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RISK EVALUATION OF EXISTING BUILDINGS BY USING RAPID VISUAL SCREENING

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CANDIDATE'S DECLARATION

I, Abhijeet Ghosh, Roll No. 2K21/STE/26 of M.Tech Structural Engineering, hereby declare that the project dissertation titled **"Risk Evaluation of Existing Buildings Using Rapid Visual Screening"** which is submitted by me to the 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 original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship, or other similar title or recognition.

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I hereby declare that the Project Dissertation titled **"Risk Evaluation of Existing Buildings Using Rapid Visual Screening"** which is submitted by Abhijeet Ghosh, Roll No 2K21/STE/26 [Civil Engineering] Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master in Technology, is a record of the project work carried 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.

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ABSTRACT

Poor and substandard construction practices results in the failure of a structure during a seismic event. Delhi is a rapidly urbanising city and lies in Seismic zone IV as per IS 1893:2016, without considering the standard construction practices a major earthquake will lead to huge damages to the structures or structure may fail. In order to protect deficient structures from seismic occurrences, a quick performance review technique is required.

There are many guidelines for screening of buildings but FEMA P-154, 2015 and FEMA P-155, 2015 provides the screening in the most comprehensive manner by scoring the screened building for its various attributes. Using this score, risk of an earthquake causing the building to collapse cam be calculated.

In this dissertation, a thorough investigation on 100 buildings was conducted and Level 1 RVS score has been calculated. On the basis of RVS Level 1 score two buildings from each typology has been selected and probability of collapse was then compared to the probability of MCE shaking, to determine the chance of building collapse. Considering the technique provided in FEMA P-154, 2015, four distinct typologies of existing structures were chosen as case studies for the computation of collapse probability i.e., Concrete Moment-Resisting Frame Buildings (C1), Concrete Shear Wall Buildings (C2), Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), and Unreinforced Masonry Bearing Wall (URM).

Along with that, RVS score has been used to calculate the Risk Score, its associated probability of at least one collapse causing earthquake within next 50 years has been calculated. Two different types of buildings i.e., Concrete Frame Buildings with

Unreinforced Masonry Infill Walls (C3), and Unreinforced Masonry Bearing Wall (URM) have been taken as a case study for the calculation of Risk Score using RVS score and its associated vulnerability using the technique as per FEMA for any seismic activity in the next 50 years.

Implementing the calculation of Probability of Collapse under the MCE shaking, Concrete Moment-Resisting Frame Buildings (C1) is found to have 0.02% and 0.63%. While the Concrete Shear Wall Buildings (C2) has the likelihood of failure with MCE tremor, 0.004% and 4%. The Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3) have the probability of collapsing with MCE ground shaking, 3.16% and 100%. The Unreinforced Masonry Bearing Wall (URM) has the possibility of collapsing with MCE tremor, 5% and 63%.

Implementing the calculation of at least one collapse causing earthquake within next 50 years, it has been found that the Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), its probability of encountering an earthquake that might lead to collapse is 6.11%. Whereas for, Unreinforced Masonry Bearing Wall (URM), its probability of encountering an earthquake that might lead to collapse is 3.11%. As a result, both buildings must undergo a thorough structural study for retrofitting in order to function safely during seismic activity.

As a result, according to the study, the RVS criteria of FEMA P-154(2015) may be applied adequately for preliminary inquiry, including acceptable limitations as per Indian standards. Based on this, a reasonable judgement about the need for thorough technical evaluation may be made, and the technique will assist in prioritising the building for full structural examination and retrofitting suggestions.

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Sincerely,

Abhijeet Ghosh

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Roll No.- 2K21/STE/26

DEDICATED TO MY FATHER, MOTHER AND SISTER

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Both property and persons can sustain significant damage as a result of earthquakes. In addition, they can trigger tsunamis, landslides, and other secondary dangers. In India, the majority of the land area is at risk of moderate to severe earthquake shaking, many buildings are vulnerable to earthquake effects because of owner's convenience and preference during construction and lack of knowledge of the provisions of earthquake standards for design and construction. As a result, during previous earthquakes, building performance was poor. All of the above problems indicate the urgent need to evaluate the seismic safety of the more than 300 million buildings that have previously been constructed in India. By assessing the safety of buildings and monitoring earthquake hazards, cities can make themselves more resilient to these disasters. This can help to protect people and property, and it can also help to reduce the economic and environmental costs of earthquakes. Some materials and structures are more resistant to earthquakes than others. By using the right materials and structures, cities can make their buildings safer. By identifying these areas, cities can take steps to mitigate the risk of damage. This could include building stronger buildings, or relocating people to safer areas. [3]

1.2 RISK

The probability of danger, loss, or damage occurring as a result of a specific action, event, or decision is referred to as risk. It is the likelihood that a bad thing will happen, and it can be influenced by a variety of factors like as the nature of the activity, the environment in which it is taking place, and the skill of individuals involved. Risk can be quantified in a variety of ways, including probability and severity, and it is frequently managed through the application of various techniques and tools aimed at mitigating or avoiding any negative outcomes.

1.3 EARTHQUAKE IN DELHI

Earthquakes are a major concern for humanity because they cause thousands of deaths annually in various parts of the world. It's a natural disaster that can cause extensive damage on communities, infrastructure, and structures. From minor tremors to severe quakes lasting several minutes and causing widespread destruction, earthquake magnitude and duration can vary. They may likewise prompt avalanches, tidal waves, and auxiliary seismic tremors known as delayed repercussions.

In the country-wide macro earthquake one, Delhi falls under Zone IV. Though the nation's capital does not sit in the most seismically active region, but it is always vulnerable to a high-intensity earthquake with an epicentre anywhere in the Himalayas. Without taking into account typical construction practises, Delhi is fast urbanising. Due to its location in seismic zone IV, it's an easy target for any major earthquake (according to IS 1893:2016). A timely performance evaluation technique is also required to protect structures from seismic excitation. A number of developing nations, notably India, have made various proposals to plan the assessment of existing institutions, but because to their complexity, they were unable to successfully execute the concept. Adopting numerous basics of practise from various guidelines such as FEMA and ATC, In order to develop a more effective probabilistic method in the future, this study aims to make the implementation of RVS in the evaluation of various Indian Standard Codes simpler. Different kinds of existing structures were chosen as case studies to give real data for the study.

1.4 FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

Rapid visual screening (RVS) is a procedure that “FEMA P-154(2015)”, Rapid Visual Screening of Buildings for Potential Seismic Hazards, outlines for detecting structures that might significantly raise the risk of fatalities and injuries from a building's collapse during a strong earthquake. This offers comprehensive instructions on what quick visual inspection works and how to carry it out successfully. [1]

The FEMA P-154 was created with building screeners in mind, as well as for the policymakers who must choose the best kind of screening programme to put into place. As compared to that, “FEMA P-155” is written for individuals wish to learn the details and presumptions that support the methodology and calculation of Basic Scores and Score Modifiers. A competent expert should be able to compute the Basic Ratings and Score Modifiers independently using the information and clarity provided by FEMA P-155, if they have a basic understanding of fragility curves, the capacity spectrum approach, and statistics. [2]

1.5 RAPID VISUAL SCREENING

Rapid Visual Screening is a methodical strategy of identifying structures that may pose a threat in the event of a seismic hazard. It was released by the “Federal Emergency Management Agency of the United States” as “FEMA P-154” and “FEMA P-155” in two volumes in 1988. It includes a wide range of structures, from low rise to high rise, making it all-inclusive. The "Structurally Deficient" building is taken further for a thorough examination.

The Rapid Visual Screening procedure is being developed to inspect the building and determine whether it is currently conditionally assessed. A screener's job in this survey is to complete the data collection sheet based on how seismically active the area is where the building is located. Based on observations, the screener assesses if any of the abnormalities stated in the datasheet exist in the building that is being 'inspected'. Following that, the screener marks the shortcoming and applies a rating modification to building's baseline score. After completing the exercise, we are given an RVS rating, which gives us a good idea of the building's existing state by connecting it to a likelihood of collapsing. Similar to that, any building may be inspected. [1]

It assesses two aspects of every building:

a) The building's lateral load resisting system.

b) Building characteristics that may hamper the lateral load system's ability to behave seismically as intended.

1.6 OBECTIVE OF THE STUDY

Rapid visual screening (RVS) of building is too fast and effectively evaluate a building's potential seismic risk by identifying vulnerabilities and deficiencies. RVS is a cost-effective tool for identifying possibly hazardous buildings that require additional seismic evaluation or alteration.

The study of RVS of buildings has the following objectives, which include:

1. Visual assessment of the building's structural and non-structural components which is used to determine the building's seismic vulnerability and possible risk level.

2. Assessing defects in the building's construction or maintenance that could make it more vulnerable to seismic disasters.

3. Buildings are given preference for detailed visual evaluation or retrofitting depending on their level of risk and the potential consequences of failure.

1.7 SCOPE OF THE STUDY

Rapid visual screening (RVS) is a quick and effective approach for determining a building's seismic risk. It is used as a preliminary screening method in seismic risk assessment as it can quickly identify the vulnerability of structures. RVS involves evaluating building characteristics such as age, height, construction type, and seismic design codes used in construction. This information can be used to calculate the building's overall seismic performance, including its probability of collapse, damage, or loss of function during an earthquake.

1.8 ORGANISATION OF THESIS

This dissertation has six chapters, a bibliography, and is titled **"RISK EVALUATION OF EXISTING BUILDINGS USING RAPID VISUAL SCREENING".**

The following chapters make up this dissertation:

Chapter 1 includes the Introduction of Rapid Visual Screening, objectives, and scope of the study.

Chapter 2 includes of the literary works that were looked at during the investigation.

Chapter 3 elucidates the concept of RVS and the factors that impact it in detail.

Chapter 4 consists of the survey of various buildings and case studies of utilizing RVS as a technique to calculate the probability that an existing structure may collapse.

Chapter 5 contains methods for calculating risk scores and case studies for estimating the probability that a structure would collapse and cause an earthquake within the next 50 years to help prioritise the need for upgrading.

Chapter 6 contains a summary of the case studies that have been finished.

References of the literatures that were referred in the study are mentioned.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

To provide a solid foundation for the preliminary inquiry, references to "FEMA-154 (2015)", "FEMA-155 (2015)", "IS: 1893 (2016)", "IS: 456 (2000)", "IS: 13935 (2009)", and other articles have been made throughout this dissertation. Speaking of FEMA literature, FEMA-154 (2015) gives a thorough explanation of the standards for rapid visual screening and how it is carried out. While FEMA-155 (2015) provide a thorough mathematical foundation for the ratings given to common building structures. In order to maintain consistency, Indian Standards have been scrupulously observed when connecting the numerous technical data supplied by FEMA and other articles.

2.2 EXISTING LITERATURE ON RAPID VISUAL SCREENING

Mahin and Hamburger (2001) this research aims to develop practical and affordable solutions that can be included in the analysis, design, and construction methods of welded steel moment-frame buildings because of the unexpected damage to these buildings during earthquakes. The "US Federal Emergency Management Agency (FEMA)" supported a significant 6-year project. This project collected and analyzed research findings and also carried out further investigations. The goal was to create dependable, practical, and affordable guidelines for designing and building new steel moment-frame structures. Additionally, the project aimed to provide guidelines for inspecting, evaluating, and repairing or improving existing structures of this type.

Daniele and Maria (2015) in this Research The building's interior and exterior are visually inspected with the Rapid Visual Screening (RVS) to find any possible weak spots. RVS has been applied to two Italian hospitals, one in a high-seismic area and one in a low-seismic area. The results of the RVS were compared to the results of a more detailed analysis called a push-over analysis. The RVS method was found to be accurate in predicting the seismic vulnerability of the hospitals. Additionally, two hospitals that suffered earthquake damage in 2009 and 2012 have used RVS. The RVS method was able to identify the damage caused by the earthquakes and assess the need for repairs.

Nath and Adhikari (2015) this study investigates The following susceptibility factors are used to categorise the seismic risk zones in Kolkata: land use, population density, building typology, age, and height. After that, by incorporating seismological, geological, and geotechnical themes into GIS, the seismic risk of the city was micro-zoned. In a logic-tree framework, these vulnerability factors were later combined with the seismic risk to evaluate the socioeconomic and structural threats to the city. Severe, high, and moderate danger zones were established. It has been determined that the city's design horizontal seismic coefficients are suitable for "A," "B," and "C" types of structures for all fundamental time periods. For each seismic structural risk zone in the city, building types—RM2, URM have been evaluated in terms of "none," "slight," "moderate," "extensive," and "complete." Both the seismic threat and danger maps are anticipated to be essential tools for handling and minimizing the effects of the earthquake that struck Kolkata.

Sekhar and Sanket (2015) this study aims to highlight the lack of preparedness for moderate earthquakes in the Indian subcontinent. During the Gorkha earthquake, buildings hundreds of miles away from the core suffered medium to serious damage. For inexpensive houses in India, this study suggests a modified fast visual identification system. This method can be used to evaluate a location's susceptibility fast. The study also provides examples of retrofitting measures for typical buildings. These measures can be used to upgrade valuable structures. This study can help to improve the preparedness of earthquake-prone developing countries by providing a quick way to assess vulnerability and adopt retrofitting measures.

Tanaya and Sutapa (2018) this paper describes a study that was conducted to create a ward-level hazard map of a city. The study used a systematic vulnerability analysis to identify the most vulnerable areas of the city. The analysis was based on Population Density, Building Height, Building Type and Roof Type. A structured survey of the buildings was conducted in the five wards. In order to establish how susceptible the structures were to earthquakes, the survey employed a Rapid Visual Screening (RVS) technique. 100 buildings altogether were chosen at random for the survey. The buildings were grouped according to nine key vulnerability factors. Based on Indian examples, these specifications were modified to be more thorough for different types of building structures, such masonry or light-weight timber constructions. Based on the buildings' seismic susceptibility, a score and ranking system was developed.

Ehsan and Tom (2020) this paper discuss three common Rapid Visual Screening (RVS) methods: “FEMA P-154”, “IITK-GGSDMA”, and “EMPI”. To test their accuracy and validity, After the 1 May 2003 seismic event in the Bingol district of Turkey, the authors conducted a street survey there and compared the estimates produced using these approaches to the observed destruction of reinforced concrete structures. The results showed that RVS methods are a valuable tool for preliminary damage estimation. The comparison investigation, however, also revealed that FEMA P-154 overstates damage levels and is not financially feasible. EMPI and IITK-GGSDMA, on the other hand, provide more accurate and practical estimates.

Palagala and Singhal (2021) in this research a method has been developed to evaluate the susceptibility of India's RC-framed structures to earthquakes. The method is based on the HAZUS earthquake loss estimation methodology and takes into account the seismicity, soil conditions, type, and irregularities of the buildings. Each building is given a structural rating by the approach, indicating how likely it is to collapse. The structural rating is calculated using nonlinear-static pushover analysis, which is a computer simulation that models the behaviour of a building under seismic loading. The analysis takes into account the most commonly observed irregularities in RC framed buildings in India, such as open ground stories, severe vertical irregularities, short columns, and plan irregularities.

Aniket and Pradeep (2021) in this research the methods for assessing the seismic vulnerability of reinforced concrete (RC) buildings were compared based on their vulnerable parameters, damage grades, and general descriptions. A scoring system was also developed to rank the methods. A case study was conducted to assess the performance of the methods. 100 RC structures in each of the three cities of India were the subject of a quick visual assessment. Different earthquakes, geological, and topographic circumstances exist in these cities. The case study's findings demonstrated that, in each city for the same sample of structures, each of the five methodologies produced a different result. Additionally, it was noted that the techniques contained a lot of unusual vulnerability parameters. The findings also revealed a wide range in the weights used to determine each vulnerable parameter across all five techniques.

Ehsan and Seyed (2021) this research recognises that rapid urbanization and the growth of slums have led to the use of improper construction practices, which makes the reliability of building stock uncertain. This includes old structures that were built before seismic codes were revised. Even though we are proficient in structural analysis, it is not feasible to carry out a thorough nonlinear analysis of every building in a particular area to assess its seismic risk. This indicates that a quick, trustworthy, and computationally simple approach of assessing seismic susceptibility is required. Rapid Visual Screening (RVS) is one of them. Among the most significant and extensively used methods in this regard are Soft Computing (SC) approaches, including probabilistic methods, and artificially intelligent (AI) theories, including neural network theory and machine learning techniques. These techniques are capable of targeting the inherent imprecision of phenomena in the real world.

Nurullah and Orsolya (2022) this research reviews the traditional rapid visual screening (RVS) techniques for assessing seismic risk. It summarises, assesses, and contrasts the results of earlier studies that made use of these techniques. The research also provides ways to approach particular objectives and suggests potential improvement tactics. The paper talks about the time-consuming RVS procedures, such NRCC, which takes an hour, and FEMA 154, which takes between 15 and 30 minutes. Additionally, it gives an outline of the domains in which the techniques are applied, such as pre-earthquake (FEMA 154, NRCC, NZEE, etc.) and post-earthquake (GNDT, EMS, etc.). A thorough reference and guide are provided for field practitioners, such as engineers and architects, in this analysis of the traditional RVS approaches. Additionally, it suggests that researchers apply advancement strategies like machine learning and fuzzy logic for the next advancements.

2.3 RESEARCH GAPS

Based on the literature review, following drawbacks have been identified in the previous research:

1. To identify potentially hazardous regions in Delhi City, India by creating an earthquake hazard profile at the ward level.

2. To identify risk mitigation techniques and conduct a structural vulnerability evaluation of existing masonry structures in order to assess the preparedness for future earthquakes.

3. To calculate the risk score of structures based on the number of earthquakes that might cause a structure to collapse during the course of its design life

CHAPTER 3

TECHNIQUES AND METHODOLOGY FOR RVS

3.1 INTRODUCTION

Rapid Visual Screening (RVS) is a quick way to check if a building is at verge of failure during an seismic event. It is done by visually inspecting the building for signs of vulnerability, such as poor construction, weak materials, and damage from previous earthquakes. RVS can help identify buildings that need to be further evaluated or retrofitted to make them more earthquake-resistant. RVS is a valuable tool for initial seismic risk assessment, but it is not a substitute for detailed engineering analysis. Detailed engineering analysis is needed to get a complete understanding of a structure's seismic performance. [1]

The methodology for the research work has been briefly described below.

a) Geographical area, Soil type, Climatic conditions, and Seismic history are considered for understanding of the research.

b) Select the Data Collection Form for different type of Buildings.

c) If available, Construction Drawings are reviewed.

d) Screening of Existing Buildings at Field.

e) Calculation of RVS Score.

f) Decision Making.

3.2 ASPECTS IN RAPID VISUAL SCREENING (LEVEL 1)

3.2.1 Basic Score

Using the existing damage and loss functions, the basic score categories for the various seismic regions have been calculated. In the case of a Risk Targeted

Maximum Considered Earthquake (MCE_R), the likelihood of a structure collapsing is evaluated [2]. It includes:

a) Determining the seismic zone in accordance with IS 1893:2016

IS 1893:2016 is a standard that provides guidelines for designing buildings to withstand earthquakes. It covers topics such as how to assess the risk of an earthquake, how to classify sites for their earthquake resistance, and how to design buildings to withstand the forces of an earthquake. The standard is meant for use by designers who are designing buildings in places where earthquakes are likely to occur. It is also used by government agencies and regulatory bodies that are responsible for ensuring the safety of buildings. IS 1893:2016 is a comprehensive and up-to-date standard that provides a sound basis for the earthquake-resistant design of buildings. It is an essential reference for engineers and architects who are working in areas that are prone to earthquakes. [4]

The “FEMA P-154 (2015)” methodology estimates the area's seismic activity based on the MCE_R Spectral Acceleration Response over the period of O.2 seconds and 1second. This is in contrast to the IS 1893:2016 methodology, which correlates seismicity to MSK intensity. It is difficult to predict damage from a specific degree of seismic hazard, as different building types behave differently. However, the “FEMA P-154 (2015)” methodology does provide a discretization of the spectrum acceleration response and its associated seismicity hazard. Additionally, there are several factors that can affect damage during severe shaking in high (Zone IV) and very high (Zone V) seismicity regions.

The seismicity of a location can be illustrated by its spectral acceleration for short periods (O.2 s) and long periods (1.O s). This is according to FEMA 154 (2015), which is a document published by the “Federal Emergency Management Agency (FEMA)”. Table 3.1 in this document provide information about a location's seismicity based on these two parameters.

The seismicity of a region can also be illustrated by its MSK intensity and the associated damage. This is according to IS 1893:2016, which is a document published by the "Bureau of Indian Standards" (BIS). Table 3.2 in this document provides a table that illustrates the seismicity of a region based on these two parameters.

Table 3.1 Seismic Region Based on MCE_R Spectral Acceleration Response [1]

Seismicity region	Spectral Acceleration Response, S_S (Short-period, or 0.2 seconds)	Spectral Acceleration Response, S_1 (Long-period, or 1.0 second)
Low	Less than 0.250g	Less than 0.1g
Moderate	Greater than or equal to 0.250g but less than 0.500g	Greater than or equal to 0.1g but less than 0.2g
Moderately High	Greater than or equal to 0.500g but less than 1.0g	Greater than or equal to 0.2g but less than 0.4g
High	Greater than or equal to 1.0g but less than 1.5g	Greater than or equal to 0.4g but less than 0.6g
Very High	Greater than or equal to 1.5g	Greater than or equal to 0.6g

Table 3.2 Seismic zone in India according to "IS 1893:2016" [4]

Zone I and II	Low seismic risk (earthquake damage up to MSK level VI at its highest)
Zone III	Moderate Seismic Risk (earthquake damage that might reach MSK level VII).
Zone IV	High Seismic Risk (earthquake damage that might reach MSK intensity VIII).
Zone V	Very High Seismic Risk (earthquake damage that might cause up to MSK intensity IX or more)

b) Type of Structures and its Lateral Load Resisting Structure

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

Table 3.3 Types of Structures according to FEMA and their corresponding Building Type as per IS 1893:2016 [1]

Types of Structures according to FEMA P-154 (2015)		According to IS 1893:2016
Concrete Moment-Resisting Frame Buildings	C1	Type C
Concrete Shear Wall Buildings	C2	Type C
Concrete Frame Buildings with Unreinforced Masonry Infill Walls	C3	Type C
Unreinforced Masonry Bearing Wall	URM	Type B
Reinforced Masonry Buildings with Flexible Floor and Roof Diaphragms	RM1	Type C
Reinforced Masonry Buildings with Rigid Floor and Roof Diaphragms	RM2	Type C
Tilt-up Buildings	PC1	Type C
Precast Concrete Frame Buildings	PC2	NA
Steel Moment-Resisting Frame Building	S1	Type B
Braced Steel Frame Buildings	S2	Type B
Light Metal Building	S3	Type B
Steel Frame Buildings with Concrete Shear Walls	S4	Type B
Steel Frame Buildings with Unreinforced Masonry Infill Walls	S5	Type B
Light Wood Frame single or multiple- family dwellings	W1	Type C
Light Wood Frame multi-unit, multi-story residential buildings with plan areas greater than 3,000sqft each floor	W1A	Type C
Wood Frame commercial and industrial buildings > 5,000sqft	W2	Type C
Manufactured Housing	MH	NA

3.2.2 SCORE MODIFIER

Score in relation Buildings' performance is impacted by a number of factors that might be positive or negative, increasing or decreasing the Basic.

a) Height of the structure

The structure's susceptibility to a seismic event rises with the height of the building. As a result, the basic score for various kinds of building has been changed accordingly for only soil type E. [1]

b) Vertical Irregularity of the Building

In the seismic event, it is important for all forces to be transmitted from the superstructure to the substructure. However, this may not be possible in all construction practices due to factors such as slope plots, divided floors, floating columns, stilt parking, short columns, and setback constructions. These factors are known as vertical irregularities, and they may lessen the building's overall stability and safety.

“Table 6 in IS I893: 2016, Clause 7.1”, provides a list of vertical irregularities and assigns a negative score modifier to each one. This score modifier is used to calculate the overall seismic design force for the structure.

Here are some examples of vertical irregularities:

i. Setback: These are structures that have different heights at different level.

ii. Floating Columns: These are columns that are not directly connected to foundation.

iii. Stilt Parking: This is a type of parking garage that is supported by Stilts.

iv. Short Columns: These are columns that are shorter than the typical column height.

v. Split Levels: These are structures that have different floor levels that are not aligned.

vi. Sloping Sites: These are sites that have slopes.

c) Plan Irregularity of the Building

Any structure can experience plan irregularities, but they are most common in the construction of masonry, precast, and timber structures. Invoking plan irregularity into a structure can be done in the following ways:

i. when the centre of rigidity and the centre of mass are not congruent

ii. Non-parallel system

iii. Re-entrant curves

iv. Diaphragm slits

v. Beams and columns are not aligned

“Table 5 in IS 1893: 2016, Clause 7.1”, makes a clear distinction between the many types of plan irregularities that may exist in a construction.

d) Pre-Code

The Working Stress Method served as the foundation for the 1978 introduction of the “Indian Standard Code for Reinforced and Plain Concrete” (IS 456). While limit state method-based IS code was published in 2000.

The following lists several codes for earthquake resistance:

i. "Criteria for Earthquake Resistance Design of Structure," IS 1893:1962, which was updated in 2016.

ii. IS 4326:1967, "Earthquake Resistance Design and Construction of Buildings, Code of Practice", revised in the year 2013.

iii. IS 13920:1993, "Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice", updated in the year 2016.

As a result, all buildings built before the introduction of the IS standards will be regarded as having inadequate seismic design.

e) Type of Soil in the Foundation

Type of Soil in the Foundation where the building is situated has a significant impact on how buildings respond to seismic excitation. While “IS 1893:2016” divides soil into three groups, “FEMA P-154 (2015)” assessed six various types of soil. According to “FEMA 154 (2015)” and “IS 1893:2016”, different types of soil based on SPT N value is shown in Table 3.4.

Table 3.4 Various Types of Soil [1]

Soil Type/Site Class (As per FEMA P-154, 2015)	Corrected SPT N Value (As per FEMA P-154, 2015/ Shear Wave Velocity (V_{S30}))	Soil Type/ Site Class (As per IS 1893:2016)	Corrected SPT N Values (As per IS 1893:2016)
Soil Type A/ Hard Rock	Shear Wave Velocity >5000ft/s	-	-
Soil Type B/ Rock	5000ft/s >Shear Wave Velocity >2500ft/s	-	-
Soil Type C/ Very Dense Soil and Soft Rock	N >50	Rock/ Hard Soil	N >30
Soil Type D/ Stiff Soil	15 <N <50	Medium Soil	10 <N <30
Soil Type E/ Soft Clay Soil	N < 15	Soft Soil	N < 10
Soil Type F/ Poor Soil	a) Clays which are Highly Plastic (i.e., PI > 75) b) Soil are highly sensitive, liquefiable and highly organic. c) Deposit of soft or medium stiff clays, more than 120ft.	-	-

Buildings constructed on Soil Type F (liquefiable or extremely compressible soil) cannot be screened using rapid visual inspection [1]. Soil type III according to IS 1893:2016 should be excluded from screening. Geological maps of the area must be researched in advance as it is impossible to determine the kind of soil by eye observation alone.

f) Pre- Code

It shows that the building was planned and constructed following stringent adjustments to the codes. As a result, it will positively affect the score. Since IS 1893 was updated in the year 2016, we will use 2016 as our benchmark year in this instance.

3.3 GEOLOGICAL HAZARDS

A geological hazard is a circumstance that increases a building's susceptibility to earthquake excitation. In accordance with “FEMA P-154(2015)”, geologic risks include the possibility of landslides, surface fault rupture, and liquefaction. Although “IS 1893:2016” recognises the role that liquefaction potential plays in a building's susceptibility to earthquakes, there is no mention of landslip risk or surface fault rupture.

3.4 ADJACENCY

In the seismic event, buildings next to one another could prove disastrous since they can collide as a result of the ground shaking. Buildings must therefore be examined for their impact as well. The minimal distance between two structures in areas with strong seismic activity is two inches per story [1]. The distance between two buildings shall not be less than "R" times the total of the storey displacement of each building, according to IS 1893:2016.

3.5 EXTERIOR FALLING HAZARD

Non-structural components include things like unbraced chimneys, parapets, veneers, overhangs, cornices, panels for ads. When exposed to seismic excitation, claddings pose a serious threat to human life.

3.6 LOSS AND DETERIORATION IN STRUCTURE

Its focus is on building construction; every structure must be made of sturdy materials. However, over time and with poor maintenance, the structure deteriorates, and when exposed to seismic forces, such structures are more vulnerable to damage.

3.7 CALCULATION OF RVS SCORE

The score modifier is added to or subtracted from the building's base score to determine the RVS score. Based on the structure of the building and the area's seismic risk, a score modifier is applied to it. The basic score is a value that is assigned to the building based on its age, occupancy, and construction type

Final Score (S) = Basic Structural Hazard Score + Score Modifier (3.1)

And, $S = -\log_{10} (P[\text{Collapse}|\text{MCE}_R \text{ ground motion}])$ (3.2)

A building collapses when the load-bearing system, which is responsible for supporting the weight of the building, fails. This can happen due to a number of factors, such as excessive weight, poor construction, or natural disasters. When the load-bearing system fails, the building will eventually fall apart. [1]

$P[\text{Collapse}|\text{MCE}_R \text{ ground motion}] = 10^{-S}$ (3.3)

The failure possibility of a building increases as the final RVS score (S) increases. A building with Score 1 has a 10% chance of collapse, which is 10 times the probability of collapse of a building with Score 2 [2]. This is shown in Table 3.5.

Table 3.5 Probability of Collapse versus Final Score

Final Score S	4.0	3.5	3.0	2.5	2.0	1.5	1.0	0.5	0
Probability of Collapse at MCE_R	0.01%	0.03%	0.01%	0.32%	1%	3.16%	10%	32%	100%

3.8 FACTORS AFFECTING RAPID VISUAL SCREENING (LEVEL 2)

Level 1 score modifier values and the relevant engineering justification were used to generate level 2 score modifiers.

3.8.1 Vertical Irregularity Score Modifier

Any of the following construction flaws will result in the addition of a vertical irregularity score modifier:

a) Sloping site

b) Weak/soft storey

c) Setback

d) Short column/pier

e) Split level

The vertical irregularity score modifier is a numerical value that is used to assess the risk of collapse in a building with vertical irregularities. The likelihood of collapse increases with score. The vertical irregularity score modifier is used in conjunction with other factors, such as the seismic design category, to determine the required seismic design forces for a building [2]. Table 3.6 provides the vertical irregularity score modifier for each deficiency:

Table 3.6 Vertical Irregularity Score Modifier

Deficiency	Vertical Irregularity Score Modifier
Sloping Site	1.0
Weak/Soft Storey	1.5
Set back	1.2
Short Column/Pier	1.5
Split Level	1.2

3.8.2 Plan Irregularity Score Modifier

A Planar Irregularity Score Modifier shall be applied to a building if it has any of the following deficiencies:

a) Torsional Irregularity

b) Non-Parallel System in the building

c) Presence of re-entrant curves

d) Diaphragm Openings

e) Out-of-plane offset in C1, C2 buildings

3.8.3 Redundancy of the structure

A structure is referred to as redundant if it has more force-resisting components than is necessary. This means that the building can still stand even if some of the forces resisting elements are damaged or destroyed. Redundant buildings are typically more expensive to build, but they are also more resilient to damage in the seismic event. [2]

3.8.4 Retrofitting of structure

Positive score modifications must be applied in the Level 2 datasheet if there is evidence of thorough retrofitting in the structure. There shouldn't be a score modifier applied if there is only partial retrofitting.

3.8.5 Pounding effect

When buildings are near to one another, pounding damage might happen and move in sync during an earthquake. This can cause the floors of the buildings to collide, which can damage the buildings and injure the occupants.

When buildings are close together, three factors are considered to determine the severity of pounding damage:

a) The buildings' floors are not exactly 2 feet vertically aligned.

b) One structure is at least two storeys taller than the other.

c) The building is situated at the end of a row of buildings.

3.8.6 Building with K bracing

K bracing is a type of structural bracing that uses diagonal members to resist lateral loads. It is typically made from steel, aluminium, or wood, and is connected to columns at mid-height. K bracing is often used in buildings in areas with high winds or seismic activity, and is also a good choice for buildings with large openings. It is a relatively simple and inexpensive system to design and construct, and can be used to build a wide variety of structures. [2]

3.8.7 C1 building with flat plate moment frame

A C1 building is a type of building that is made with a flat concrete floor and concrete columns and beams that are connected together. They are typically used for low-rise commercial and residential buildings. They are relatively easy and inexpensive to build, and they are good at resisting earthquakes. However, they can crack due to shrinking and expanding.

3.8.8 URM with Gable Walls

Unreinforced masonry (URM) with gable walls is a type of building made of bricks or stones held together by mortar. Gable walls are triangular walls at the ends of a building. URM with gable walls is simple and cheap to build, but it is weak and can be damaged by earthquakes or other hazards. Gable walls are especially vulnerable to overturning, which can cause the whole building to collapse. [2]

3.9 ADVANTAGES OF RVS

a) Because it doesn't require a lot of information or processing time, the RVS approach is rapid.

b) The RVS method is easy to understand because it is based on simple principles that are easy to follow.

c) The RVS method is easy to use because it does not require specialized training or equipment.

d) Because it doesn't take a lot of resources to implement, the RVS approach is economical.

3.10 CALCULATION OF PROBABILITY OF COLLAPSE

The three-step HAZUS approach may be used to estimate the possibility of failure:-

a) Calculation of Peak Response

According to the HAZUS approach, the peak response of a building can be calculated by finding the point where the demand spectrum for earthquake ground motions intersects with the building's capacity curve.

To determine a building's peak response, the intersection of the demand spectrum and the building's capacity curve is shown in Fig.3.1.

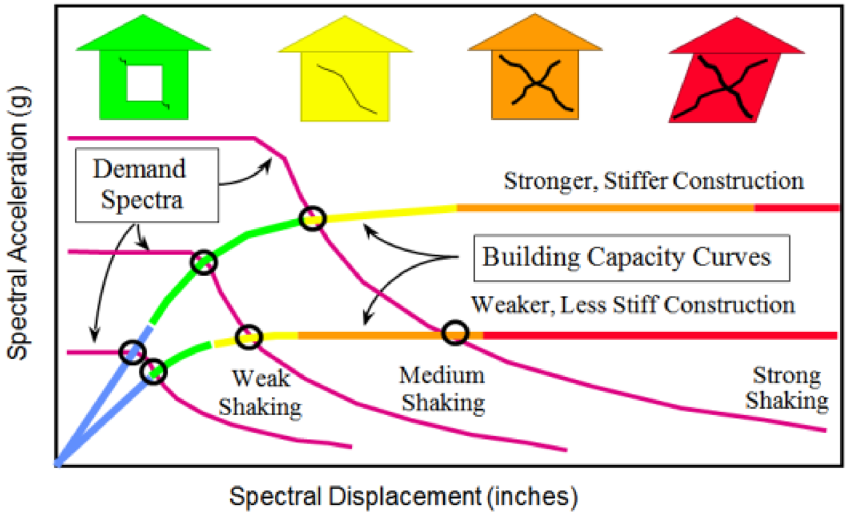

Figure 3.1 Intersection of the demand spectrum and the building's capacity curve [2]

A force-displacement plot of a structure called the "Building's Capacity Curve" establishes a separate lateral load displacement as a function of lateral load resistance. The yield capacity point (D_y, A_y) and the ultimate capacity point (D_u, A_u) serve as the two control points that determine the capacity curve.

The yield capacity takes into consideration design strength, design redundancies, and expected material strength to indicate the lateral strength of the building at initial yield. Up until the yield capacity threshold, the structure is considered to be completely elastic. The ultimate capacity indicates the displacement at which the building reaches its maximum strength when additional sources of over-strength are taken into account. The HAZUS approach makes the assumption that the capacity curve is completely plastic (i.e., constant strength) beyond its ultimate capacity point between the yield point and the ultimate point, the capacity curve is predicted to have an elliptical shape and to be tangent to both the elastic segment at the yield capacity point and the plastic segment at the ultimate capacity point.

The Building's capacity curve with various control points and parameters are shown in Fig.3.2.

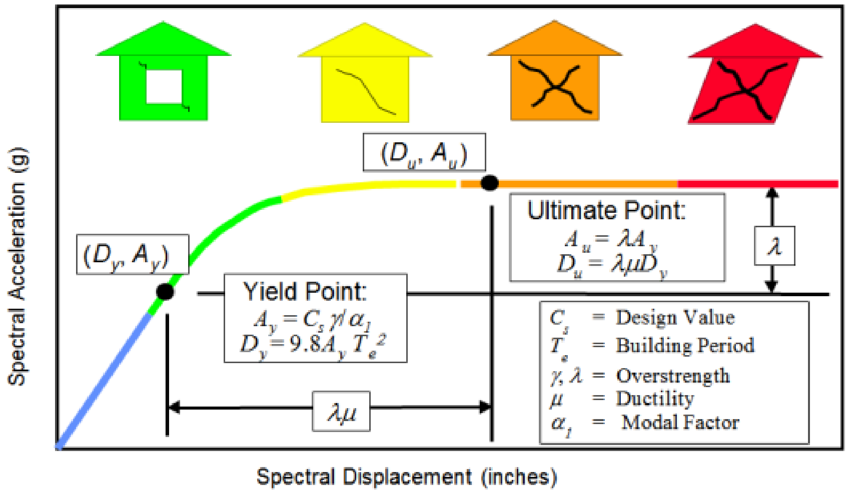

Figure 3.2 Building's capacity curve and control points [2]

b) Probability of Complete Damage State

For the basic score and score modifications, the fragility curves for the full damage state are necessary. When a structure is completely damaged, it is either about going to fall or has already failed.

In a HAZUS building, given a measure of maximum spectral displacement, the lognormal likelihood functions are employed as fragility curves to depict the likelihood of attaining or surpassing a particular level of non-structural and structural damage.

Fragility Curve for different shaking intensities and their associated damage states has been shown in Fig.3.3.

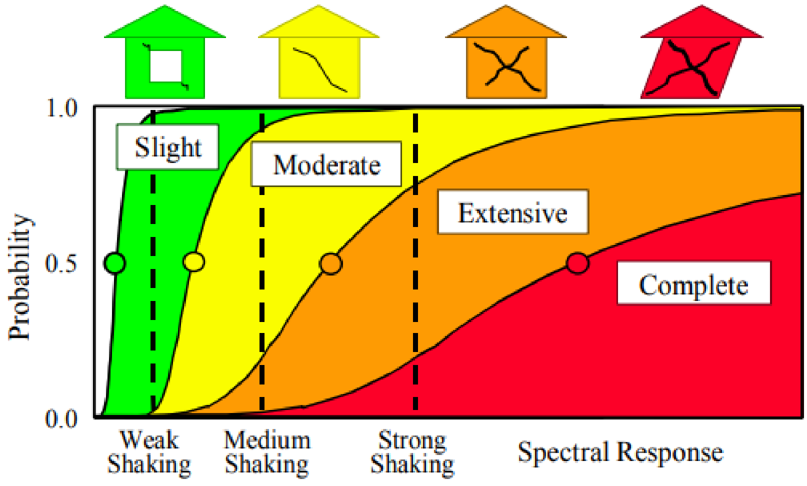

Figure 3.3 Fragility Curves for different Damage States [2]

Fragility curves are defined by two things:

a) The demand parameter's (spectral displacement, $S_{d,dc}$) median value that corresponds to the damaging state ceiling.

b) The overall variability linked to that damage state.

The median values were calculated using engineering judgment, laboratory testing of structural systems and components, and observation of damage from previous earthquakes.

Mathematically,

$$S_{d,C} = H_R\ \Delta_c\ (\alpha_2/\alpha_3) \tag{3.4}$$

$S_{d,C}$ = Spectral displacement of the complete structural damage state

α_2 = Modal height factor

α_3 = Modal shape factor relating maximum story drift and roof drift

H_R = Height of building (metres)

Δ_c = Story drift ratio

The complete range of damage states along the fragility curve ($\beta_{S,ds}$), is determined by lognormal standard deviation values.

The fragility-curve's total variability for each given damage condition is influenced by the factors listed below.

a) Variability of the capacity curve.

b) Variability of Demand Spectrum.

c) Variability of damage state thresholds.

Using the values of $S_{d,C}$ and $\beta_{S,C}$ suggested by OSHPD HAZUS, the probability for the total damage is estimated and the peak response (D) is determined.

$$P[\text{Complete Damage}] = \varphi \left[\frac{1}{\beta S,C} \ln\left(\frac{D}{Sd,C}\right)\right] \quad (3.5)$$

c) Probability of Collapse

Once the extent of the damage has been established, the likelihood of collapse is calculated using a collapse factor.

“Probability of Collapse = P[COL|Complete Damage] X P[Complete Damage]” [2]

Where:

“P[COL|Complete Damage] = Collapse Factor”

Collapse Factor for respective Building Type is provided in OSHPD HAZUS.

CHAPTER 4

CASE STUDIES AND PROBABILITY OF COLLAPSE

4.1 INTRODUCTION

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

4.2 SCREENING OF BUILDINGS

4.2.1 Types of Buildings

Total 100 of Buildings were surveyed, out of which 4% buildings are C1 type and used for commercial purpose, 26% buildings are C2 type and are residential buildings. 36% buildings are C3 type and are residential buildings and 34% buildings are URM type and are residential buildings. Preliminary survey of buildings have been shown in Table 1-A in appendix.

The reinforced concrete building type comprises of walls made of clay bricks that are supported by cast-in-place concrete beams and columns, which adds some ductility. However, URM constructions, which lack concrete columns and have walls supported by clay bricks, do not provide any ductility.

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Fig 4.1 shows the variety of building types surveyed.

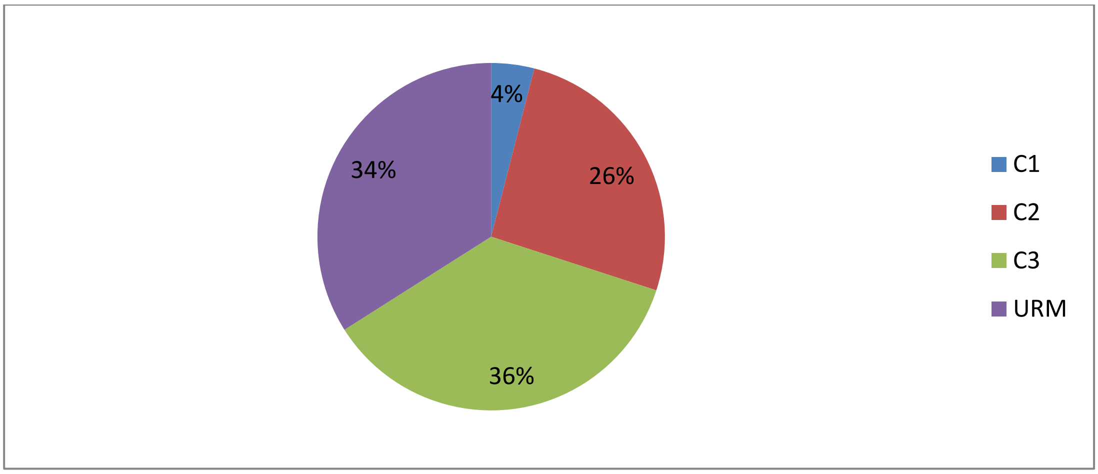


Figure 4.1 Types of Buildings

4.2.2 Age of Buildings

One of the most crucial considerations while researching the seismic hazard assessment is the age of the structure. Fig 4.2 shows that 10 buildings are new, 29 buildings are of about 10 years, 23 buildings are of about 20 years. and 25 buildings are constructed before 2002 because IS 1893 was amended in 2002, 2002 has been used as the benchmark year because structures built after 2002 can withstand earthquakes.

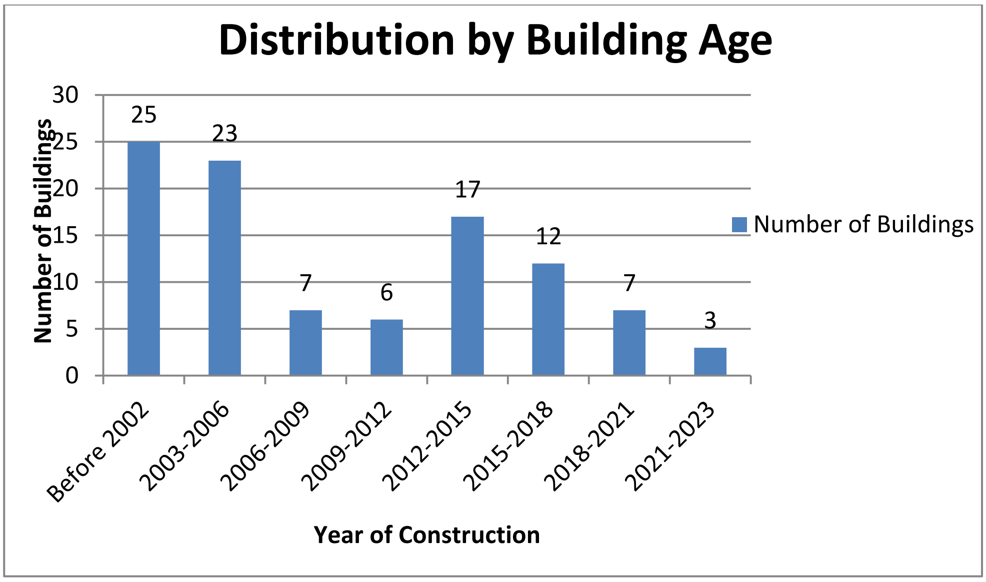


Figure 4.2 Year of construction

4.2.3 Analysis of Heavy Overhangs, Plan Irregularity and Vertical Irregularity

Many buildings, both ancient and new, have substantial overhangs. Everything from modest houses to imposing cathedrals may be found with them. In addition to protecting against the weather, overhangs can provide shade and provide visual appeal to a building's architecture. A structure may become heavier due to large overhangs. As a result, the foundation and structure may be under more stress, which might raise expenses and increase the risk of damage in the case of a seismic event.

Plan irregularity describes how strength or stiffness are distributed unevenly throughout a structure's layout. Structures with uneven floor plans are more vulnerable to severe earthquake damage.

A structural irregularity known as vertical irregularity describes the unequal distribution of mass, stiffness, or strength along a building's height. In the case of an earthquake, buildings with vertical inconsistency are more probable to sustain serious damage.

Fig 4.3 shows the number of buildings having Heavy overhangs, Plan irregularity and Vertical irregularity.

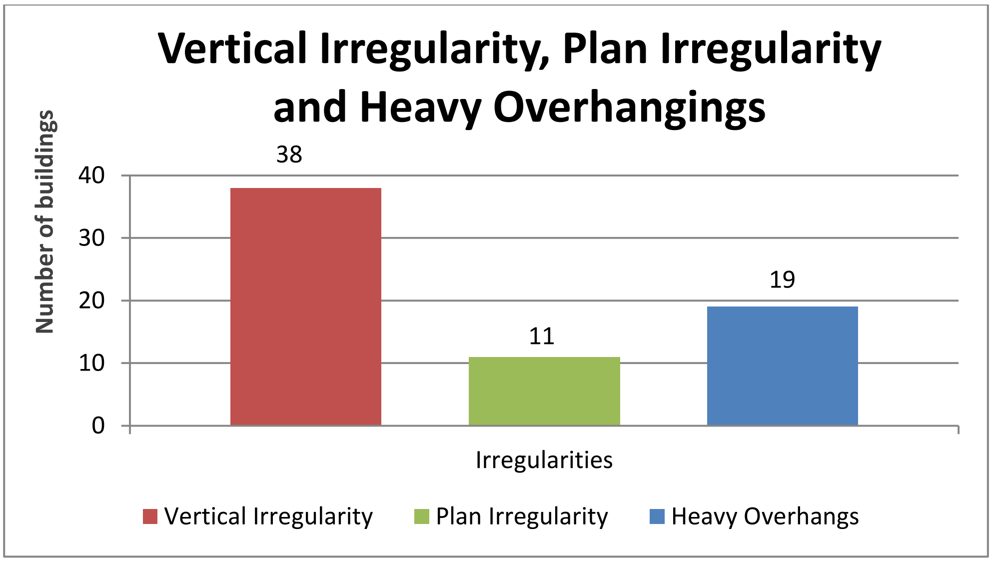


Figure 4.3 Buildings having Vertical irregularities, Plan irregularities and Heavy overhangs

4.2.4 Analysis of Soft Stories

Soft storeys are more prone to sustain significant lateral displacements during earthquakes, making them more susceptible to damage. The floor or the entire structure may collapse as a result of this.

Fig 4.4 shows the percentage of buildings having Soft Storey.

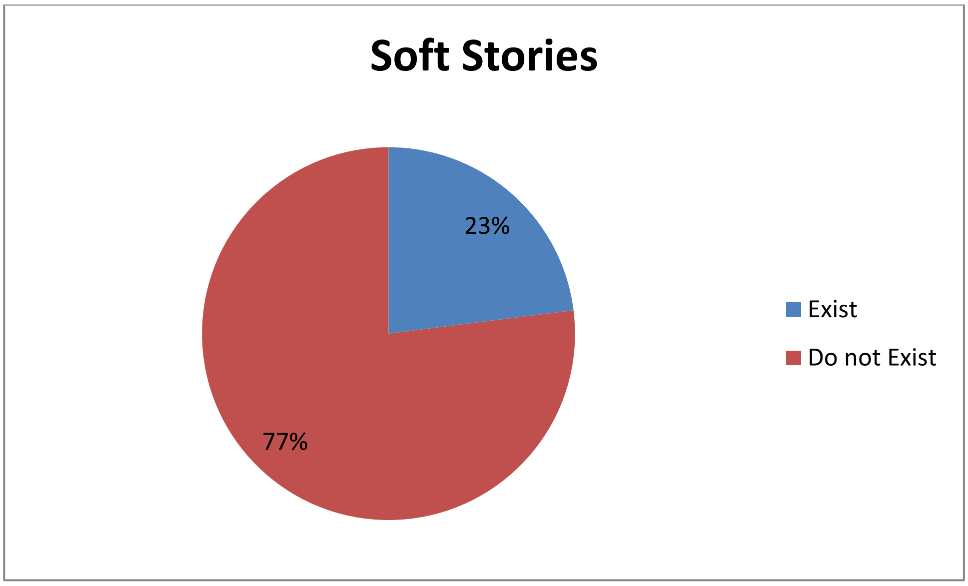


Figure 4.4 Percentage of buildings having Soft Stories

4.2.5 Analysis of Level 1 Score

Each building has been assigned a level 1 RVS rating based on the survey and appraisal of the structures. In this study, we saw four different sorts of structures: C1, C2, C3, and URM.

Level 1 RVS Score of C1 type buildings varies from 2.9 to 3.4, for C2 type buildings Score varies from 1.3 to 4.1, for C3 type buildings Score varies from -0.1 to 1.2 and for URM buildings Scores varies from 0.6 to 1. On the basis of this observation we have taken buildings having the highest Level 1 RVS Score and the least Level 1 RVS Score, and the Probability of Collapse of the Buildings have been evaluated.

4.3 PROBLEM STATEMENT

According to FEMA P-154, 2015, there are total seventeen distinct types of buildings based on the material used to build. However, only four of the many building kinds that are often used in construction practices are taken into account in this study.

Different types of Buildings are

a) Concrete Moment-Resisting Frame Buildings (C1)

b) Concrete Shear Wall Buildings (C2)

c) Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3)

d) Unreinforced Masonry Bearing Wall (URM)

4.3.1 Case study on G+3 storied Commercial Building situated in OKHLA Phase-1, Delhi is a C1 type structure. Assess the Probability of failure of this Building.

Table 4.1 Probability of Collapse of G+3 C1 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent	PL1 = 0
D)	Type of Building	According to construction materials and type of building, the building is classified as Concrete	For a structure of this type in a seismically

		Moment-Resisting Frame Building (C1), as per FEMA 154, 2015.	active area, the basic score is 1.5.
E)	Age of Building	According to the data building was constructed in year 2014, therefore 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 >Smin (0.3) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	-
RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 3.4-0-0 = 3.4	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 3.4-0-0+0.3+0 = 3.7	S = 3.7
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Non-Structural Hazard = Glass Claddings are found in each storey	-

K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-3.7}$ Probability of failure = 0.0002	Building has 1 in 5000 chances of being failed under MCE shaking.
L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.2 Case study on G+2 storied Commercial Building situated in OKHLA, Delhi is a C1 type structure. Assess the Probability of failure of this Building.

Table 4.2 Probability of Collapse of G+2 C1 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, Weak storey, In plane discontinuity has not observed. Except the vertical geometric irregularity. This will give a negative score of 0.5	VL1 = -0.5
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent.	PL1 = 0
D)	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.	For a structure of this type in a seismically active area, the basic score is 1.5

E)	Age of Building	According to the data building was constructed in year 2018, therefore 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= 1.5+(-0.5)+1.9 = 2.9 >Smin (0.3) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	-
RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 2.9-0.5-0 = 2.4	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Geometric irregularity is observed	VL2 = -0.5
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 2.4-0.5-0+0.3+0 = 2.2	S = 2.2
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Non-Structural Hazard = Glass Claddings are found in each storey	-

K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-2.2}$ Probability of failure = 0.0063	Building has 1 in 158 chances of being failed under MCE shaking.
L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.3 Case study on G+3 storied Residential Building situated in CR Park, E-block, Delhi is a C2 type structure. Assess the Probability of failure of this Building.

Table 4.3 Probability of Collapse of G+3 C2 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent.	PL1 = 0
D)	Type of structure	According to construction materials and type of building, the building is classified as Concrete Shear Wall Buildings (C2), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 2.0
E)	Age of Building	According to the data building was constructed in year 2013, therefore age of building is 10 years. Hence, a positive score modifier of Post Benchmark	Post Benchmark = 2.1

		will be added.	
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1+Post benchmark SL1= 2.0+2.1= 4.1 >Smin (0.3) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	-
RVS Level 2			
G)	Baseline score, S'	S'= SL1-VL1-PL1 S'= 4.1-0-0 = 4.1	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S'-VL2-PL2+R1+R2 SL2 = 4.1-0-0+0.3+0 = 4.4	S = 4.4
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Non-Structural Hazard = Not Present	-
K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-4.4}$ Probability of failure = 0.00004	Building has 1 in 25000 chances of being failed under MCE shaking.

L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.4 Case study on G+3 storied Residential Building situated in CR Park, Pocket 40, Delhi is a C2 type structure. Assess the Probability of failure of this Building.

Table 4.4 Probability of Collapse of G+3 C2 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per" IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent.	PL1 = 0
D)	Type of structure	According to construction materials and type of building, the building is classified as Concrete Shear Wall Buildings (C2), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 2.0
E)	Age of Building	According to the data building was constructed before 2000, therefore age of building is more than 25 years. Hence, a negative score modifier of Pre-Code will be added.	Pre-Code = -0.7
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1+Pre-Code SL1= 2.0+ (-0.7)= 1.3 >Smin (0.3) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage.	-

		But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	
RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 1.3-0-0 = 1.3	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 1.3-0-0+0.3+0 = 1.4	S = 1.4
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Non-Structural Hazard = Not Present	-
K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-1.4}$ Probability of failure = 0.04	Building has 1 in 25 chances of being failed under MCE shaking.
L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.5 Case study on G+2 storied Residential Building situated in CR Park, New Delhi is a C3 type structure. Assess the Probability of failure of the Building.

Table 4.5 Probability of Collapse of G+2 C3 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent.	PL1 = 0
D)	Type of structure	According to construction materials and type of building, the building is classified as Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 1.2
E)	Age of Building	According to the data building was constructed in the year 2017, therefore age of building is 6 years. Hence, a positive score modifier of Post Benchmark will be added.	Post Benchmark for C3 buildings are Not Available
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1 SL1= 1.2+0+0 = 1.2 >Smin (0.3) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	-

RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 1.2-0-0 = 1.2	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 1.2-0-0+0.3+0 = 1.5	S = 1.5
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Non-Structural Hazard = Not Present	-
K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-1.5}$ Probability of failure = 0.0316	Building has 1 in 32 chances of being failed under MCE shaking.
L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.6 Case study on G+2 storied Building situated in Kalkaji N Block, New Delhi is a C3 type structure. Assess the Probability of failure of this Building.

Table 4.6 Probability of Collapse of G+2 C3 type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Ground Storey is 6.1m high whereas other stories are 3.1m high, also mass irregularity is observed in the building. Hence Severe Vertical Irregularity should be taken in this case	VL1 = -0.7
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, and offsets that aren't in the plane in vertical elements are absent, but the building has re-entrant curves.	PL1 = -0.5
D)	Type of structure	According to construction materials and type of building, the building is classified as Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 1.2
E)	Age of Building	According to the data building was constructed before 2002, therefore age of building is more than 25 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+Pre-Code SL1= 1.2+(-0.7)+(-0.5)+(-0.1) = -0.1 <Smin (0.3) Level 1 Score is coming out to be negative, at this stage surveyer must recommend the Building for the Detailed structural Evaluation	-

J)	Screening Process	Building Reviewed = All sides Interior = Entered Drawing = Not reviewed Non-Structural Hazard = Absent Level 2 Screening not performed	-
I)	Conclusion	Detailed Structural Evaluation is required as RVS Level 1 Score is less than the Smin	-

4.3.7 Case study on G+1 storied Residential Building situated in CR Park D Block, New Delhi is a Unreinforced Masonry Bearing Wall (URM) type structure. Assess the Probability of failure of this Building.

Table 4.7 Probability of Collapse of G+1 URM type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent.	PL1 = 0
D)	Type of structure	According to construction materials and type of building, the building is classified as Unreinforced Masonry Bearing Wall (URM), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 1.0
E)	Age of Building	According to the data building was constructed before year 2002, therefore age of building is more	Pre Code for URM

		than 25 years. Hence, a negative score modifier of Pre Code will be added.	buildings is 0
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1+Pre Code SL1= 1.0+0+0+0 = 1.0 >Smin (0.2) Level 1 Score is very high than the Smin, hence surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	-
RVS Level 2			
G)	Baseline score, S'	S'= SL1-VL1-PL1 S'= 1.0-0-0 = 1.0	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0,3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S'-VL2-PL2+R1+R2 SL2 = 1.0-0-0+0.3+0 = 1.3	S = 1.3
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Interior = Not Entered Non-Structural Hazard = Absent	-
K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-1.3}$ Probability of failure = 0.0501	Building has 1 in 20 chances of being failed under MCE shaking.

L)	Conclusion	Level 2 RVS score is much higher, hence no requirement of Detailed Structural evaluation.	-

4.3.8 Case study on G+2 storied Unreinforced Masonry Bearing Wall (URM) type structure, situated in CR Park, Delhi. Assess the Probability of failure of this Building.

Table 4.8 Probability of Collapse of G+2 URM type Building

RVS Level 1			Remarks
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 at location	"Medium Soil" category (as per "IS 1893:2016") "Soil Type D" (as per "FEMA 154,2015")	-
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, and offsets that aren't in the plane in vertical elements are absent, but Re-entrant curves are present on each floor.	PL1 = -0.4
D)	Type of structure	According to construction materials and type of building, the building is classified as Unreinforced Masonry Bearing Wall (URM), as per FEMA 154, 2015.	For a structure of this type in a seismically active area, the basic score is 1.0
E)	Age of Building	According to the data building was constructed before year 2002, therefore age of building is more than 25 years. Hence, a negative score modifier of Pre Code will be added.	Pre Code for URM buildings is 0
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1+Pre Code SL1= 1.0+0+(-0.4)+0 = 0.6 >Smin (0.2) Level 1 Score is very high than the Smin, hence	-

		surveyer can stop the survey at this stage. But we will proceed to RVS Level 2, as it will give a detailed evaluation of the building.	
RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 0.6-0-0.4 = 0.2	-
H)	Score modifiers		
	Vertical Irregularity, VL2	No Vertical irregularity is observed	VL2 = 0
	Plan Irregularity, PL2	Re-entrant corners as plan irregularity is observed	PL2 = -0.4
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 0.2-0-0.4+0.3+0 = 0.1 < Smin (0.2)	SL2 = Smin = 0.2
J)	Screening Process	Review of building = All sides Drawing = Not reviewed Interior = Reviewed Non-Structural Hazard = Absent	-
K)	Probability of failure (P)	Probability of failure = 10^{-S} Probability of failure = $10^{-0.2}$ Probability of failure = 0.6309	Building has 1 in 1.58 chances of being failed under MCE shaking.
L)	Conclusion	Detailed Structural evaluation is needed as the Final Level 2 Score, SL2 is less than Smin	-

4.3.9 Results and Discussions

From these case studies it can be concluded that every building yields different results, as per their configurations and characteristics. Different building types may be compared based on their likelihood of collapsing to see which one will function well under MCE Ground Shaking. Speaking about the building's performance, it is evident from the case study that, despite first impressions, the buildings were not as good as they appeared to be. However, after RVS, a number of abnormalities, either in the plan or in the vertical orientation, added up to be negative. These drawbacks, in addition to the building's many flaws, lead to the failure of the structure. A thorough examination of building qualities and a less cautious Score modification may be able to accommodate for situations in which the Level 2 Score will be greater Level 1 Score. Therefore, a less cautious outcome will result in a roughly accurate evaluation of the structure.

Table 4.9 displays the 8 buildings' RVS scores together with the likelihood that they will collapse.

Table 4.9 Type of Buildings and Probability of Collapse

S.no.	Type of Buildings	Building’s Photograph	Value of RVS Score	Probability of Collapse of the Buildings
1.	G+3 C1 type Building		3.7	0.02% probability, i.e., 1 in 5000

2.	G+2 C1 type Building		2.2	0.63% probability, i.e., 1 in 158
3.	G+3 C2 type Building		4.4	0.004% probability, i.e., 1 in 25000
4.	G+3 C2 type Building		1.4	4% probability, i.e., 1 in 25
5.	G+2 C3 type Building		1.2	3.2% probability, i.e., 1 in 32

6.	G+2 C3 type Building		-0.1	100% probability, i.e., 1 in 1
7.	G+1 URM Building		1.3	5% probability, i.e., 1 in 20
8.	G+2 URM Building		0.2	63% probability, i.e., 1 in 1.58

4.3.10 Concluding Remarks

Eight distinct building types are chosen for the investigation i.e., Concrete Moment-Resisting Frame Buildings (C1), Concrete Shear Wall Buildings (C2), Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), Unreinforced Masonry Bearing Wall (URM). According to the case study, Concrete Frame Building with Unreinforced Masonry Infill Walls (C3) due to the presence of severe vertical irregularity has 100% probability of Collapse, making it hazardous for activities and requires quick response. Unreinforced Masonry Bearing Wall (URM) Building has 63% probability of Collapse, and hence it might be subjected to a thorough structural investigation.

On other hand, Concrete Moment-Resisting Frame Buildings (C1) and Concrete Shear Wall Buildings (C2) showed Collapse Probability very less; this suggests the advantages of a regular construction free from flaws.

The results of the study provide credence to the idea that the RVS criteria of "FEMA P-154, 2015" may be used as a tool for carrying out the initial inspections of existing structures.

CHAPTER 5

RISK SCORE CALCULATION AND POSSIBILITY OF FAILURE DUE TO SEISMIC EVENT

5.1 INTRODUCTION

A performance metric known as the Risk Score (S_R) rates how well buildings will hold up in the event of numerous earthquakes that cause them to collapse. The amount of tremors that might cause a structure to fail during the course of its construction, which is typically 50 years, is calculated to get the Risk Score [2].

S_R is Comparing to S results in a distinct measure of performance since S does not take into account design life or earthquakes that result from collapse, whereas S does.

The Risk Score is calculated by adding the likelihood of a building collapsing under a given seismic event to the total number of times in 50 years that level will occur, adding all levels of tremors, and calculating the resulting negative base10 logarithm of that result. [2]

Risk relates to the frequency at which collapse-causing earthquakes occur, whereas "fragility" signifies the risk of failure in response to a given seismic event.

5.2 RISK SCORE CALCULATIONS (S_R)

Equation 5.1 demonstrates how to compute Risk Score (S_R) using the base-10 negative logarithm of a combination of Collapse rate and built life of the Building. On the other hand, equation 5.2 may be used to compute the risk modification factor (PMF_R).

$$S_R = -\log_{10} (\tau \times \lambda) \quad (5.1)$$

$$PMF_R = S_R - S \quad (5.2)$$

λ= Collapse Frequency

τ = Building's design life, generally taken as 50 years

PMF_R is Risk modification component

Equation 5.3 depicts the selected fragility function

$$\Upsilon = \varphi\left(\frac{\ln(\frac{x}{\theta})}{\beta}\right) \tag{5.3}$$

φ = standard normal distribution cumulatively assessed at the period in brackets

Ɵ = Median

β = the standard deviation in logarithms

The equation for calculating the risk score using the RVS Score is shown in Equation 5.4.

$$S_R = S+1 \tag{5.4}$$

Table 5.1 provides the risk multiplier of an existing structure relative to the new construction based on the risk score of the current building.

Table 5.1 Risk in relation to new building risk for varied S_R levels in existing structures [2]

Risk Score S_R	**Risk multiplier of existing building versus new buildings**
1.5	100X
2.0	32X
2.5	10X
3.0	3X
3.5	1X
4.0	0.3X
4.5	0.1X

Equation 5.5 is the equation for the computation of the probability that there will be at least a single seismic event within the next 't' years which is sufficiently severe to trigger destruction.

$$R(t) = 1 - \exp\left(- \frac{10 - SR}{\tau} X\, t\right) \quad (5.5)$$

The person conducting the inspection may or may not have exposure to the building's interior because whole rating is based on an outside survey. As a result, the real risk can be higher than the risk that was assessed. The Engineer-in-Charge's judgment should be used to determine whether to lower the risk score.

5.3 SELECTION OF STRUCTURES FOR SEISMIC RESTORATION USING RVS SCORE

5.3.1 Estimation of probability that a seismic event will cause a building to fail

The risk score is notably different from RVS score in that it indicates the possibility of failure at any sort of shaking. However, in order to calculate Risk score, RVS score is necessary. According to the Investigation, it has been shown that FEMA P-154 neglects to take into consideration the building's flaws. In order to account for any cracks or other construction flaws that could go undetected during the survey, it is recommended to cut the visual survey score in seismic zone IV and zone V by 25%. According to FEMA P-154, 2015, it was found that a rating of 1.4 is exclusively used for a building which is retrofitted globally. In the end, the Risk Scores for that structure will be raised by 1.4 in future surveys, which will significantly lower the likelihood of a building collapse triggering an earthquake during the next 50 years. However, the score modifier in the RVS score does not take local retrofitting into consideration. Therefore, the Cost-Benefit ratio must be in favour of any global retrofitting measures that are implemented. Although as a general guideline, retrofitting must be used if the cost is less than 30% of the cost of reconstruction [5].

Fig. 5.2 illustrates the RVS technique for determining the need for retrofitting by estimating the likelihood that at least one seismic event will cause a collapse within the next "t" years.

Probability of Earthquake causing a Collapse r(t)	
Level 1 RVS	Level 2 RVS
Determine the Seismic Zone of the area as per IS 1893, 2016	Baseline score S' is calculated and then Final Level 2 score SL_2 is calculated
Determine type of Soil and any other hazards according to IS 1893, 2016	Check if $SL_2 \geq$ Smin (cut-off score)
Identify the Vertical and Plan Irregularities in the building according to IS 1893, 2016	If yes, then take SL_2 as final score and calculate Risk score (S_R) / If no, the take Smin as final score and calculate risk score (S_R)
On the basis of type of building and construction materials used, provide a basic score to the building using FEMA 154, 2015	Calculate risk score using equation, $S_R = S+1$
Provide Score modifiers for the discontinuities and soil conditions provided in FEMA 154, 2015	Probability of earthquake leading to collapse can be calculated using, $R(t) = 1 - \exp\left(-\frac{10-SR}{\tau} \times t\right)$
Calculate Final Score for RVS Level 1 SL_1 = Basic score – Score modifier	Check if, $R(t) \geq 1.5$ times probability of occurrence of MCE ground motion (2% for 50 years)
Check if $SL_1 \geq$ Smin (cut-off score)	If yes, then take Global retrofitting measures. / If no, then either take Local retrofitting measures or the building is considered as SAFE

If yes, then proceed to Level 2 RVS	If no, then take Smin as final score and calculate Risk score (S_R)

Figure 5.1 Methodology for estimation of possibility of collapse

5.4 PROBLEM STATEMENT

As per our case study, FEMA P-154, 2015 lists 17 distinct types of structures based on the construction method and materials employed. We have chosen two distinct types of structures, however, in order to match the actual observation at the location with the Risk Score. One type of building is G+2 Storied RCC building and other one is Unreinforced Masonry Hostel building, situated in Delhi.

5.4.1 Case study on G+2 Storied Concrete Frame Building with Unreinforced Masonry Infill Walls situated in Delhi, was constructed in the year of 1991and is under routine maintenance. Comment on the chances of at least one failure during seismic event and repair requirements.

Table 5.2 Possibility of at least one seismic event causing failure of C3 type building within next 50 years

RVS Level 1			Remarks
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 at the location	"Medium Soil" category (as per IS 1893:2016)	-
		"Soil Type D" (as per FEMA 154,2015)	
C)	Vertical Irregularity	All Stories are equal in space, Mass irregularity, Weak storey, In plane discontinuity has not observed. But Vertical geometric irregularity is present	VL1 = -0.4
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent	PL1 = 0
D)	Type of Structure	According to construction materials and type of building, the building is Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), as per FEMA	-

		154, 2015. For a structure of this type in a seismically active area, the basic score is 1.2.	
E)	Age of Building	According to the data building was constructed in the year 1991, therefore age of building is 32 years. Hence, a negative score modifier of Pre-code will be added. *2002 is considered as the base year	Pre-code = -0.1
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1 SL1= 1.2+(-0.4)+(-0.1) = 0.7 >Smin (0.3)	-
RVS Level 2			
G)	Baseline score, S’	S’= SL1-VL1-PL1 S’= 0.7-0.4-0 = 0.3	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Vertical Geometric irregularity is observed	VL2 = -0.4
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0
	Redundancy, R1	It is observed that the building is redundant structure, hence a positive score modifier will be assigned	R1 = 0.3
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S’-VL2-PL2+R1+R2 SL2 = 0.7-0.4-0+0.3+0 = 0.6	S = 0.6 > Smin(0.3)
J)	Risk score, S_R = S+1	S_R = 1.6	-
	The risk score must be decreased by 25% to account for previously undiscovered seismic fractures that might have disastrous consequences.	0.75 X 1.6 = 1.2	-

	Probability that at least one earthquake with a magnitude large enough to create failure during t years. $R(t) = 1 - e(-\frac{10-SR}{\tau} X\ t)$ τ = Design life of the building (50 years) t = Number of years (taking 50 years)	$R(t) = 1 - e(-\frac{10-1.2}{50} X\ 50)$ R(t) = 0.0611 R(t) = 6.11%	Higher than the likelihood of MCE (i.e., 2% for 50 years)
L)	Conclusion		
	a)	When compared to the likelihood of MCE Ground Shaking, the possibility that at least one seismic event will occur within the next 50 years that is powerful enough to trigger collapse is much higher. As a result, Structure is rated as Unsafe.	-
	b)	The structure's potential for fatalities is 100 times greater than that of the new construction; a thorough technical study of the current building is required. Buildings must thus be updated internationally in accordance with IS 4326:2013.	-

5.4.2 Case study on G+2 story masonry hostel building in Delhi has undergone extensive renovations and routine maintenance. Comment on the likelihood that at least one collapse will result in an earthquake and the need for retrofitting.

Table 5.3 Probability of at least one seismic event causing failure of URM type building within next 50 years

RVS Level 1			Remarks
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 at the location	"Medium Soil" category (as per IS 1893:2016)	-

		"Soil Type D" (as per FEMA 154,2015)	
C)	Vertical Irregularity	Stories are equal in space, irregularity in mass, geometric irregularity, Weak storey, In plane discontinuity has not observed.	VL1 = 0
	Plan Irregularity	Floor area at every storey is same, unnecessary cuts-outs, re-entrant curves, and offsets that aren't in the plane in vertical elements are absent	PL1 = 0
D)	Type of Structure	According to construction materials and type of building, the building is classified as Unreinforced Masonry Bearing Wall (URM) Building, as per FEMA 154, 2015. For a structure of this type in a seismically active area, the basic score is 1.0.	-
E)	Age of Building	According to the data building was constructed before 2000, therefore age of building is more than 25 years. Hence, a negative score modifier of Pre-code will be added. *2002 is considered as the base year	Pre-code = 0
F)	Final Level 1 Score (SL1)	SL1= Basic Score+VL1+PL1 SL1= 1.0+0+0 = 1.0	> Smin(0.2)
RVS Level 2			
G)	Baseline score, S'	S'= SL1-VL1-PL1 S'= 1.0-0-0 = 1.0	-
H)	Score modifiers		
	Vertical Irregularity, VL2	Vertical irregularity is not observed	VL2 = 0
	Plan Irregularity, PL2	No plan irregularity is observed	PL2 = 0

	Redundancy, R1	Not observed	R1 = 0
	Retrofit, R2	Retrofitting is not observed	R2 = 0
I)	Final Level 2 Score (SL2)	SL2= S'-VL2-PL2+R1+R2 SL2 = 1-0-0+0+0 = 1.0	S = 1.0 > Smin(0.3)
J)	Risk score, S_R = S+1	S_R = 2.0	-
	The risk score must be decreased by 25% to account for previously undiscovered seismic fractures that might have disastrous consequences.	0.75 X 2 = 1.5	-
K)	Probability that at least one earthquake with a magnitude large enough to induce failure happens during t years. $R(t) = 1 – e(- \frac{10-SR}{\tau} X t)$ τ = Design life of the building (50 years) t = Number of years (taking 50 years)	$R(t) = 1 – e(- \frac{10-1.5}{50} X 50)$ R(t) = 0.03112 R(t) = 3.112%	Higher than the likelihood of MCE (i.e., 2% for 50 years)
L)	Conclusion		
	a) When compared to the likelihood of MCE Ground Shaking, the probability that at least one earthquake will occur within the next 50 years that is powerful enough to trigger collapse is much higher. As a result, Structure is rated as Unsafe.		-
	b) The fatality risk of the building is 100 times greater than that of the new construction; a thorough technical study of the current building is required. Buildings must thus be updated internationally in accordance with IS 4326:2013.		-

Table 5.4 Type of buildings and probability of earthquake leading collapse

S.No.	Type of Structure	Building's Photograph	Risk Score (S_R)	Possibility of earthquake leading failure R(t)	Remarks
1.	G+2 Storied C3 type Building		1.2	6.11% i.e., 1 in 16	1. R(t) exceeds the chance of MCE, hence the building is regarded as being unsafe. 2. The existing structure is 100 times more deadly than a new one, a thorough technical examination and extensive retrofitting are necessary.
2.	G+2 storied URM Building		1.5	3.11% i.e., 1 in 32	1 R(t) exceeds the chance of MCE, hence the building is regarded as being unsafe. 2. The existing structure is 100 times more deadly than a new one, a thorough technical examination and extensive retrofitting are necessary.

5.4.3 Concluding Remarks

In this Case study, two distinct buildings have been chosen one is Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3) and other one is Unreinforced Masonry Bearing Wall (URM) building for evaluating their Risk Score (S_R). The findings of this study is that the chance of earthquake creating failure for G+2

Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3) is 6.11 for the next 50 years, that is more than the likelihood of MCE ground shaking (2% for 50 years). In fact, the risk for fatalities from existing structure is 100 times higher than from a new structure. As a result, the Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3) building has been classified as "UNSAFE".

Similarly, the analysis suggests that the chance of an earthquake leading to the collapse of a is Unreinforced Masonry (URM) structure is equivalent to 3.11% over the course of the next 50 years, which is higher than the possibility of an MCE tremore (2% over the same period). In fact, the risk for fatalities from existing structure is 100 times higher than from a new structure. As a result, the Unreinforced Masonry (URM) building has been classified as "UNSAFE".

CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

Different surveying criteria is released by various organisations, however, “FEMA P-154, 2015” and “FEMA P-155, 2015” augment the survey in the most considerate way by rating the surveyed structures for their distinctive elements. This research seeks to improve the probabilistic technique in calculation of likely life building by streamlining the execution of RVS utilising the codal rules of Indian Standard.

This study has used the RVS Score to calculate the likelihood of a structure failing. By contrasting the likelihood of a structure failing with the likelihood of MCE shaking, it may be established whether a comprehensive vulnerability evaluation of the building structure is necessary.

Additionally, the probability that a structure would collapse under the influence of a severe earthquake during the following fifty years has been determined using the RVS score. The likelihood that a structure would collapse under a severe earthquake during the following fifty years is determined after the Risk Score has been calculated. The results obtained from the study is follows, in accordance with the discussions.

1. The Concrete Moment-Resisting Frame Buildings (C1) shows the possibility of collapsing under MCE tremor, is 0.02% and 0.63%. While the Concrete Shear Wall Buildings (C2) has the likelihood of failure with MCE tremor, 0.004% and 4%. The Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3) have the probability of collapsing with MCE ground shaking, 3.16% and 100%. The Unreinforced Masonry Bearing Wall (URM) has the possibility of collapsing with MCE tremor, 5% and 63%.

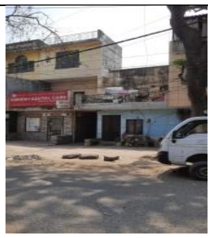
2. For the probability of collapse both structures are extremely vulnerable to an earthquake that causes a building to collapse, increasing the possibility that it will fail within the next 50 years. The Concrete Frame Buildings with Unreinforced Masonry Infill Walls (C3), its probability of encountering an earthquake that might lead to collapse is 6.11%. Whereas for, Unreinforced Masonry Bearing Wall (URM), its probability of encountering an earthquake that might lead to collapse is 3.11%. As a result, both buildings must undergo a thorough structural study for retrofitting in order to function safely during seismic activity.
3. The RVS criteria of "FEMA P-154(2015)" can thus be applied adequately for early investigation using the codal requirements of Indian Standards. The technique will aid in prioritising the building for extensive structural examination and retrofitting suggestions, allowing a fair determination of the need for detailed technical evaluation to be made.

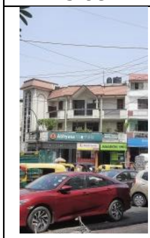
6.2 FUTURE SCOPE

The current study focused on the initial investigation of structures utilising RVS as a technique to evaluate how well they will function during seismic activity. However, after prioritising the existing building structures using the RVS tool, the task's future scope will involve doing a complete vulnerability analysis of such structures. To simplify the procedure, a solid foundation for the sort of retrofitting necessary must be developed using the findings of a thorough vulnerability assessment.

APPENDIX 1

Table 1-A Preliminary survey of buildings

 House No. 176, Kalkaji A-block	 House No. 177, Kalkaji A-block	 House No. 132, Kalkaji A-block	 House No. 94, Kalkaji A-block	 House No. 93, Kalkaji A-block	 House No. 92, Kalkaji A-block
 House No. 91, Kalkaji A-block	 House No. 12, CR Park, Pocket 40	 House No. 12, CR Park, Pocket 40	 House No. 13, CR Park, Pocket 40	 House No. 14, CR Park, Pocket 40	 House No. 15, CR Park, Pocket 40
 House No. 16, CR Park, Pocket 40	 House No. 17, CR Park, Pocket 40	 House No. 18, CR Park, Pocket 40	 House No. 19, CR Park, Pocket 40	 House No. 20, CR Park, Pocket 40	 House No. 21, CR Park, Pocket 40
 House No. 22, CR Park, Pocket 40	 House No. 23, CR Park, Pocket 40	 House No. 24, CR Park, Pocket 40	 House No. 126, CR Park D-block	 House No. 127, CR Park D-block	 House No. 130, CR Park D-block

 House No. 131, CR Park D-block	 House No. 132, CR Park D-block	 House No. 133, CR Park D-block	 House No. 134, CR Park D-block	 House No. 135, CR Park D-block	 House No. 136, CR Park D-block
 House No. 14, CR Park D-block	 House No. 15, CR Park D-block	 House No. 16, CR Park D-block	 House No. 17, CR Park D-block	 House No. 18, CR Park D-block	 House No. 19, CR Park D-block
 House No. 20, CR Park D-block	 House No. 21, CR Park D-block	 House No. 22, CR Park D-block	 House No. 23, CR Park D-block	 House No. 24, CR Park D-block	 House No. 25, CR Park D-block
 House No. 14, Kalkaji N-block	 House No. 13, Kalkaji N-block	 House No. 12, Kalkaji N-block	 House No. 122, CR Park E-block	 House No. 123, CR Park E-block	 House No. 124, CR Park E-block
 House No. 125, CR Park E-block	 House No. 126, CR Park E-block	 House No. 127, CR Park E-block	 House No. 128, CR Park E-block	 House No. 129, CR Park E-block	 House No. 130, CR Park E-block

 House No. 131, CR Park E-block	 House No. 132, CR Park E-block	 House No. 133, CR Park E-block	 House No. 134, CR Park E-block	 House No. 811, CR Park E-block	 House No. 956, CR Park E-block
 House No. 963, CR Park E-block	 House No. 964, CR Park E-block	 House No. 965, CR Park E-block	 House No. 983, CR Park E-block	 House No. 949, CR Park E-block	 House No. 25, Kalkaji B-block
 House No. 26, Kalkaji B-block	 House No. 27, Kalkaji B-block	 House No. 28, Kalkaji B-block	 House No. 29, Kalkaji B-block	 House No. 30, Kalkaji B-block	 House No. 31, Kalkaji B-block
 House No. 93, Kalkaji C-block	 House No. 92, Kalkaji C-block	 House No. 91, Kalkaji C-block	 House No. 90, Kalkaji C-block	 House No. 89, Kalkaji C-block	 House No. 88, Kalkaji C-block

 House No. 102, Kalkaji C-block	 House No. 103, Kalkaji C-block	 House No. 104, Kalkaji C-block	 House No. 105, Kalkaji C-block	 House No. 106, Kalkaji C-block	 House No. 107, Kalkaji C-block
 House No. 108, Kalkaji C-block	 House No. 109, Kalkaji C-block	 House No. 110, Kalkaji C-block	 House No. 111, Kalkaji C-block	 House No. 72, Kalkaji J-block	 House No. 69, Kalkaji J-block
 House No. 68, Kalkaji J-block	 House No. 66, Kalkaji J-block	 House No. 106, OKHLA	 House No. 107, OKHLA	 House No. 215, OKHLA	 House No. 243, OKHLA
 House No. 244, OKHLA	 Hostel Building at DTU	 Hostel Building at DTU	 Hostel Building at DTU		

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