- Increase by build-up or reinforce with belt.
2) b5- Increase by build-up or reinforce with belt.
3) Mortar- Change of mortar not feasible. Hollowness may be filled by grouting or walls may be strengthened by ferro-cement plating or fibre-wrapping.
4) Door window lintel level- Provide seismic belt on both sides
5) Ceiling or Eave Level- Provide seismic belt on both sides

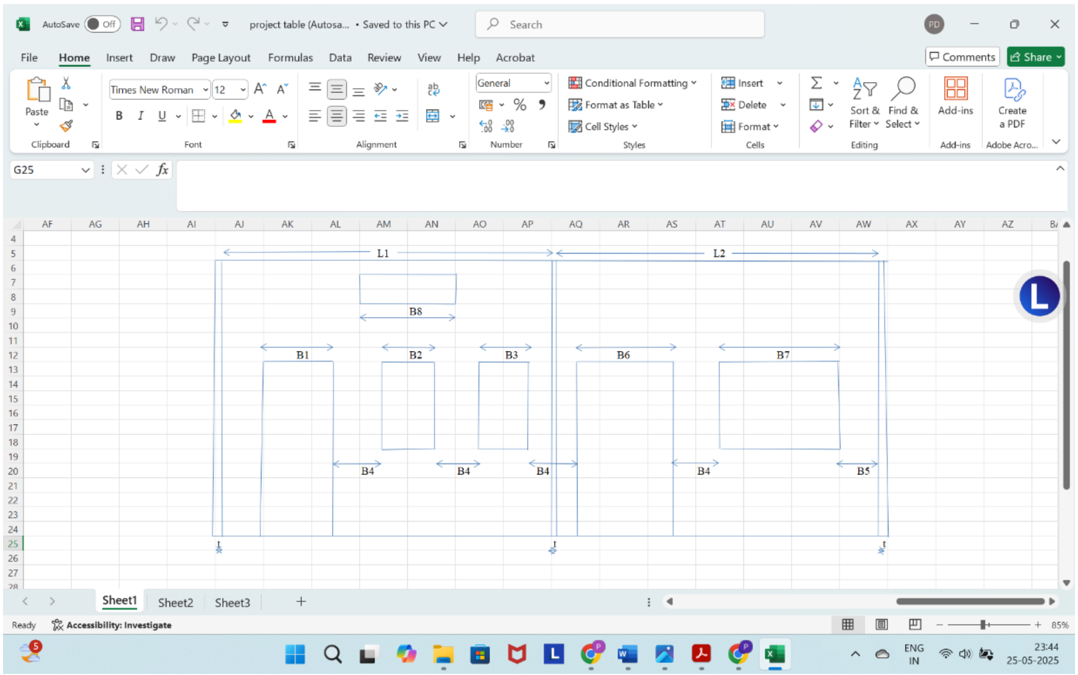


Figure 4.2.1 Manik chowk, jhansi, sheet 1

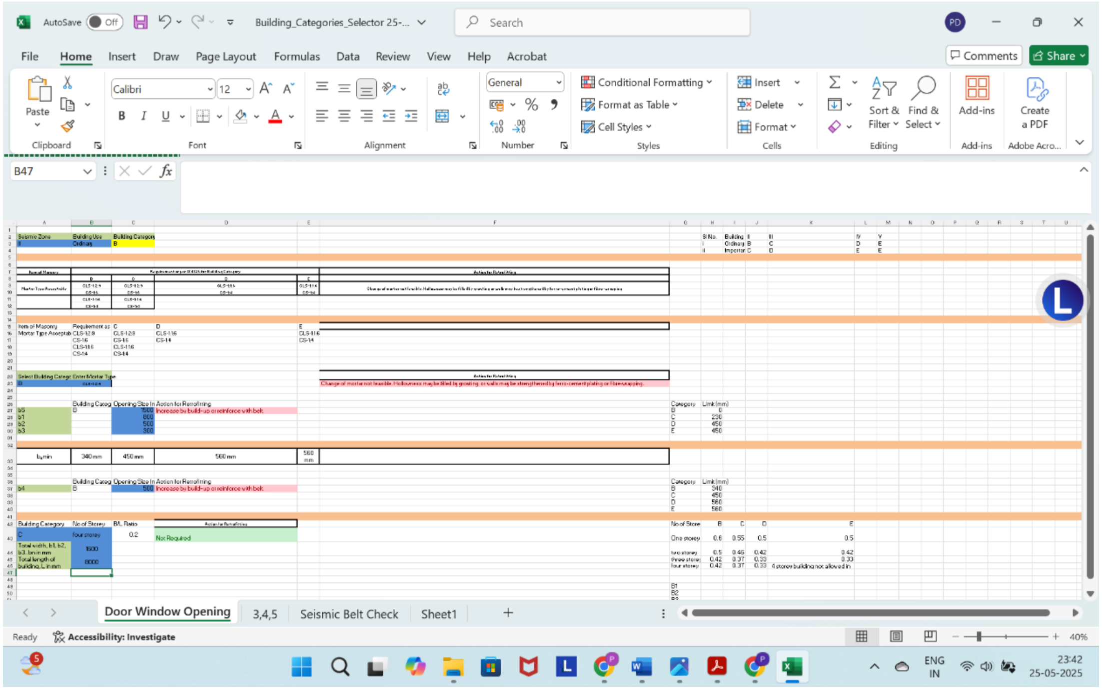


Figure 4.2.2 Manik chowk, jhansi, sheet 2

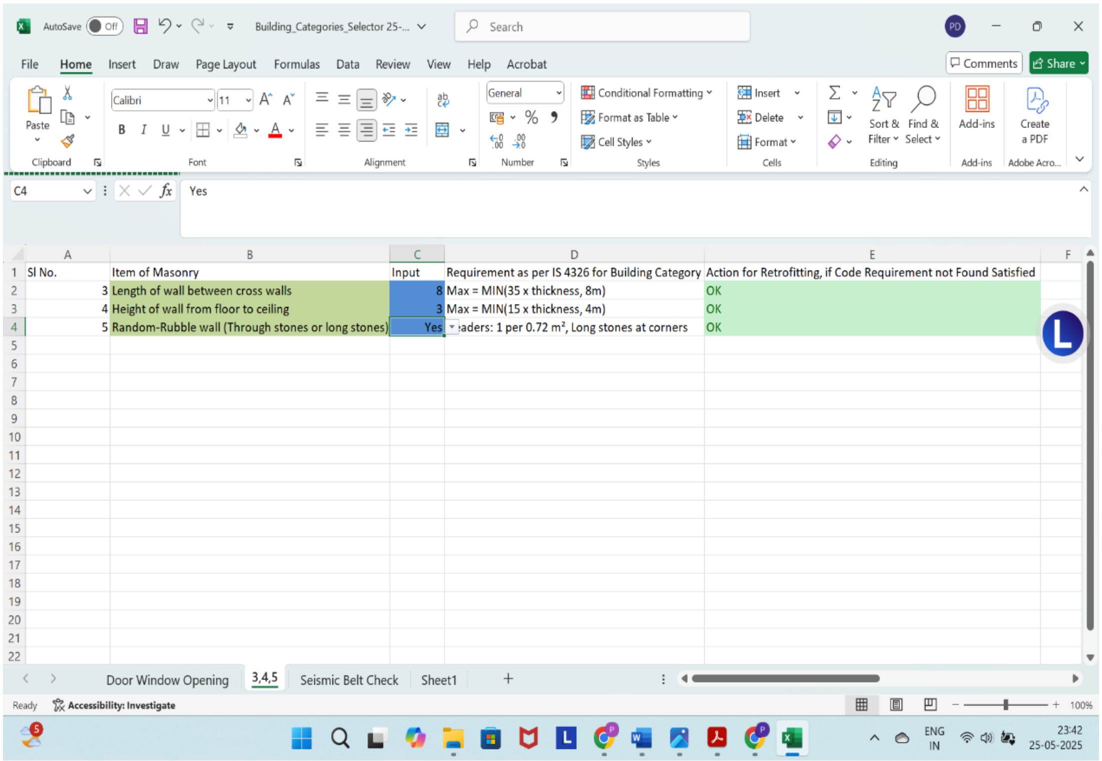


Figure 4.2.3 Manik chowk, Jhansi, sheet 3

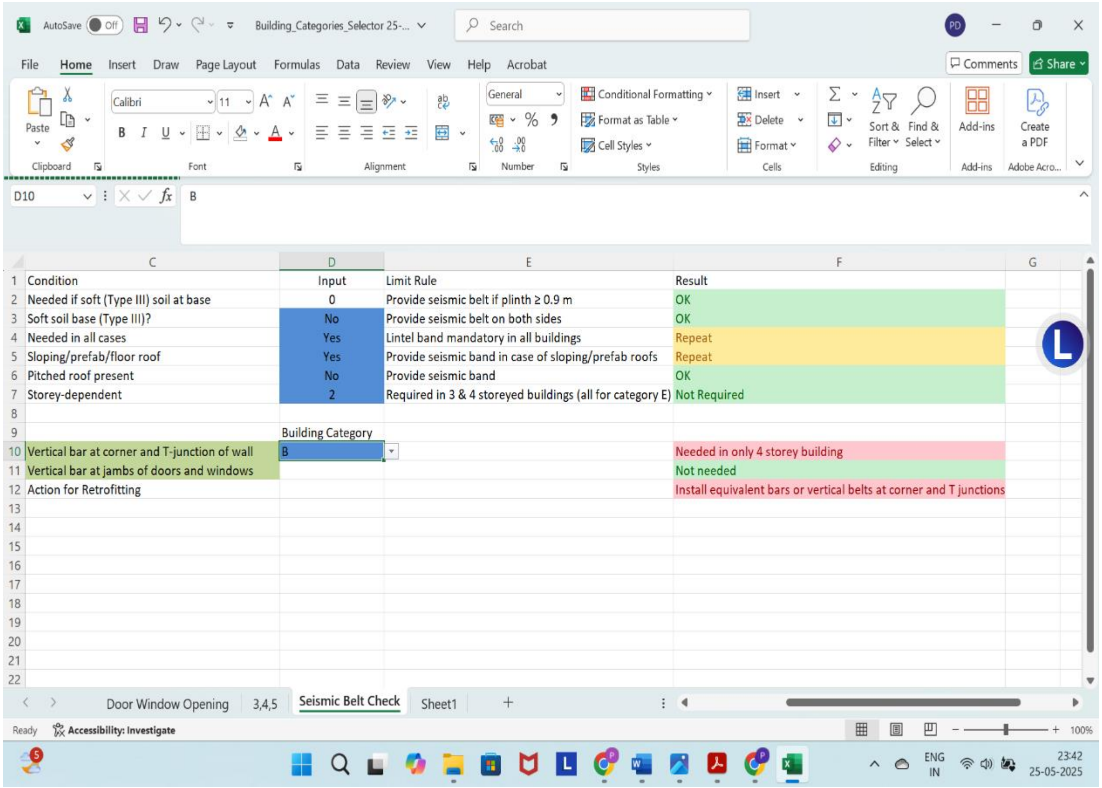


Figure 4.2.4 Manik chowk, Jhansi, sheet 4

Table 4.3 CASE B

Figure 4.3 Temple, Jhansi

	Seismic Zone	II	
	Building use	Important	
	Building category	C: Table no 2 IS 13935	
	Soil Type	Type II (medium)	
	Foundation type	Isolated	
	Mortars	C:L:S – 1:1:6	
	Type of masonry	confined masonry	
	Masonry as per Load bearing	D: Masonry construction with vertical and horizontal reinforcing of walls	
	Dimensions	B1=1.25m, B2=1m, B3=2.5m, B4=.5m, B5=.5m ,L=10 m, H=3.5m	
	Damageability	G1 a) Structural hair line cracks in very few walls. b)Non-structural Fall of small pieces of plaster only. Fall of loose stones from	

		upper parts of building in very few cases	
	No of floors	2	
	Falling hazard	No	
	Special hazard	No	
	Item of roof/floor	Roof/floor with prefabricated/pre-cast elements	

Retrofitting Measures -:

1) b4- Increase by build-up or reinforce with belt.
2) b5- Increase by build-up or reinforce with belt.
3) B/L Ratio- Attain the limit by closing/ narrowing an opening or reinforce the opening by seismic belting
4) Mortar- Change of mortar not feasible. Hollowness may be filled by grouting or walls may be strengthened by ferro-cement plating or fibre-wrapping.
5) Length of wall between cross walls- Provide plaster or buttress
6) Height of wall from floor to ceiling- Add plaster to increase effective thickness
7) Random-Rubble wall (Through stones or long stones)- Install RC headers in removed stone holes
8) Plinth Level (Soft soil)- Provide seismic belt on both sides
9) Door window lintel level- Provide seismic belt on both sides
10) Ceiling or Eave Level- Provide seismic belt on both sides
11) Vertical bar at corner and T-junction of wall- Needed in 3 and 4 storey building
12) Vertical bar at jambs of doors and windows- Needed in 3 and 4 storey building.

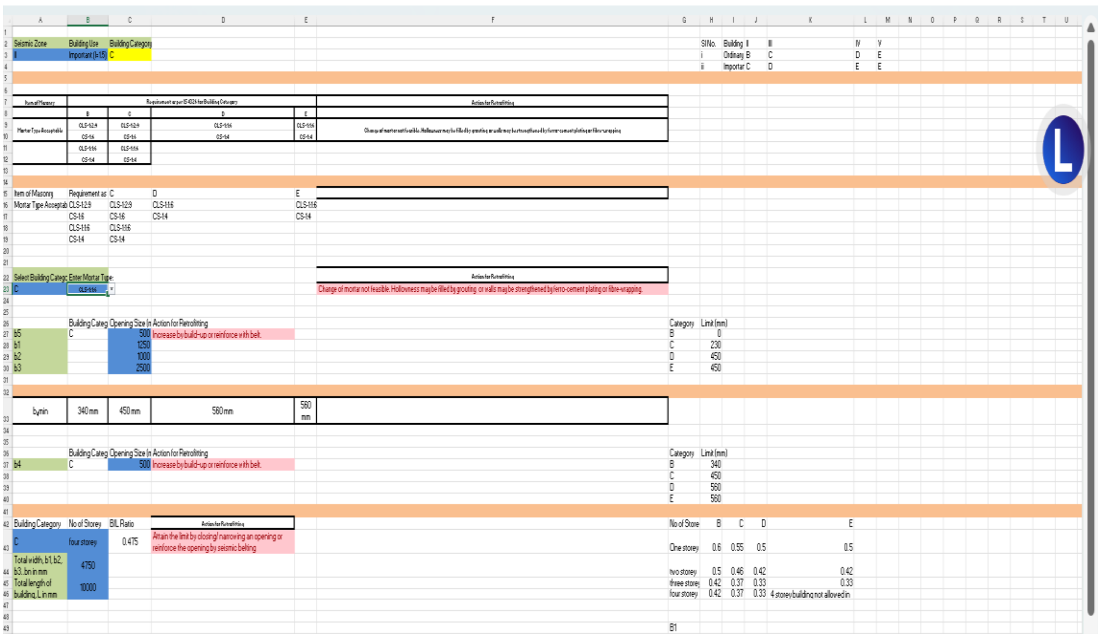
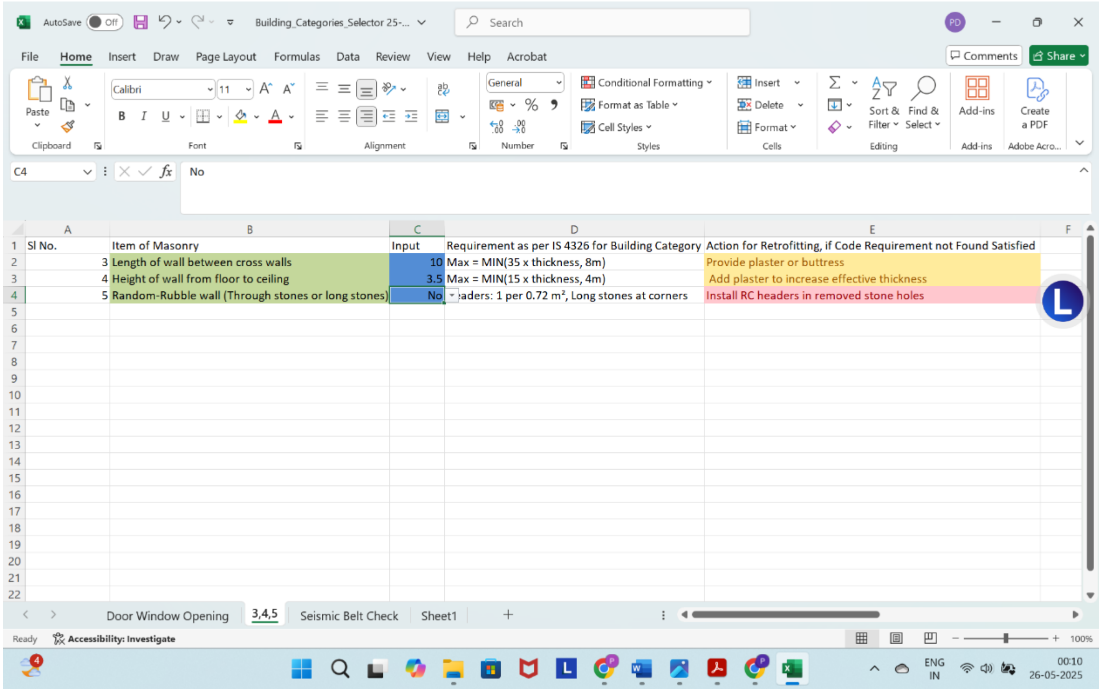
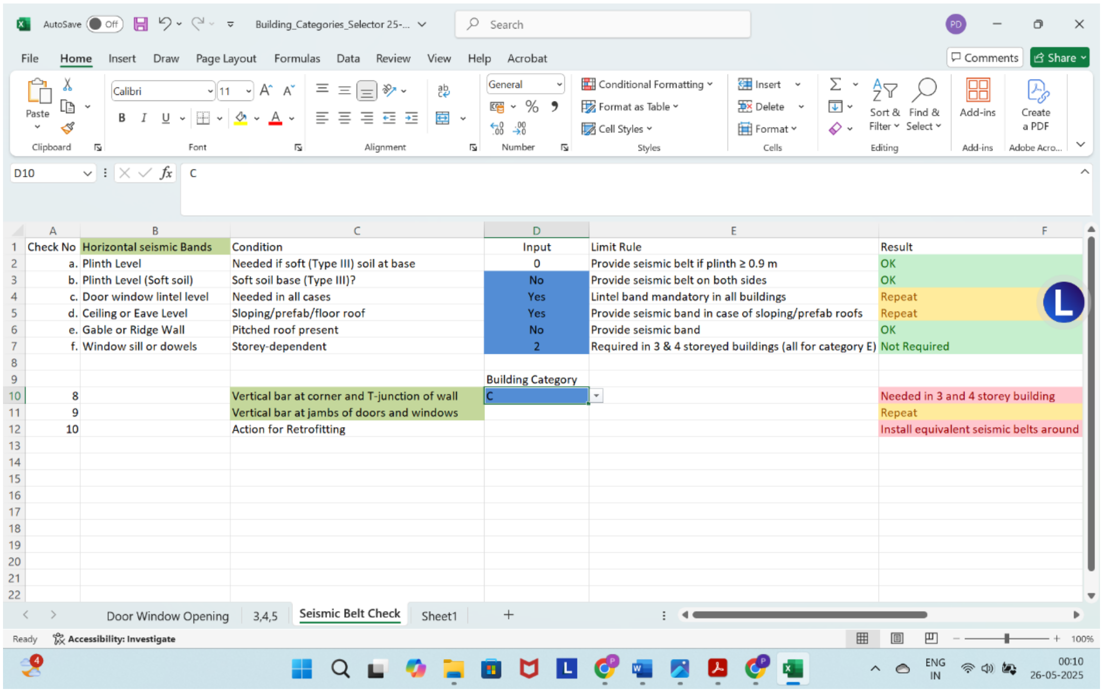


Figure 4.3.1 Temple, Jhansi



Sl No.	Item of Masonry	Input	Requirement as per IS 4326 for Building Category	Action for Retrofitting, if Code Requirement not Found Satisfied
3	Length of wall between cross walls	10	Max = MIN(35 x thickness, 8m)	Provide plaster or buttress
4	Height of wall from floor to ceiling	3.5	Max = MIN(15 x thickness, 4m)	Add plaster to increase effective thickness
5	Random-Rubble wall (Through stones or long stones)	No	:aders: 1 per 0.72 m², Long stones at corners	Install RC headers in removed stone holes

Figure 4.3.2 Temple, Jhansi



Check No	Horizontal seismic Bands	Condition	Input	Limit Rule	Result
	a. Plinth Level	Needed if soft (Type III) soil at base	0	Provide seismic belt if plinth ≥ 0.9 m	OK
	b. Plinth Level (Soft soil)	Soft soil base (Type III)?	No	Provide seismic belt on both sides	OK
	c. Door window lintel level	Needed in all cases	Yes	Lintel band mandatory in all buildings	Repeat
	d. Ceiling or Eave Level	Sloping/prefab/floor roof	Yes	Provide seismic band in case of sloping/prefab roofs	Repeat
	e. Gable or Ridge Wall	Pitched roof present	No	Provide seismic band	OK
	f. Window sill or dowels	Storey-dependent	2	Required in 3 & 4 storeyed buildings (all for category E)	Not Required
			Building Category		
8		Vertical bar at corner and T-junction of wall	C		Needed in 3 and 4 storey building
9		Vertical bar at jambs of doors and windows			Repeat
10		Action for Retrofitting			Install equivalent seismic belts around

Figure 4.3.3.0.1Temple, Jhansi

Table 4.4 CASE C

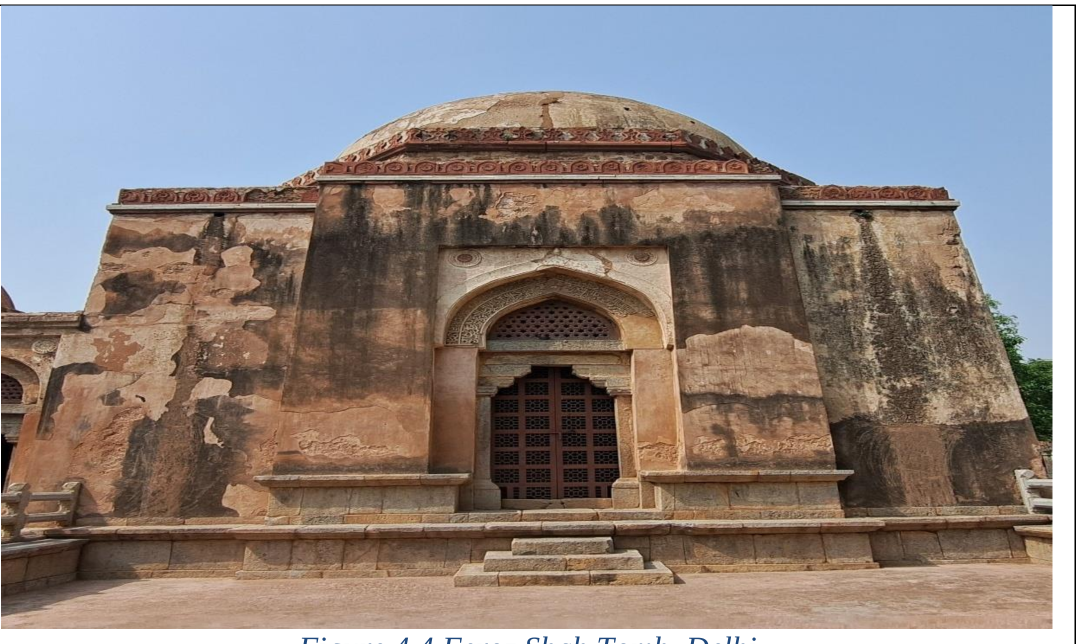


Figure 4.4 Feroz Shah Tomb, Delhi

	Seismic Zone	IV	
	Building use	Important	
	Building category	E: Table no 2 IS 13935	
	Soil Type	Type III (soft)	
	Foundation type	Isolated	
	Mortars	Lime mortar	
	Type of masonry	rubble masonry finished with lime plaster	
	Masonry as per Load bearing	C: Unreinforced masonry walls built from fully dressed (Ashlar) stone masonry using good lime with sloping roof .	
	Dimensions	B1=1.75m, B2=0, B3=0 ,L=11 m, H= 7.5 m, B4=0, B5= 4.625m.	
	Damageability	G1 : a) Structural hair line cracks in very few walls. b)Non-structural Fall of small pieces of plaster only. Fall of loose stones from upper parts of building in very few cases	
	No of floors	1	

	Falling hazard	No	
	Special hazard	No	
	Item of roof/floor	Boulder rocks	

Retrofitting Measures -:

1) b5- Increase by build-up or reinforce with belt.
2) Mortar- Change of mortar not feasible. Hollowness may be filled by grouting or walls may be strengthened by ferro-cement plating or fibre-wrapping.
3) Length of wall between cross walls- Provide plaster or buttress
4) Height of wall from floor to ceiling- Add plaster to increase effective thickness
5) Plinth Level- Provide seismic belt
6) Plinth Level (Soft soil)- Provide seismic belt on both sides
7) Door window lintel level- Provide lintel band
8) Ceiling or Eave Level- Provide lintel band
9) Vertical bar at corner and T-junction of wall-Needed in all buildings (4 storeys not permitted)
10) Vertical bar at jambs of doors and windows- Needed in all buildings (4 storeys not permitted)

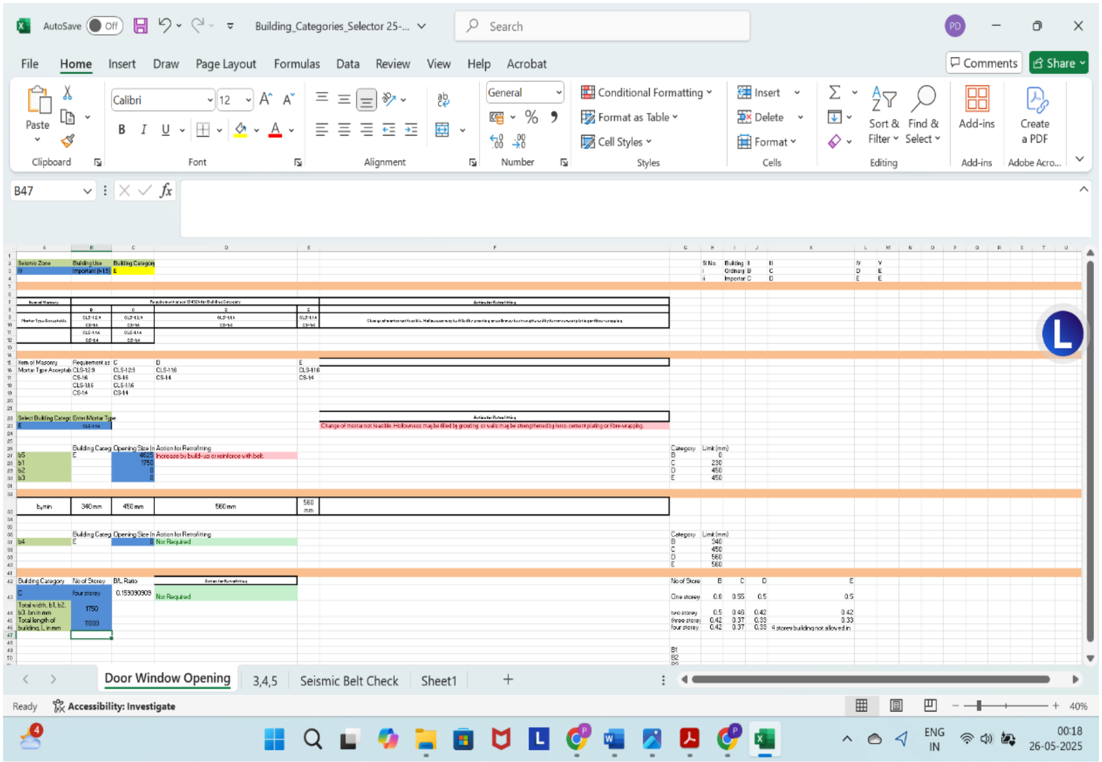


Figure 4.4.1 Feroz Shah Tomb, Delhi

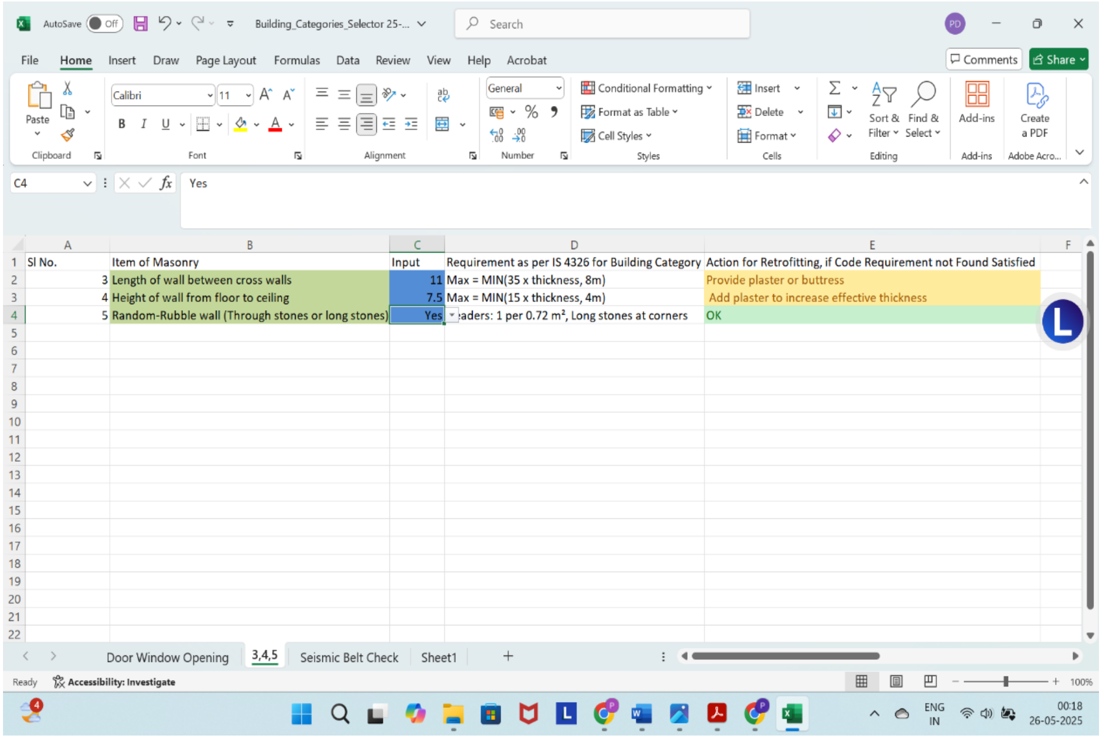


Figure 4.4.2 Feroz Shah Tomb, Delhi

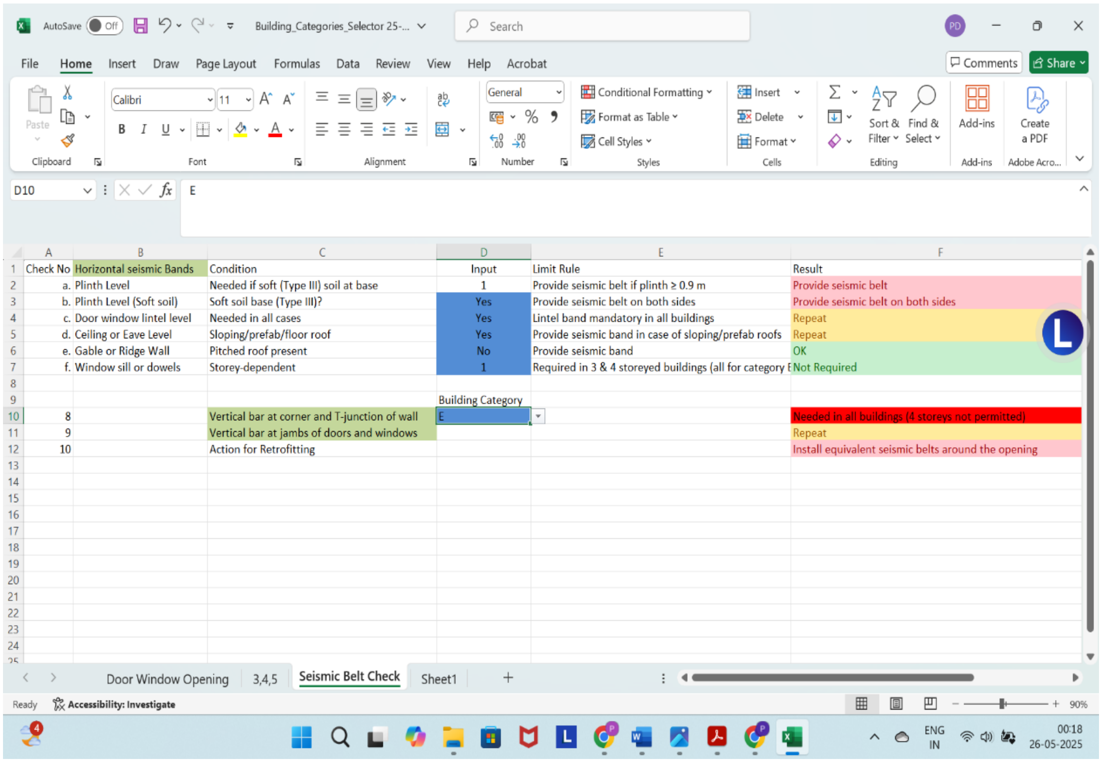


Figure 4.4.3 Feroz Shah Tomb, Delhi

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

This study concludes that The development of generalized Method on seismic Retrofitting of Masonry Structures, limited research articles has been referred. Currently in India there is no IS Code for seismic retrofitting of structures, which can provide a straightforward Retrofitting measures. This work shows that a masonry structure can be repaired, rehabed and retrofitted. So, the procedure is conducted on three different cases of structures showing seismic strengthening at local level. Therefore, this work can be considered as a reference for the repair, rehabilitation, and retrofitting of masonry structure which is constructed in India.

5.2 FUTURE SCOPE

- **Retrofitting Cost – Estimation**- Based on the application, the costing parameters can be easily assessed which will eventually help in evaluating the price amount of retrofitting

- Usefulness for surveyor to be used by **Insurance Company**- The method may provide a leap on advantage in framing policies in anticipating clients need, helping clients in getting most benefits, offer a new type of enrolment process, offer valuable insights, and to create frictionless customer experience.

- The method Can be **registered/patented to govt. of India** from where it can be accessed to mass application, restricting the cost gauging by stating the cost controls.

- This can help in **resource optimization** by strategically allocating resources and resource levelling to ensure critical activities are completed on time and within the budget.

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APPENDIX

House no 12, Vyas Mohalla, Jhansi


House no 13, Vyas Mohalla, Jhansi


House no 14, Vyas Mohalla, Jhansi

	 Daru bhondela, Manik chowk, jhansi	
	 Daru bhondela, Manik chowk, jhansi	
	 House No 2, Pichchore, Jhansi	

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