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RISK EVALUATION OF EXISTING BUILDINGS USING RVS AS TOOL

A DISSERTATION

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Submitted by:
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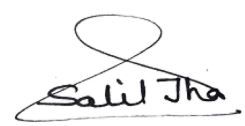
CANDIDATE’S DECLARATION

I, Salil Jha, Roll No. 2K19/STE/06 student of M. Tech (Structural Engineering), hereby declare that the project dissertation titled “**RISK EVALUATION OF EXISTING BUILDINGS USING RVS AS TOOL**” 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 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.



Place: Delhi **SALIL JHA**

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**RISK EVALUATION OF EXISTING BUILDINGS USING RVS AS TOOL**" which is submitted by Salil Jha, Roll No. 2K19/STE/06, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Place: Delhi

Date: 25/06/2021

Dr. SHILPA PAL

Supervisor

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At the last, I would like to extend a note of thanks to my parents, whose uninterrupted efforts have been a constant motivation throughout the journey.

Salil Jha

ABSTRACT

As per the studies conducted in past, it has been stipulated that it is not the earthquakes which kill humans, instead it is the poor and substandard practices involved in the construction of building which leads to its failure in the seismic event. Although, various IS codes for the design of building are available, but due to the rapid urbanization they have been overlooked. Being a seismic zone IV (as Per IS 1893:2016) and a rapidly urbanizing city without considering the standard construction practices, Delhi becomes a soft target for any severe seismic event. Hence, in order to safeguard deficit structures against seismic excitation; a rapid performance evaluation strategy is the need of hour. A lot of effort for the assessment of existing structures has been laid upon, but the basic idea could not be inherited. Eventually the strategy could not be implemented, owing to their technical complexities.

Although, Various screening guidelines have been issued by different agencies, but FEMA P-154(2015) and FEMA P-155(2015) supplements the screening in the most comprehensive manner by scoring the screened building for its various attributes, like RVS score has been used to calculate risk of earthquake causing the collapse of building. Adopting the various fundamentals of practices in various guidelines such as FEMA, ATC etc., this dissertation aims to simplify the application of RVS in purview of various Indian Standard Codes, in order to achieve a better probabilistic approach in estimation of probable life building.

In this dissertation, a detailed study has been carried out to calculate the probability of collapse of building using RVS score and subsequently that probability of collapse is compared with the probability of MCE shaking. Eventually, the result from comparison is used to decide, if the detailed vulnerability assessment of the building is required or not. Following the methodology prescribed by FEMA 154(2015), four Different types of existing structures have been taken as case study for the calculation of the collapse probability i.e., High-Rise RCC Building, Mid Rise RCC Building, RCC plus Masonry Combined Building and Load Bearing Masonry Building.

In addition, RVS score has been used to calculate the Probability of the collapse mechanism to happen in a building under a significant earthquake within next 50 years. Following the calculation of 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., RCC G+3 building and Load Bearing Masonry building, 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.

Following the calculation of Probability of Collapse under the MCE shaking, RCC plus Masonry Combined Building is found to have the least likelihood of being collapsed under MCE ground shaking, i.e., 0.63%, whereas the Mid-Rise RCC Building shows the highest likelihood of being collapsed under MCE ground shaking i.e., 100%. However, the High-Rise RCC Building has 50% likelihood of being collapsed under MCE ground shaking and Load Bearing Masonry Building have been found to have fairly high likelihood of being collapsed under MCE ground shaking i.e., 63%.

Following the calculation of at least one collapse causing earthquake within next 50 years, it has been found that the Load Bearing Masonry building has 3.11% chance of being confronted by an earthquake that can cause collapse. And, the probability of an earthquake causing the RCC G+3 building to collapse over the next 50 years has been calculated to be 1.57 %. The risk score is an indicator of the degree of fatality of the building and it has been calculated that Load Bearing masonry building is 100 times more fatal than the newly constructed Load Bearing masonry building. Therefore, detailed structural evaluation for retrofitting the Load Bearing masonry building to be safe under any seismic activity, is required.

Hence, as per the study, the RVS guidelines of FEMA P-154(2015) can be used satisfactorily including permissible limits as per Indian standard for preliminary investigation. Based on which a fair decision regarding the necessity of detailed technical evaluation can be done and the methodology will help in prioritizing the building for detailed structural evaluation and retrofitting recommendations.

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CHAPTER 1

INTRODUCTION

1.1 Rapid Visual Screening: An Introduction

Rapid Visual screening is a systematic approach to pinpoint the structures which could be potential threat in the event of seismic hazards. It has been introduced by the federal emergency management agency, in two volumes in the year of 1988 as FEMA 154 and FEMA 155. A variety of structures are included in it ranging from low rise to high rise, which makes it inclusive. Buildings which are stated “Structurally Deficit” are furthered for the detailed investigation.

The development of Rapid Visual Screening procedure is done, with an aim to survey the building for its existing conditional assessment. In this survey, a screener is assigned with a job to fill the survey data sheet as per the seismicity of the area in which the building is standing. The screener, based on the observations, decide if the building being surveyed has any of the irregularity as mentioned in the datasheet. Subsequently, the screener encircles the deficiency and assigns a score modifier to the basic Score of the building. Eventually, we get a RVS Score at the end of the exercise, which gives a fair idea of the existing condition of the building under survey by corelating it with probability of collapse. Similarly, any building can be surveyed.

Basically, it assesses the two components in any building: -

1) Lateral load resisting systems in the building.
2) Various building aspects that may interfere with expected seismic behavior of the lateral load system.

1.2 Rapid Visual Screening and Decision Making

Although, at the end of Rapid Visual Screening, a fair idea of the existing condition of a building can be made from the results. But RVS Score is particularly a result for MCE Ground Shaking and it doesn’t radiate any light on the performance of Building at different level of Shaking. RVS score is a measure which tells us about the Collapse

Probability at MCE ground shaking. Hence based on the RVS Score, it cannot be discretized as Safe or Unsafe for other level of seismic shaking.

At this stage, the Risk Assessment of the existing structures creeps in, in order to render the building as Safe or Unsafe for future seismic events.

1.3 Objective of the Study

The objectives of the study are as follows

i. To prepare a methodology for the rapid visual assessment of existing structures using relevant codal provisions of Indian standards.

ii. To develop a methodology for existing structure using Indian standards, to calculate the probable collapse of an existing structure under MCE shaking and suggesting if it requires a detailed structural evaluation or not.

iii. To develop a methodology for existing structure using Indian standards, to calculate the risk of an earthquake which can cause collapse in the existing structure in next 50 years and suggesting if the existing structure requires a retrofitting or not.

1.4 Scope of the Study

This study deals with the Preliminary investigation of building structures using technical parameters of various Indian Standard and methodologies adopted by FEMA. In this study, six different types building have been selected as per the local typologies prevalent in construction, for the preliminary investigation of building. Four buildings have been investigated for their probability of collapse under MCE shaking, whereas two buildings are investigated for the risk assessment of existing building for a collapse causing earthquake in next 50 years.

1.5 Limitation of the Study

This study is limited upto the preliminary investigation part only and sorting of building structure based on RVS score is dealt in this dissertation. However, recommendation for detailed structural evaluation and retrofitting can be made, using the results. But, analysis for detailed structural evaluation and retrofitting measure is the future scope of study.

1.6 Organization of Thesis

This Dissertation titled "**RISK EVALUATION OF EXISTING BUILDINGS USING RVS AS TOOL**" is composed of six chapter, a bibliography and list of publication. following are the chapters included in this dissertation,

Chapter 1 consist of the Introduction of the RVS, in which objective, scope and limitation of thesis is also given.

Chapter 2 comprises of literatures which have been reviewed, during the study.

Chapter 3 discusses in detail the concept of RVS and factors affecting it.

Chapter 4 comprises of the methodology for the calculations for RVS score and a case study of calculation of collapse probability of existing building using RVS as a tool.

Chapter 5 comprises of the methodology for the calculations for risk score and a case study of calculation of probability of collapse causing earthquake within next 50 years for prioritization of structure for retrofitting requirements.

Chapter 6 consist of the conclusion for the case studies conducted.

Bibliography of the literatures which have been referred in the study is also provided

CHAPTER 2

LITERARTURE REVIEW

2.1 INTRODUCTION

In this dissertation, FEMA 154(2015), FEMA 155(2015), IS:1893(2016), IS:456(2002), IS:13935 (2009) and various other articles have been referred, in order to provide a strong basis for the preliminary investigation. Speaking of FEMA literatures, FEMA 154(2015) provides detailed descriptions of guidelines associated with rapid visual screening and its execution. Whereas, FEMA 155(2015) provides detailed mathematical basis for the scores assigned to typical building structures. And, Indian standards have been followed meticulously for corelating various technical parameters provided in FEMA and other articles, in order to maintain the coherence.

2.2 LITERATURE REVIEW

2.2.1 RVS using FEMA guidelines

FEMA P-154(2015) and FEMA P-155(2015) have been strategically developed for the assessment of seismic risk. FEMA P-154(2015) has outlined the swift screening procedures, in which depending upon the type of buildings and their construction material, a basic score is assigned. The basic score is also resorted to the seismic zone of location of the building. Factors such as pounding, soil condition, height of building etc. are also accounted for.

Subsequently, score modifiers addressing the irregularities present in the buildings are assigned. And, either by subtracting or by adding the score modifier to the basic score, the final RVS score is determined. Eventually, the RVS score is corelated to the collapse probability under MCE shaking.

Whereas, the FEMA P-155(2015) provides the mathematical basis of basic score and score modifiers, as per HAZUS methodology. It also lay emphasis upon the calculation of Risk Score, which is then corelated with risk of at least one collapse causing MCE shaking with in next “t” number of years.

2.2.2 RVS using Indian Standards

a) Method proposed by Sinha and Goyal (IIT Bombay,2004)

This method has its gist focused upon the guidelines of FEMA P-154 (2002). This method has attempted to incorporate the parameters of Indian standards such IS 1893, in the procedure of FEMA. However, this procedure has successfully corelated the damage level and RVS score.

b) Method proposed by Bureau of Indian Standards

The method proposed by the IS 13935 in 2004, is limited to masonry structures only. For a particular building type, codal seismic intensity, and its corresponding damage grade are corelated in this standard. This method assigns grade to the building only, depending upon the various parameters present in datasheet. However, it has no basic score and score modifiers for the type of building and score modifier respectively.

c) Method proposed by Jain and Mitra (IIT Gandhinagar,2010)

This method has been put forward for the RCC Frame buildings, and it is an outcome of Istanbul master plan for earthquake. This method is unique from FEMA, in a way that it is depended upon the statistics of damage from previous earthquakes. This method proposed is based upon the data of 6500 buildings which were damaged in Bhuj earthquake (2001) and surveyed in the region of Ahmedabad and its vicinity, which were primarily RC and masonry building stocks. Eventually, based upon the damage buildings bore, were graded as no damage (G0) and collapse (G5).

d) Method proposed by BMPTC

This method is based upon the study which has been conducted for the safety of typical construction typologies in India. In this study, a total of 7 towns has been surveyed for development of methodology of evaluation of seismic safety. In this method, experts are employed to assign the index value and performance rating to a house.

CHAPTER 3

RVS AND FACTORS AFFECTING IT

3.1 RAPID VISUAL SCREENING

RVS is a systematic approach to evaluate the building stocks and to pin point those buildings, which require detailed vulnerability assessment based on the preliminary evaluation. Figure 3.1 depicts the various stages involved in the calculation of RVS score as per FEMA P-154(2015)

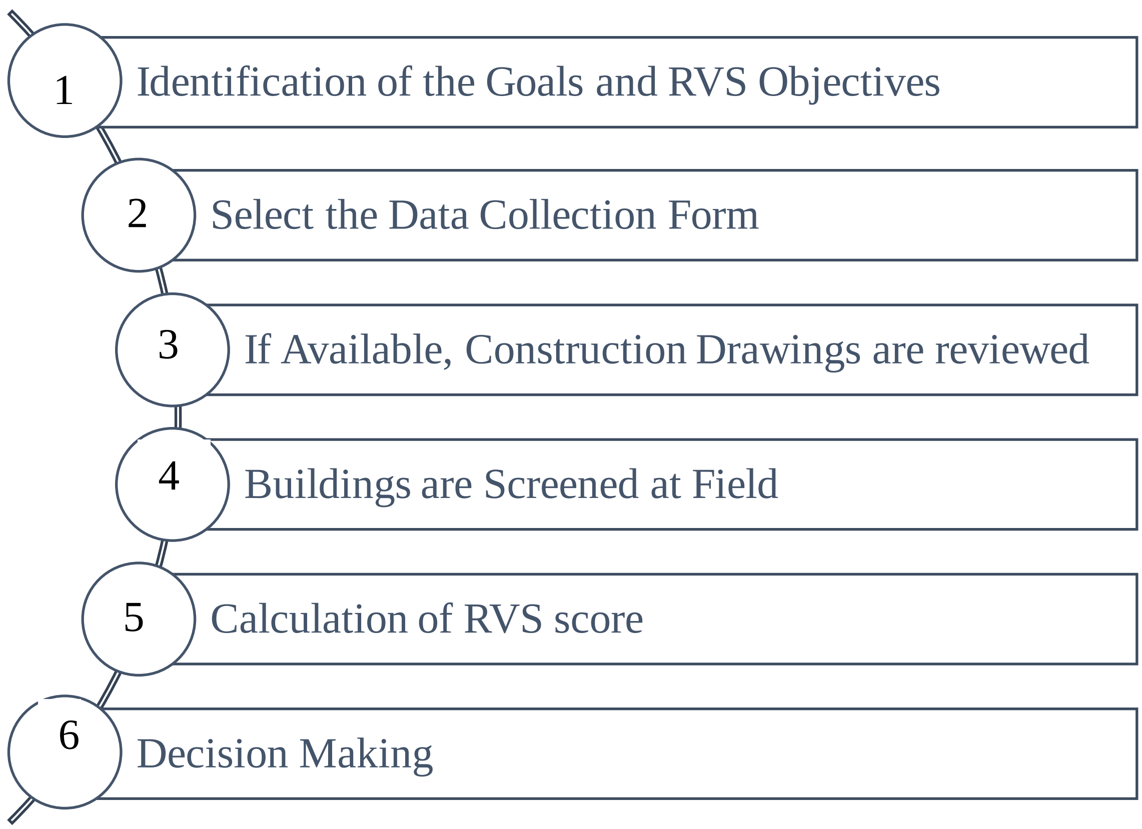

Figure 3.1 Sequence of RVS Implementation

3.2 FACTORS IN RAPID VISUAL SCREENING (LEVEL 1)

A rational bifurcation and inclusion of various technical parameters makes the rapid visual screening easy and executable. The technical parameters used in the level 1 screening, assists the evaluator to determine the numerical hazard score of the building under screening. Parameters have been bifurcated in two major categories, as under

3.2.1 Basic Score Category

Basic score category for different seismic region, has been computed using damage and loss function available. It ascertains the probability of building collapse, which may occur in the event of Risk Targeted Maximum Considered Earthquake (MCE_R). It includes

a) Determination of Seismicity region as per IS 1893:2016

In the Purview of FEMA P-154 (2015), the seismicity of region is derived out of MCE_R Spectral acceleration response for the time period of 0.2s and 1s, whereas IS 1893:2016 relate the seismicity of a region to MSK intensity.

To envisage damage to a particular level seismic hazard is complex, as different building types have different behaviour owing to their inherent characteristics. Though, the FEMA P-154 (2015) has discretized the spectral acceleration response and their corresponding seismicity hazard, but a number of other factors come into play during vigorous shaking corresponding to high (Zone IV) and very high (Zone V) seismicity region.

In Table 3.1, the seismicity of a region based upon spectral acceleration for a short period (0.2 s) and long period (1.0 s) is demonstrated, as given in FEMA 154(2015).

In Table 3.2, the seismicity of a region based upon MSK intensity and their corresponding damage is demonstrated, as given in IS 1893:2016.

Table 3.1 Seismicity Region Determination Based on MCE_R Spectral Acceleration Response [3]

Seismicity region	**Spectral acceleration response, S_s (Short-period, or 0.2 seconds)**	**Spectral Acceleration Response, *S1* (long-period, or 1.0 second)**
Low	less than 0.250g	less than 0.100g
Moderate	greater than or equal to 0.250g but less than 0.500g	greater than or equal to 0.100g but less than 0.200g
Moderately High	greater than or equal to 0.500g but less than 1.000g	greater than or equal to 0.200g but less than 0.400g
High	greater than or equal to 1.000g but less than 1.500g	greater than or equal to 0.400g but less than 0.600g
Very High	greater than or equal to 1.500g	greater than or equal to 0.600g

g = acceleration of gravity in horizontal direction

Table 3.2 Seismicity in India as per IS 1893:2016[8]

Zone II	Low seismic hazard (maximum damage during earthquake may be upto MSK intensity VI)
Zone III	Moderate seismic hazard (maximum damage during earthquake may be upto MSK intensity VII)
Zone IV	High seismic hazard (maximum damage during earthquake may be upto MSK intensity VIII)
Zone V	Very high seismic hazard (maximum damage during earthquake may be of MSK intensity IX or greater)

b) Building Type and its Lateral Load Resisting Structure

With advance in the construction technology and construction material, various types of building are being constructed depending upon the requirements of inhabitant and their budget.

Table 3.3 shows the17 different building types covered by FEMA P-154(2015), but in this study, we are only concerned about framed concrete buildings, framed steel buildings and confined and unconfined masonry construction.

Table 3.3 FEMA Building Types and their corresponding building type as per IS :2016 Rapid Visual Screening Under Consideration [3]

Building Types as per FEMA P-154(2015)		As Per IS 1893:2016
W1	Light wood frame single- or multiple-family dwellings	Type C
W1A	Light wood frame multi-unit, multi-story residential buildings with plan areas on each floor of greater than 3,000 sqft	Type C
W2	Wood frame commercial and industrial buildings > 5,000 sqft	Type C
S1	Steel moment-resisting frame buildings	Type B
S2	Braced steel frame buildings	Type B
S3	Light metal buildings	Type B
S4	Steel frame buildings with concrete shear walls	Type B
S5	Steel frame buildings with unreinforced masonry infill walls	Type B
C1	Concrete moment-resisting frame buildings	Type C
C2	Concrete shear wall buildings	Type C
C3	Concrete frame buildings with unreinforced masonry infill walls	Type C
PC1	Tilt-up buildings	Type C
PC2	Precast concrete frame buildings	NA
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms	Type C
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms	Type C
URM	Unreinforced masonry bearing wall buildings	Type B
MH	Manufactured housing	NA

3.2.2 Score Modifier Category

Score respectively Various characteristics present in building affect its performance either positively or negatively, hence increases or decreases the Basic.

a. Height of The Building

With the increase in height of building, the vulnerability of building during a seismic event increases. Hence, basic score for different building types is modified accordingly for soil type E only [3].

b. Vertical Irregularity of The Building

In the event of seismic excitation, it is deemed to have all forces be transmitted to substructure for the overall safety and stability of superstructure. But in certain construction practices, the foresaid may not prevail due to various conditions, e.g., setback buildings, floating columns, stilt parking, short column, split levels and sloping sites. Score modifier dedicated to vertical irregularity is negative. IS 1893: 2016, Clause7.1, table 6 clearly distinguishes among the various vertical irregularity, which could be present in the structures.

c. Plan Irregularity of The Building

It is very common to have a plan irregularity in any structure, but is mainly concerned in the wood, precast and masonry construction. Plan irregularity can be invoked into a structure by the following ways

i. When the center of stiffness and center of mass are not coinciding
ii. Nonparallel systems
iii. Re-entrant corners
iv. Diaphragm openings
v. Beams do not align with columns

IS 1893: 2016, Clause7.1, table 5 clearly distinguishes among the various plan irregularity, which could be present in the structures.

d. Pre-Code

In India, Indian standard code for reinforced and plain concrete (IS 456) was first produced in the year 1978 and it was based on Working Stress Method, whereas IS code based on limit state method was published in the year 2000.

Various other codes for the Earthquake Resistance were published as mentioned under: -

i. IS 1893:1962, "Criteria for Earthquake Resistance Design of Structure", which has been revised very lately in the year of 2016

ii. IS4326:1967, "Earthquake Resistance Design and Construction of Buildings, Code of Practice", revised in the year of 2013

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

Hence, all the structures constructed prior to the introduction of IS codes will be considered seismically deficient and inappropriately designed.

e. Post benchmark

It reflects that the structure was designed and built after stringent revisions were implemented in the codes. Hence, it will modify the score in positive sense. In our case, year 2016 will be taken as the benchmark year, as IS 1893 has been revised in this year.

f. Soil Type in the foundation

The type of soil present at location of building plays a pivotal role in the behaviour of building subjected to seismic excitation. FEMA P-154(2015) has considered six types of soil, whereas IS 1893:2016 distinguishes the soil into three categories, as described below. Table 3.4 shows the classification of different types of soil as per FEMA 154(2015) and IS 1893:2016 on the basis of SPT N value.

Table3.4 Different Types of Soil

Soil Type/Site Class As per FEMA P-154(2015) [3]	Corrected SPT N Value As per FEMA P-154(2015)/ Shear Wave Velocity ($V_{s\,30}$) [3]	Soil Type/Site Class As per IS 1893:2016 [8]	Corrected SPT N Value As per IS 1893:2016 [8]
Soil Type A/ Hard Rock	Shear Wave Velocity>5000 ft/s	-	-
Soil Type B/ Rock	5000 ft/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 Soils	N<10
Soil Type F/ Poor Soil	a). Clays which are highly Plastic (i.e., PI >75) b). Soils which are liquefiable, quick and weakly cemented C). Clays which are highly sensitive d). Deposits of Peat/Highly organic Clay more than 10 feet deep e). Deposits of soft or medium stiff clays, more than 120 ft.	-	-

Rapid Visual Screening cannot screen the buildings on Soil Type F (Liquefiable or highly compressible soil) [3]. Hence, soil type III as per IS1893:2016 should be left out for screening. Geological maps of the area where screening is to be carried out must be studied in advance, as one cannot judge the type of soil mere by visual inspection.

3.2.3 Geologic hazards

Geological hazard is a condition, presence of which may aggravate the vulnerability of building during the seismic excitation. Conditions such as liquefaction, landslide potential and surface fault rupture have been recognised as geologic hazard by FEMA P-154(2015). Although, IS 1893:2016 acknowledges the contribution of liquefaction potential in the seismic vulnerability of buildings, but nothing has been stipulated for landslide potential and surface fault rupture.

3.2.4 Adjacency

Proximity of buildings to each other could prove fatal in the event of earthquake, as they can pound together in response to the shaking of ground. Hence buildings must be checked for pounding effect also. "In very high seismic regions, the minimum gap between two buildings is 2 inches per story" [3]. As per IS 1893:2016, the minimum gap separating two building should not be less than the 'R' times the sum of storey displacement of respective buildings under consideration.

3.2.5 Exterior Falling Hazard

Various Non-Structural components such as unbraced chimney, parapets, veneers, overhangs, cornices panels for advertisement and heavy claddings are major threat to the life, when subjected to seismic excitation.

3.2.6 Damage and Deterioration

Although, it is aimed in the construction of every building, that it must be constructed of sound material. But with the passage of time and poor maintenance, the structure gets deteriorated and such structures have high damage potential when subjected to seismic forces.

3.3 FACTORS AFFECTING RVS (LEVEL 2)

Level 2 score modifiers have been derived using level 1 score modifier values, using appropriate engineering rationale.

3.3.1 Vertical Irregularity Score Modifier

If any of the following deficiency is present in the building, then vertical irregularity score modifier will be applied

a) Sloping Site
b) Weak/Soft Storey
c) Setback
d) Short Column/Pier
e) Split Level

3.3.2 Plan Irregularity Score Modifier

If any of the following deficiency is present in the building, then planar irregularity score modifier will be applied

a) Torsional Irregularity
b) Non-Parallel System
c) Reentrant corners
d) Diaphragm opening
e) out-of-plane offset in C1, C2 building

3.3.3 Redundancy

If the building is having more than the required force resisting elements, then it is termed as redundant.

3.3.4 Retrofit

If the evidence of comprehensive retrofitting is found in the structure, then the positive score modifiers are assigned in level 2 datasheet. If there is partial retrofit, then no score modifier for it.

3.3.5 Pounding

If the condition for pounding exists, i.e., the buildings are separated by small distance, then three conditions are considered.

a) Within the range of 2 feet, floors are not vertically aligned
b) One building is taller than the other building by two or more stories
c) Within the group of building, the building is situated at the end of row.

3.3.6 Building with K bracing

3.3.7 C1 building with flat plate moment frame

3.3.8 URM with Gable Walls

3.4 ADVANTAGES OF RVS

i. RVS method is expeditious for preliminary investigation.
ii. Very easy to understand and carry out.
iii. Evaluation can be carried in a cost-effective manner.

3.5 LIMITATION OF RVS

i. Accuracy is considerably low as the buildings are screened externally.

ii. As the level of expertise varies widely, hence errors are unavoidable.

iii. Building’s interior may not be accessed in some of the cases; hence evaluation may be ambiguous.

CHAPTER 4

CALCULATION OF RVS SCORE AND PROBABILITY OF COLLAPSE UNDER MCE SHAKING

4.1 INTRODUCTION TO RVS SCORE

RVS Score provides an approximate idea of probability of collapse, when a particular building is subjected to MCE shaking. Probability of collapse is approximate as it is based upon limited number of observed data.

4.2 SELECTION OF RVS CUT OFF SCORE

Probability of collapse is specifically related to the final RVS score(S). A less collapse probability is depicted by high RVS score or vice-versa. However, the serviceability of building after earthquake is still under the grey area. In order to ascertain the performance objective, detailed structural evaluation of building, along with nonstructural evaluation is necessary.

4.3 CALCULATION OF RVS SCORE

RVS score(S) is calculated by subtracting or adding the score modifier to basic score of the building.

Final score (S) = Basic Structural Hazard score + Score Modifiers

And, S= $-\log_{10}$ (P [collapse|MCE_R ground motion])

Where, collapse is defined as, the loss in the strength of gravity load resisting system to withstand its own weight along with any imposed load, which eventually leads to the failure of a portion of building or the entire building [3].

Or, P [collapse|MCE_R ground motion) = 10^{-s}

Therefore, a building with Score 1 has 10% chance of being collapsed, which is 10 times the probability of collapse of the building having Score 2[4].

Table 4.1 demonstrates the collapse probability for a building structure with respect to final RVS score(S).

Table 4.1 Calculated Probability of Collapse versus Final Score(S)

Final Score, S	4	3.5	3	2.5	2	1.5	1	0.5	0
Probability of Collapse (at MCE_R)	0.01%	0.03%	0.01%	0.32%	1%	3.16%	10%	32%	100%

4.4 CALCULATION OF PROBABILITY OF COLLAPSE

Collapse probability has been calculated using HAZUS methodology, which is a three-step method: -

4.4.1 Calculation of Peak Response

HAZUS methodology suggest that building's Peak response, can be determined by the intersection of building capacity curve and demand spectrum of the earthquake ground motions is found out, as suggested by.

In Figure 4.1, the intersection of building capacity curve and demand spectrum is shown, to determine peak response of building.

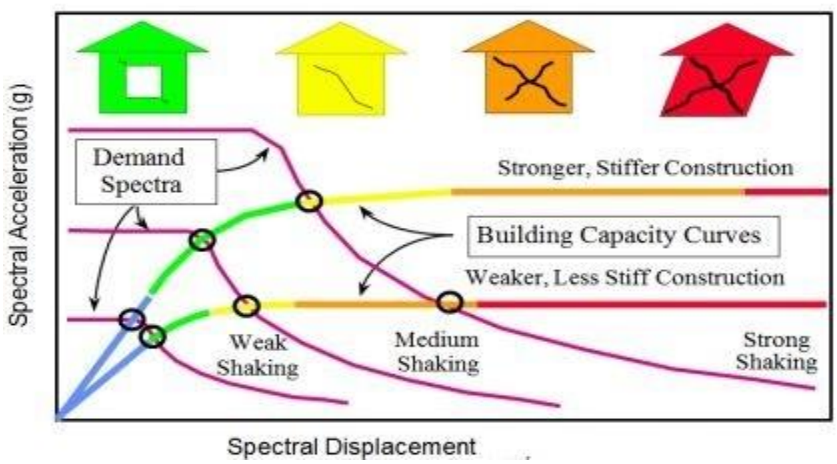

Figure 4.1 Intersection of Demand Spectra and Building Capacity Curves [4]

A force-displacement plot of building in which characteristic lateral load displacement is established as the function of lateral load resistance is referred as ***Building's Capacity***

Curve. The yield capacity point and the ultimate capacity point are the two control points of capacity curve.

Upto yield point, fully elastic behaviour is expressed by the structure and yield point accounts for design strength, redundancies in design and expected strength of material.

"Considering the additional sources of overstrength, the displacement at which the full strength of building is reached, is ultimate capacity point" [4]. Capacity curve is assumed fully plastic beyond the ultimate point.

In Figure 4.2, the capacity curve if a building along with its various control points and parameters are shown.

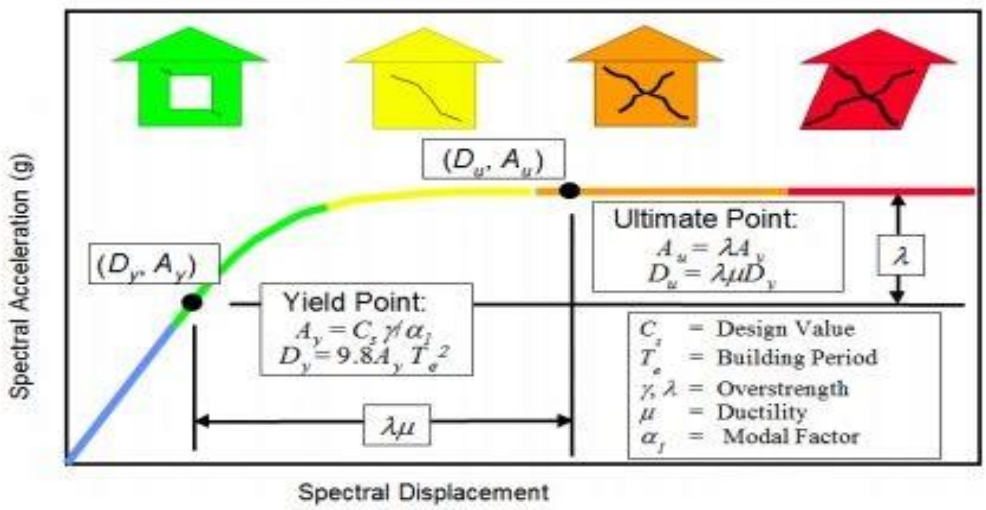

Figure 4.2 Building Capacity Curve and Control Points [4]

4.4.2 Probability of Complete Damage State

In order to develop basic score and score modifiers, the fragility curves for complete damage state is required. A state, at which structure is bound to have collapse or has collapsed, is referred as complete damage state.

A lognormal Probability function is used as fragility curves in a HAZUS building which describes the likelihood of reaching, or exceeding, discrete state of nonstructural and structural damage, given a measure of peak spectral displacement.

Figure 4.3 demonstrates the fragility curves for various levels of shaking and their corresponding damage state.

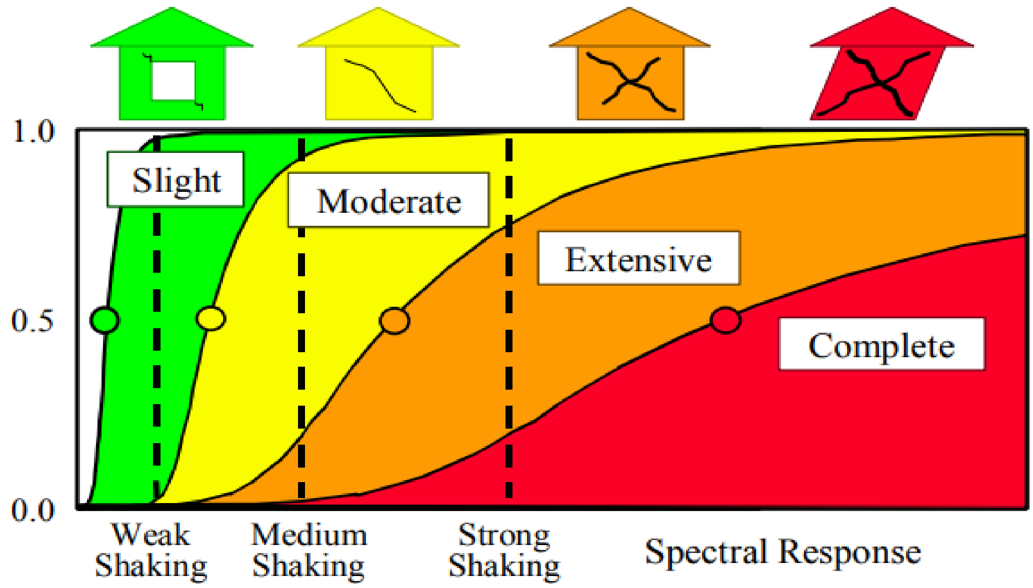

Figure 4.3 Fragility curves for different damage states [4]

A fragility curve is characterized by the median value of the demand parameter (spectral displacement, $S_{d,ds}$) corresponding to the damage state threshold and by the total variability associated with that damage state. Such median values are obtained from the observation of damages in previous earthquakes, laboratory test of structural components and systems and engineering discretion.

Mathematically,

$$S_{d,C}= (\alpha_2/ \alpha3)\ H_R\ \Delta_c \qquad (4.1)$$

Where,

$S_{d,C}$ =spectral displacement of the Complete structural damage state

α_2 =modal height factor

$\alpha3$=modal shape factor relating maximum-story drift and roof drift

H_R=building height (inches)

Δ_c= story drift ratio

Total variability of fragility-curve damage states($\beta_{S,ds}$), is defined by Lognormal standard deviation values[4].

Fragility-curve's total variability for any given damage state is contributed by the following components.

a). capacity curve's variability

b). demand spectrum's variability

c). damage state threshold's variability

The probability of complete damage is calculated using HAZUS TM which provides the values of $S_{d,C}$ and $\beta_{S,C}$, and the peak response determined (D).

$$P\ [\text{Complete Damage}] = \Phi[\frac{1}{\beta s,c} \ln (\frac{D}{Sd,c})] \tag{4.2}$$

4.4.3 Probability of Collapse

After determining the likelihood of complete damage, a collapse factor can be used to measure the probability of collapse.

"Probability of Collapse = P [COL|*Complete Damage*] X P [*Complete Damage*]" [4]

Probability of collapse under the given condition of Complete Damage = Collapse Factor

HAZUS TM can be referred in order to determine the *Collapse factor* for respective Building Type.

4.5 DEVELOPMENT OF SCORE MODIFIER

Following are the steps involved in the calculation of Score Modifier

i. First, the probability of collapse under the given condition (e.g., plan irregularity, pre-code) is calculated: P[COL|Condition]

ii. Then, the probability of collapse is converted to an equivalent score,

$S_{Condition} = -\log_{10}(P[COL|Condition]$

iii. Eventually, Basic Score is subtracted from Equivalent Score to Calculate the modifier.

Modifier = $S_{Condition}$ – Basic Score

4.6 CASE STUDY ON DETERMINATION OF THE PROBABILITY OF COLLAPSE FOR EXISTING BUILDING USING RAPID VISUAL SCREENING AS TOOL

4.6.1 Methodology of RVS to Calculate the Collapse Probability

Methodology of the rapid visual screening hovers around the aspects affecting the seismic vulnerability of any building such as seismic susceptibility of soil type available in the area of survey, irregularity in building, presence of non-structural hazards, etc.

In the entire process of Level 1 data collection, duration of 30 minutes at most is expected at one building site usually. The data collection sheet (FEMA P-154,2015) pertaining to the pertinent seismicity of the area is used and is filled meticulously by correlating the existing condition with Indian Standard codes, to reach a fair conclusion eventually.

Level 2 screening adds cost as it requires a structural engineer or someone having equivalent expertise, and the concerned person may have high hourly compensation. Level 2 screening may be done high priority structures, taking into account the expertise and cost involved.

Figure 4.4 has described the methodology for the calculation of collapse probability of a building in two levels as recommended by FEMA 154(2015)

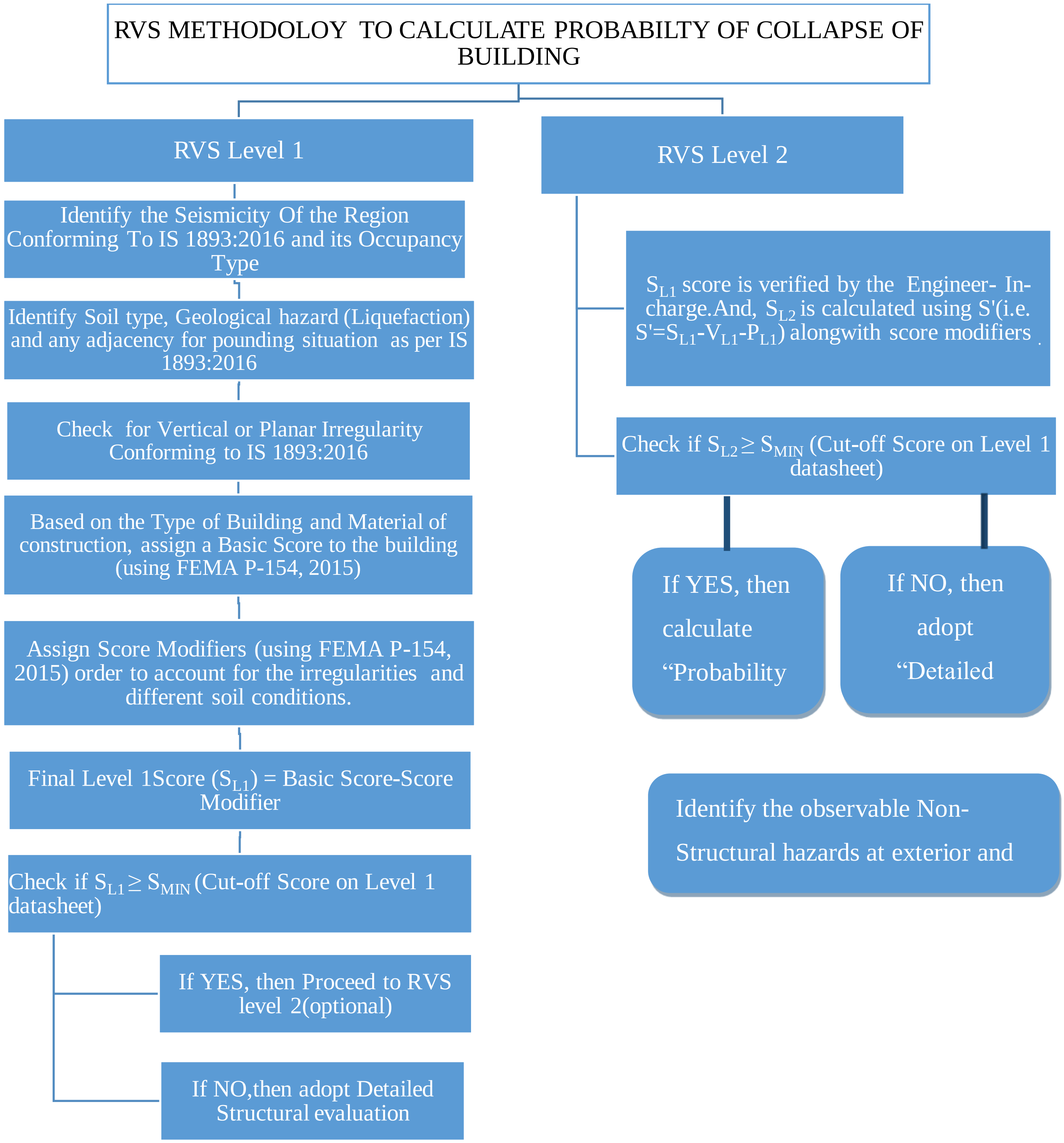

Figure 4.4 Methodology of RVS for calculation of collapse probability [3]

4.6.2 Case Studies on Collapse Probability of Different Building Types

There are seventeen different types of buildings as per the material of construction, as per FEMA P-154(2015). But we have considered only four Different types of buildings that are prevalent in the Construction Practices. Here in this case study, an attempt has been made to elucidate the procedure in a simplified and self-explanatory way. The different types of buildings are

a. High-Rise RCC Framed Building
b. Mid-Rise RCC Framed Building
c. Combined RCC and Masonry Building
d. Load Bearing Masonry Building

4.6.3 Case Study on High Rise RCC Framed Building

Problem Statement A Basement+G+11 storied Residential Building situated in Dwarka, Delhi has five towers A, B, C, D and E, where Tower A, B, D, E are identical in plan and form. Assess the Structure for its collapse Probability.

Comment

A) As the Buildings fall in ZONE IV as per IS 1893:2016, hence it can be categorized as situated in region of HIGH seismicity as per FEMA P-154, 2015.

B) Soil type at the site was found to be of "Medium Soil" category (As per IS: 1893, 2016), which corroborates to Soil type D/Stiff Soil (As per FEMA P-154, 2015). Moreover, geological hazard such as liquefaction is not present. Although, there are five blocks of building but all of them are separated far enough, i.e. 4m. Hence chances of Pounding have been ruled out.

C) Vertical Irregularity: - All the stories are spaced equally, Vertical Irregularity such as Soft Storey, Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey conforming to table 6 of IS 1893:2016, has not been observed during survey in the building block A, B, C, D and E.

Plan Irregularity: - The floor Plan of Block A, B, D, E was found to be same and it has been found that the foresaid blocks have Re-Entrant Corners, whereas plan Irregularities such as Excessive Cutouts and Out of Plane Offsets in vertical Elements have been missing.

The floor Plan of Block C was found to have Re-Entrant Corners, whereas plan Irregularities such as Excessive Cutouts and Out of Plane Offsets in vertical Elements have been missing.

D) Based on the Type of Building and its material of Construction, the building can be categorized as Concrete frames with unreinforced masonry infill walls (C3) as described In FEMA P-154, 2015. Hence the BASIC SCORE rendered for such a Building in High Seismicity Zone is 1.2.

E) As discussed above, only Plan Irregularity in terms of Re-Entrant Corners is Present in all of the Building Blocks. Hence Score Modifier for Plan Irregularity is -0.5. As per the data obtained, the building is 17-year-old which means it falls within the Scope of Post Benchmark. But, the Score Modifier for Post Benchmark is N.A. for the given category of building (C3).

F) Final Level 1Score (S_{L1}) = 1.2+ (-0.5) = 0.7 > S_{min} (0.3). At this Stage, the screener can stop the Survey if the RVS level 1 score is twice of S_{min} or the Cutoff Valve. However, we now proceed toward RVS level 2. As RVS Level 2 is a detailed assessment of entire building based on technical discretion of screener, hence the screener must have strong technical background.

G) The first step in RVS level 2 is to adjust the Baseline Score, therefore

$S'=S_{L1}-V_{L1}-P_{L1}$

Where, S_{L1}= Final Level 1Score

V_{L1}= Score Modifier due to Vertical Irregularity

P_{L1}= Score Modifier due to Plan Irregularity

$S'=0.7-0-0.5=0.2$

H) Now, apply Score Modifier on the basis of irregularity present in the building. However, in this building stock only reentrant corners are present, to which a negative score modifier of -0.4 is to be assigned. Moreover, the structure can be observed as a redundant one, therefore a positive Score Modifier of 0.3 can be assigned.

Eventually, Final Level 2 score S_{L2} = 0.2-0.4+0.3= 0.1< S_{min} (i.e.,0.3)

Therefore, $S_{L2} = S_{min} = 0.3$

I) Extent of review = All Sides

Interior= Entered

Drawing reviewed= NO

Level 2 Screening Performed= YES

Pounding Potential= Ignore Pounding as Level 2 Screening is Performed.

Non-Structural hazard = Absent

Therefore, Probability of Collapse = 10^{-S}

Probability of Collapse= $10^{-0.3}$

Probability of Collapse= 0.5

Probability of Collapse= 50%

Hence, it can be inferred that the buildings have 1 in 2 chances of being collapse under MCE ground motion.

J) Action Required

Detailed Structural Evaluation is required as RVS Level 2 score is less than cut off.

4.6.4 Case study on Mid Rise RCC Framed Building

Problem Statement A Basement+ G+1 storied Commercial Building situated at Mathura Road, Delhi is an RCC OMRF Structure. Assess the Structure for its collapse Probability.

Comment

A) As the Buildings fall in ZONE IV as per IS 1893:2016, hence it can be categorized as situated in region of HIGH seismicity as per FEMA P-154, 2015.

B) Soil type at the site was found to be of "Medium Soil" category (As per IS: 1893, 2016), which corroborates to Soil type D/Stiff Soil (As per FEMA P-154, 2015). Moreover, geological hazard such as liquefaction is not present. However, the building is separated far enough from adjacent buildings. Hence chances of Pounding have been ruled out.

C) Vertical Irregularity: -Ground Storey is 6.1m high whereas other stories are 3.1 m high. At Ground Story, various heavy instruments and apparatus for the calibration and testing of commercial machines are kept, due to which there is mass irregularity in the building along Soft Storey. Vertical Irregularity such as Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey conforming to table 6 of IS 1893:2016, has not been observed during survey in the building block A, B, C, D and E.

Plan Irregularity: - The floor Plan at each storey is found to be same and it has been found that the building has Re-Entrant Corners, whereas plan Irregularities such as Excessive Cutouts and Out of Plane Offsets in vertical Elements have been missing.

D) Based on the Type of Building and its material of Construction, the building can be categorized as Concrete frames with unreinforced masonry infill walls (C3) as described in FEMA P-154, 2015. Hence the BASIC SCORE rendered for such a Building in High Seismicity Zone is 1.2.

E) As discussed above, Severe Vertical irregularity along with Plan Irregularity in terms of Re-Entrant Corners is Present in the Building. Hence Score Modifier for Severe Vertical irregularity is -0.7 and for Plan Irregularity is -0.5. As per the data obtained, the building is 14-year-old which means it falls within the Scope of Post Benchmark. But, the Score Modifier for Post Benchmark is N.A. for the given category of building (C3).

F) Final Level 1Score (S_{L1}) = 1.2+ (-0.7) + (-0.5) = 0 < S_{min} (0.3). At this Stage, the screener must recommend the Building for Detailed Structural Evaluation.

H) Extent of review = All Sides
Interior = Entered
Drawing reviewed = NO
Level 2 Screening Performed = NO
Pounding Potential = NO
Non-Structural hazard = Absent

I) Action Required
Detailed Structural Evaluation is required as RVS Level 1 score is less than cut off.

4.6.5 Case study on RCC plus Masonry (Combined) Building

Problem Statement A Basement+ G+2 storied structure situated in Udyog Vihar, Gurgaon, Delhi NCR is an RCC Plus Masonry (Combined) Structure having Glass Cladding as a facade. Assess the Structure for its collapse Probability.

Comment

A). As the Buildings fall in ZONE IV as per IS 1893:2016, hence it can be categorized as situated in region of HIGH seismicity as per FEMA P-154, 2015.

B) Soil type at the site was found to be of "Soft Soil" category (As per IS: 1893, 2016), which corroborates to "Soil Type E/ Soft Clay Soil" (As per FEMA P-154, 2015). Moreover, geological hazard such as liquefaction is not present. As adjacent buildings are separated far enough, hence chances of Pounding has been ruled out.

C) Vertical Irregularity: - All the stories are spaced equally except basement as it has more height, Vertical Irregularity such as Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey conforming to table 6 of IS 1893:2016, has not been observed during survey, except Soft Storey at basement level.

Plan Irregularity: - The floor Plan at each storey was found to be same and plan Irregularities such as Excessive Cutouts, Re-Entrant Corners and Out of Plane Offsets in vertical Elements have not been observed.

D) Based on the Type of Building and its material of Construction, the building can be categorized as Concrete frames with unreinforced masonry infill walls (C1) as described In FEMA P-154, 2015. Hence the BASIC SCORE rendered for such a Building in High Seismicity Zone is 1.5.

E). As discussed above, only Moderate Vertical Irregularity is Present at the Basement. Hence Score Modifier for Moderate Vertical Irregularity is -0.5. As per the data obtained, the building is 10-year-old which means it falls within the Scope of Post Benchmark. And, the Score Modifier for Post Benchmark is 1.9 for the given category of building (C1).

F) Final Level 1Score (S_{L1}) = 1.5+ (-0.5) +1.9 = 2.9> S_{min} (0.3). At this Stage, the screener can stop the Survey if the RVS level 1 score is twice of S_{min} or the Cutoff Valve. However, we now proceed toward RVS level 2. As RVS Level 2 is a detailed assessment of entire building based on technical discretion of screener, hence the screener must have strong technical background.

G) The first step in RVS level 2 is to adjust the Baseline Score, therefore $S'=S_{L1}-V_{L1}-P_{L1}$

Where, S_{L1}= Final Level 1Score

V_{L1}= Score Modifier due to Vertical Irregularity

P_{L1}= Score Modifier due to Plan Irregularity

$S'=2.9-0.5-0.0=2.4$

H) Now, apply Score Modifier on the basis of irregularity present in the building. However, in this building only Soft Storey is present at basement level, to which a negative score modifier of -0.5 is to be assigned. Moreover, the structure can be observed as a redundant one, therefore a positive Score Modifier of 0.3 can be assigned.

Eventually, Final Level 2 score S_{L2} = 2.4-0.5+0.3= 2.2> S_{min} (i.e.,0.3)

Therefore, S_{L2} = 2.2

I) Extent of review = All Sides

Interior = Entered

Drawing reviewed = NO

Level 2 Screening Performed = YES

Pounding Potential = Ignore Pounding as Level 2 Screening is Performed.

Non-Structural hazard = Glass Cladding is Present on all the faces

Therefore, Probability of Collapse = 10^{-S}

Probability of Collapse= $10^{-2.2}$

Probability of Collapse= 0.0063

Probability of Collapse= 0.63%

Hence, it can be inferred that the buildings have 1 in 158 chances of being collapse under MCE ground motion.

J) Action Required

Detailed Structural Evaluation is not required as RVS Level 2 score is much greater than Cut off Value. However, Non-Structural hazards identified must be evaluated in detail.

4.6.6 Case Study on Load Bearing Masonry Hostel Building

Problem Statement A G+ 3 storied Hostel Building situated in Shahbad Daulatpur; Delhi is a Load Bearing Masonry Structure. Assess the Structure for its collapse Probability.

Comment

A). As the Buildings fall in ZONE IV as per IS 1893:2016, hence it can be categorized as situated in region of HIGH seismicity as per FEMA P-154, 2015.

B) Soil type at the site was found to be of "Medium Soil" category (As per IS: 1893, 2016), which corroborates to Soil type D/Stiff Soil (As per FEMA P-154, 2015). Moreover, geological hazard such as liquefaction is not present. As there is enough space between the buildings, therefore Pounding Potential is ruled out.

C) Vertical Irregularity: - All the stories are spaced equally, therefore Vertical Irregularity such as Soft Storey Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey conforming to table 6 of IS 1893:2016, has not been observed during survey.

Plan Irregularity: - The floor Plan at each storey was found to be same and plan Irregularities such as Excessive Cutouts, and Out of Plane Offsets in vertical Elements have not been observed. At certain locations, Re-Entrant Corners can be seen.

D) Based on the Type of Building and its material of Construction, the building can be categorized as unreinforced masonry (URM) as described in FEMA P-154, 2015. Hence the BASIC SCORE rendered for such a Building in High Seismicity Zone is 1.0.

E). As discussed above, only Plan Irregularity is Present at all Floor in form of Re-Entrant Corners. Hence Score Modifier for Plan Irregularity is -0.4.

F) Final Level 1Score (S_{L1}) = 1.0+ (-0.4) = 0.6> S_{min} (0.2). At this Stage, the screener can stop the Survey if the RVS level 1 score is twice of S_{min} or the Cutoff Valve. However, we now proceed toward RVS level 2. As RVS Level 2 is a detailed assessment of entire building based on technical discretion of screener, hence the screener must have strong technical background.

G) The first step in RVS level 2 is to adjust the Baseline Score, therefore $S'=S_{L1}-V_{L1}-P_{L1}$

Where, S_{L1}= Final Level 1Score

V_{L1}= Score Modifier due to Vertical Irregularity

P_{L1}= Score Modifier due to Plan Irregularity

S'=0.6-0.0-0.4=0.2

H) Now, apply the Score Modifier on the basis of irregularity present in the building. However, in this building only Re-Entrant Corners are present, to which a negative score modifier of -0.4 is to be assigned. Moreover, the structure can be observed as a redundant one, therefore a positive Score Modifier of 0.3 can be assigned.

Eventually, Final Level 2 score S_{L2} = 0.2+ (-0.4) + (0.3) = 0.1< S_{min} (i.e.,0.2)

Therefore, S_{L2} = Smin (i.e., 0.2)

I) Extent of review = All Sides

Interior = Entered

Drawing reviewed = NO

Level 2 Screening Performed = YES

Pounding Potential = Ignore Pounding as Level 2 Screening is Performed.

Non-Structural hazard = NONE

Therefore, Probability of Collapse = 10^{-S}

Probability of Collapse= $10^{-0.2}$

Probability of Collapse= 0.63

Probability of Collapse= 63%

Hence, it can be inferred that the buildings have 1 in 1.58 chance of being collapse under MCE ground motion.

J) Action Required

Detailed Structural Evaluation is required as RVS Level 2 score is less than Cut off Value.

4.6.7 Results and Discussions

Each of the building, based on its characteristic and configuration, yielded different result. A comparison based on the collapse probability can be drawn among different building type, as to which building can perform satisfactorily under MCE Ground Shaking.

Speaking of the performance of building, as per the case study, it can be clearly seen that although the buildings at first sight seemed fine. But after RVS, various irregularities either in plan or in vertical direction, summed as a negative aspect. These negative aspects, along with the various deficiencies present in the building, causes collapse of the building. It is also possible that there could be instances when the S_{L2} will be higher S_{L1} and it can be accounted by detailed screening of building attributes and less conservative Score modifier. Hence, a less conservative result will lead to an approximately exact assessment of structure.

As per our case study, a high rise RCC building has been found as vulnerable, as its collapse probability is equal to 63%. And, on this basis, it can be referred to detailed structural evaluation. Similarly, a mid-rise RCC building has collapse probability of 100%, rendering it dangerous for operations and requires immediate action.
On the other hand, a RCC plus Masonry Combined Building has been found to have collapse probability less one percent, which hints the benefits of a regular structure free from deficiencies. Whereas, a load bearing masonry building has been found to have collapse probability of 63%, which is again vulnerable.

Table 4.2 has shown the RVS score of four different buildings, along with the collapse probability of each building type.

Table 4.2 Building type and their collapse probability

S.no.	Building Type	Photograph of Building	RVS Score	Collapse Probability
1	High Rise RCC Building		0.3	1 in 2 chances i.e., 50%
2	Mid Rise RCC Building		0	1 in 1 i.e., 100%
3	RCC plus Masonry Combined Building		2.2	1 in 158 i.e., 0.63%
4	Load Bearing Masonry Building		0.2	1 in 1.58 i.e., 63%

4.6.8 RVS Score and its Interpretation

RVS score can be correlated to the damage grade, which a building could suffer in the event of seismic excitation. FEMA P-154 has described various RVS score and their corresponding damage grade as discussed below,

a). If a Building is having RVS Score less than 0.3, then it can be said to have very high likelihood of Damage Grade 4 whereas Damage Grade 5 can also be observed.

b). If a Building is having 0.3 < RVS Score < 0.7, then it can be said to have very high likelihood of Damage Grade 3 whereas Damage Grade 4 can also be observed.

c). If a Building is having 0.7 < RVS Score < 2.0, then it can be said to have very high likelihood of Damage Grade 2 whereas Damage Grade 3 can also be observed.

d). If a Building is having 2 < RVS Score < 3, then it can be said to have very high likelihood of Damage Grade 1 whereas Damage Grade 2 can also be observed.

e). If a Building is having RVS Score>3, then it can be said to have very high likelihood of Damage Grade 1.

4.6.9 Conclusions

In the study, four different types of buildings are selected i.e., High-Rise RCC Building, Mid Rise RCC Building, RCC plus Masonry Combined Building and Load Bearing Masonry Building haven been evaluation for calculating the RVS score and its corresponding probability of collapse under MCE. As per the results, it can be inferred that the probability of collapse of RCC plus Masonry Combined Building under MCE ground shaking is least, i.e., 0.63%. The absence of plan irregularity and vertical irregularity in the building has resulted into least chance of collapse under MCE ground shaking. Hence, it has not been recommended for detailed evaluation.

Similarly, accounting to the presence of irregularities in High Rise RCC Building and Load Bearing Masonry Building, they have 63% chances of being collapsed under MCE ground shaking which is fairly high. Hence, the buildings have been recommended for further detailed evaluation.

And, due to a severe vertical irregularity present in the Mid-Rise RCC building, it has resulted into 100% likelihood of being collapsed under MCE ground shaking. Therefore, it has been further recommended for detailed evaluation.

Based upon the study, it can be concluded that RVS guidelines of FEMA P-154(2015) can be used as a tool for performing preliminary investigation of existing buildings.

CHAPTER 5

CALCULATION OF RISK SCORE AND PROBABILITY OF COLLAPSE CAUSING EARTHQUAKE

5.1 INTRODUCTION TO RISK SCORE

Risk Score (S_R) is a measure of performance, which assesses the safety of building under frequent collapse-causing earthquakes. The Risk Score is a calculation of the negative base-10 logarithm of the number of earthquakes that could cause a building to collapse over its design life, which is usually 50 years [4].

S_R compared to S is different measure of performance, as S has no reference to design life and collapse causing earthquake whereas S_R is referred along with design life and collapse causing earthquake.

The Risk Score sums the probability of collapse given any particular level of shaking times the number of times in 50 years that that level of shaking will occur, summing over all levels of shaking, and taking the negative base-10 logarithm of that value [4].

The term "fragility" refers to the likelihood of a system collapsing in response to a specific degree of shaking, whereas “Risk” refers to the rate at which collapse causing earthquakes occurs.

5.2 CALCULATION OF RISK SCORE

Risk Score (S_R) is calculated from negative of logarithm to base 10 of the product of frequency of collapse and design life of the building, as shown in equation 5.1. Whereas, risk modification factor (PMF_R) can be calculated using equation 5.2.

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

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

Where,

λ = frequency of collapse (measured in events per year)

τ = design life of the building, commonly taken to be 50 years

PMF_R = Risk Modification Factor

Equation 5.3 represents the representative fragility function chosen

$$y = \emptyset\left(\frac{\ln(x/\theta)}{\beta}\right) \quad (5.3)$$

Where,

$\emptyset$ = the cumulative standard normal distribution evaluated at the term in parentheses,

θ = median

β= logarithmic standard deviation

Finally, Equation 5.4 depicts the expression for the calculation of Risk Score using RVS Score

$$S_R = S+1 \quad (5.4)$$

Since the collapse rate per 50 years is about a tenth of the collapse probability due to MCER shaking, the same ratio of collapse probability due to MCER shaking to collapse rate per 50 years defined by Luco et al. (2007) also applies to existing buildings [4].

In table 5.1, risk multiplier of existing building with respect to the new building on the basis of risk score of existing building is given.

Table 5.1 Relative Risk for Various values of S_R in the existing buildings to the risk posed by the new buildings [4]

S_R	Existing Buildings Fatality Risk Multiplier versus New Construction
1.5	100x
2.0	32x
2.5	10x
3.0	3x
3.5	1x
4.0	0.3x
4.5	0.1x

Equation5.6 represents the expression for calculation of the likelihood of at least one earthquake strong enough to cause collapse, during ‘t’ years

$$R(t) = 1 - \exp\left(-\frac{10^{-SR}}{\tau} x\ t\right) \tag{5.6}$$

As the entire evaluation is based upon Sidewalk Survey, therefore it is inherent that the screener may or may not have the access to the interior of structure. Hence, the actual risk might be greater than the risk evaluated. The reduction in risk score should be based upon the discretion of Engineer-In-Charge.

5.3 CASE STUDY PRIORITIZING BUILDINGS FOR SEISMIC RETROFIT ON THE BASIS OF RVS SCORE

5.3.1 Methodology for the Calculation of Probability of Earthquake Leading to Collapse

Risk score when compared to RVS score is significantly unique in a way, that it gives the likelihood of collapse at any level of shaking. But, RVS score is required for the calculation of Risk score. As per the Study, it has been found that FEMA P-154 doesn’t account for the cracks present in the building. Therefore, as per the discretion, it has been proposed to reduce the RVS score by 25% in the seismic Zone IV and V, to account for cracks or any defects present in the building which may go unnoticed during the survey. As per FEMA P-154(2015), it has been found that only if a structure is retrofitted globally, then a score of 1.4 is added to the RVS score. Eventually, the Risk Score for that building for the future surveys will be increased by numerical value of 1.4 and correspondingly the probability of collapse causing earthquake for next 50 years will be reduced by significant percentage. Whereas the score modifier does not account for local retrofitting in RVS score. Therefore, a global retrofitting measure to be adopted must be supported by the Cost-Benefit ratio. Although as a general thumb rule, if the retrofitting is less than thirty percent of cost of reconstruction, retrofitting must be adopted [12].

Figure 5.1 elucidates the RVS methodology for the decision making of retrofitting requirements by calculating probability of at least one earthquake leading to collapse within next given “t” years.

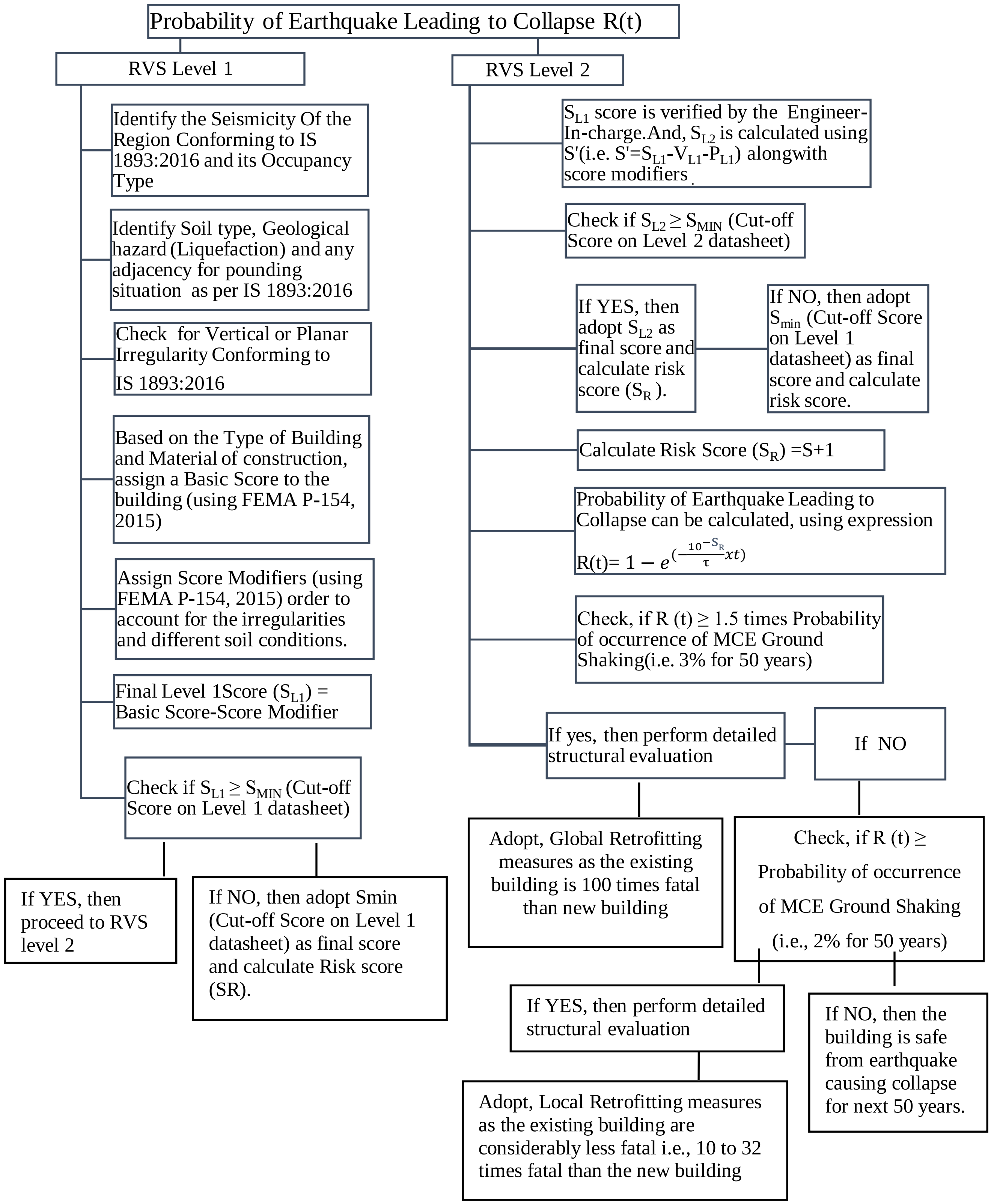

Figure5.1 Methodology of RVS for calculation of probability of collapse causing earthquake [4]

5.3.2 Case Study on Retrofitting of Buildings

As per our study, based on the type of construction and different material used, seventeen types of building have been identified in FEMA P-154(2015). But, in order to correlate the actual observation on site and Risk Score, we have adopted two different types of building. One of the structures is RCC G+3 storied building whereas other is load bearing masonry hostel building, and both of them are situated in Delhi. The case study has been carried out in a detailed manner, to promote better understanding and discretion.

5.3.2.1 Case Study on RCC G+3 Storey Framed Building

Problem Statement An RCC OMRF building having G+3 storey situated in Delhi. It has masonry infills. It was constructed in the year of 1984 and has been under periodical repair since then. It has not gone through any major upgrades ever since. Comment on its Probability of at least one collapse causing earthquake and retrofitting requirements.

Comment

In table 5.2, for the calculation of Risk score and its associated Probability for collapse causing earthquake, firstly the RVS score using FEMA 154(2015) has been calculated and then its corresponding Risk score using FEMA 155(2015) has been calculated. Subsequently, the probability of at least one collapse causing earthquake and retrofitting requirements have been commented.

Table5.2 Calculation of probability of at least one earthquake leading to collapse of RCC OMRF building within next given 50 years, to determine retrofitting requirement.

S. No	Rapid Visual Screening Procedure	RVS Score corresponding to the level of seismicity (using datasheet of FEMA P-154, 2015)	Remarks
I.	RVS Level 1		
A.	Seismicity of the region conforming to IS 1893:2016 and its occupancy type	Zone IV (IS 1893:2016)	-
		HIGH seismicity (FEMA P-154, 2015)	
		Commercial occupancy	
B.	Soil type as per IS 1893:2016	Medium (IS 1893:2016)	

		Type D/Stiff Soil (FEMA P-154, 2015)	-
	Geological hazard (Liquefaction)	None	
	Chances of Pounding	Adjacent buildings are situated far apart. Hence, no chances of pounding.	
C.	Planar Irregularity Conforming to IS 1893:2016 (P_{L1})	Plan Irregularities such as Re-Entrant Corners, Excessive Cutouts and Out of Plane Offsets in vertical Elements are not observed.	-
D.	Vertical Irregularity Conforming to IS 1893:2016 (V_{L1})	Vertical Irregularity such as Soft Storey, Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey are not observed.	-
E.	Type of Building (using FEMA P-154, 2015)	Building is identified as Concrete frames with unreinforced masonry infill walls (C3)	-
F.	Basic Score to the building (using FEMA P-154, 2015)	1.2	-
G.	Score Modifier		
	i. Planar Irregularity (P_{L1})	0.0	Not Observed
	ii. Vertical Irregularity (V_{L1})	0.0	Not Observed
	iii. Pre-Code modifier	-0.1	Built before 2002*
	iv. Post-Benchmark modifier	0.0	
H.	Final Level 1Score (S_{L1}) S_{L1}= Basic Score -Score Modifier …Eqn 1	1.1	$>S_{min}$ (i.e.,0.3)
II.	RVS Level 2		
A.	Adjusted Baseline Score, S'(i.e., $S'=S_{L1}-V_{L1}-P_{L1}$) …Eqn 2	1.1-0-0 =1.1	-
B.	Score Modifier		
	i. Planar Irregularity (P_{L2})	0.0	Not Observed
	ii. Vertical Irregularity (V_{L2})	0.0	Not Observed

	iii.	Redundancy(R_1)	0.3	Space frame with fixed supports
	iv.	Retrofit(R_2)	0.0	Not Observed
C.		Final Level 2 score S_{L2}, (S_{L2}= S'-V_{L2}-P_{L2}+ R_1+ R_2) …Eqn 3	1.4	>S_{min} (i.e.,0.3)
D.		Risk Score (S_R) = S+1 …Eqn 4	2.4	-
		To account for unnoticed cracks of past earthquake, which could be catastrophic in the events of Earthquakes, the Risk Score must be reduced by 25%.	0.75 X 2.4 = 1.8	-
E.		Probability of at least one earthquake occurs during *t* years that is strong enough to cause collapse, R(t)=$1-e^{(-\frac{10^{-SR}}{\tau}xt)}$ …Eqn 5 Where τ = design life in years (50 years) t = number of years (adopted 50 years)	R(t)= 1- $e^{(-\frac{10^{-1.8}}{50}x50)}$ R (t)= 1.57%	Less than the probability of MCE (i.e., 2% for 50 years)
F.		Recommendations		
	i.	As Probability of at least one earthquake occurs during 50years that is strong enough to cause collapse is significantly less, when compared to probability of occurrence of MCE Ground Shaking. Hence, Structure is prioritized as Safe.		-
	ii.	No need for detailed technical evaluation as the existing building is at thirty-two times the fatality risk of a New Building, which is considerably less. Hence, No requirement of retrofitting.		-

* Year 2002 has been taken as the benchmark year because IS 1893 was revised in this year. A lot of philosophical changes were observed such as four zones in India, realistic values of acceleration etc.

5.3.2.2 Case Study on Load Bearing Masonry Hostel Building

Problem Statement A Masonry Hostel building having G+3 storey situated in Delhi, has been under periodical repair and it has not gone through any major upgrades. Comment on its Probability of at least one collapse causing earthquake and retrofitting requirements.

Comment

In table 5.3, for the calculation of Risk score and its associated Probability for collapse causing earthquake, firstly the RVS score using FEMA 154(2015) has been calculated and then its corresponding Risk score using FEMA 155(2015) has been calculated. Subsequently, the probability of at least one collapse causing earthquake and retrofitting requirements have been commented.

Table5.3 Calculation of probability of at least one earthquake leading to collapse Masonry Hostel building within next given 50 years, to determine retrofitting requirement.

S.No.	Rapid Visual Screening Procedure	RVS Score corresponding to the level of seismicity (using datasheet of FEMA P-154, 2015)	Remarks
I.	RVS Level 1		
A.	Seismicity of the region conforming to IS 1893:2016 and its occupancy type	Zone IV (IS 1893:2016)	-
		HIGH seismicity (FEMA P-154, 2015)	
		Commercial occupancy	
B.	Soil type as per IS 1893:2016	Medium (IS 1893:2016)	-
		Type D/Stiff Soil (FEMA P-154, 2015)	
	Geological hazard (Liquefaction)	None	
	Chances of Pounding	Adjacent buildings are situated far apart. Hence, no chances of pounding.	
C.	Planar Irregularity Conforming to IS 1893:2016 (P_{L1})	Plan Irregularities such as Re-Entrant Corners, Excessive Cutouts and Out of Plane Offsets in vertical Elements are not observed.	-
D.	Vertical Irregularity Conforming to IS 1893:2016 (V_{L1})	Vertical Irregularity such as Soft Storey, Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity and Weak Storey are not observed.	-
E.	Type of Building (using FEMA P-154, 2015)	Building is identified as unreinforced masonry (URM)	-
F.	Basic Score to the building (using FEMA P-154, 2015)	1.2	-
G.	Score Modifier		

	i.	Planar Irregularity (P_{L1})	0.0	Not Observed
	ii.	Vertical Irregularity (V_{L1})	0.0	Not Observed
	iii.	Pre-Code modifier	0.0	Year of construction is unknown
	iv.	Post-Benchmark modifier	0.0	Year of construction is unknown
H.	Final Level 1Score (S_{L1}) S_{L1}= Basic Score -Score Modifier …Eqn 1		1.0	>S_{min} (i.e.,0.2)
II.	RVS Level 2			
A.	Adjusted Baseline Score, S'(i.e., $S'=S_{L1}-V_{L1}-P_{L1}$) …Eqn 2		1.0-0-0 =1.0	-
B.	Score Modifier			
	i.	Planar Irregularity (P_{L2})	0.0	Not Observed
	ii.	Vertical Irregularity (V_{L2})	0.0	Not Observed
	iii.	Redundancy(R_1)	0.0	Not Observed
	iv.	Retrofit(R_2)	0.0	Not Observed
C.	Final Level 2 score S_{L2}, ($S_{L2}= S'-V_{L2}-P_{L2}+ R_1+ R_2$) …Eqn 3		1.0	>S_{min} (i.e.,0.2)
D.	Risk Score (S_R) = S+1 …Eqn 4		2.0	
	To account for unnoticed cracks of past earthquake, which could be catastrophic in the events of Earthquakes, the Risk Score must be reduced by 25%.		0.75 X 2.0 = 1.5	-
E.	Probability of at least one earthquake occurs during *t* years that is strong enough to cause collapse, $R(t)=1-e^{(-\frac{10^{-SR}}{\tau}xt)}$ …Eqn 5		$R(t)= 1- e^{(-\frac{10^{-1.5}}{50}x50)}$ R (t)= 3.11%	Greater than the 1.5 times the probability of MCE (i.e.,

	Where τ = design life in years (50 years) t = number of years (adopted 50 years)			2% for 50 years)
F.	Recommendations			
	i.	As Probability of at least one earthquake occurs during 50years that is strong enough to cause collapse is significantly high, when compared to probability of occurrence of MCE Ground Shaking. Hence, Structure is prioritized as Unsafe.		-
	ii.	A detailed technical evaluation of the existing building must be carried out, as the fatality risk of the existing building is 100 times the fatality risk of New Building. Hence, building must be retrofitted globally as per IS 4326:2013.		-

5.3.3 Results and Discussion

As per the case study, the RCC G+3 building has Risk Score of 2.4 and the probability of earthquake causing its collapse R(t) is equal to 1.57%, which is less than probability of MCE (as per IS 1893:2016), hence the building can be rendered as "SAFE". Moreover, as per the Site survey done, the building was found to have sound structural system. Although, there have been some patch work done to spalling of concrete slabs. But otherwise, building was in "Satisfactory condition".

Similarly, a Load bearing masonry building was surveyed and its Risk Score is equal to1.5. The probability of earthquake causing collapse R (t) is equal to 3.11%, which is greater than the probability of MCE (as per IS 1893:2016), hence the building can be rendered as "UNSAFE". As per the actual site condition, building has suffered a lot of damages in term of spalling and corrosion. However, the building is kept serviceable by periodical maintenance.

Table 5.4 Building Type and their Collapse Probability

S.No.	Building Type	Photograph of Building	Risk Score	Probability of Earthqua Causing Collapse R(t)	Remarks
1	RCC G+3 Building		2.4	1.57% i.e., 1 in 63	1. As R (t) is less than probability of MCE, therefore building is prioritized as SAFE. 2. The retrofitting is not required as building is considerably less fatal.
2	Load Bearing Masonry Building		1.5	3.11% i.e., 1 in 32	1. As R (t) is greater than probability of MCE, therefore building is prioritized as UNSAFE. 2. The detailed technical evaluation for the building is required and global retrofitting must be done as the existing building is 100 times fatal than new building.

5.3.4 Risk Score and Its Inference

As per the study, Fatality risk of existing building can be correlated to the new building, based on Risk Score. FEMA P-155(2015) has described various Risk Score and their corresponding fatality risk as discussed below,

a). A Risk Score of 1.5 implies that the fatality Risk of an existing building is a hundred times the fatality risk of a New Building.

b). A Risk Score of 2.0 implies that the fatality Risk of an existing building is thirty-two times the fatality risk of a New Building.

c). A Risk Score of 2.5 implies that the fatality Risk of an existing building is ten times the fatality risk of a New Building.

d). A Risk Score of 3.0 implies that the fatality Risk of an existing building is three times the fatality risk of a New Building.

e). A Risk Score of 3.5 implies that the fatality Risk of an existing building is equal to the fatality risk of a New Building.

f). A Risk Score of 4.0 implies that the fatality Risk of an existing building is one-third of the fatality risk of a New Building.

g) A Risk Score of 4.5 implies that the fatality Risk of an existing building is one-tenth of the fatality risk of a New Building.

5.3.5 Limitation of the present study

The present study involves the feasibility check of RVS for the prioritization of buildings for seismic retrofit. In this study, the evaluation of buildings has been confined to only preliminary stage, based on which the decision for detailed technical evaluation for retrofitting of buildings has been presented. Detailed technical evaluation for retrofitting of the building is not a part of this study.

5.3.6 Conclusion

In this study, two different types of structures have been taken i.e., RCC G+3 building and Load Bearing Masonry building for calculating the risk score. As per the case study performed, it has been found that the probability of earthquake causing collapse for RCC G+3 building is 1.57% for next 50 years, which is less than the probability of MCE ground shaking (i.e., 2% for 50 years). As the fatality risk of existing building rounds off to only ten times fatality of new building, therefore the existing RCC G+3 building can be rendered as “SAFE” based on preliminary study.

Similarly, for the load bearing masonry structure, the study suggests that the probability of earthquake causing collapse is equal to 3.11% for next 50 years, which is greater than the probability of MCE ground shaking (i.e., 2% for 50 years). For that matter, the fatality risk of existing building rounds off to hundred times fatality of new building. Therefore, load bearing masonry building is rendered as “UNSAFE”, based on the preliminary study.

Hence, on the basis of RVS score, buildings can be prioritized for seismic retrofit.

CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

Various screening guidelines have been issued by various agencies, but FEMA P-154(2015) and FEMA P-155(2015) supplement the screening in the most thoughtful way by scoring the screened building for its unique components. This dissertation aims to simplify the application of RVS using the codal provisions of Indian Standard, in order to achieve a better probabilistic approach in estimation of probable life building.

In this study, the RVS score has been used to calculate the likelihood of a building collapse. The necessity for a complete vulnerability assessment of the structure is determined by comparing the chance of collapse with the probability of MCE shaking.

In addition, the RVS score has been used to calculate the Probability of the collapse mechanism to happen in a building under a significant earthquake within next 50 years. After computing the Risk Score, the Probability of the collapse mechanism to happen in a building under a significant earthquake within next 50 years is computed. As per the discussions, following are the conclusions which have been derived from the present study.

6.2 CONCLUSIONS

- For the Probability of Collapse under the MCE shaking, the Mid-Rise RCC Building shows the highest likelihood of being collapsed under MCE ground shaking i.e., 100% and RCC plus Masonry Combined Building is found to have the least likelihood of being collapsed under MCE ground shaking, i.e., 0.63%.

  Similarly, the High-Rise RCC Building is found to have 50% likelihood of being collapsed and Load Bearing Masonry Building stands at fairly high likelihood of being collapsed under MCE ground shaking i.e., 63%.

- For the Probability of the collapse mechanism to happen in a building under a significant earthquake within next 50 years, the Load Bearing Masonry Hostel building is highly vulnerable to such a collapse causing earthquake as it has 3.11% chance of being confronted by an earthquake that can cause collapse. It is found that the Load Bearing Masonry building is 100 times more fatal than the newly constructed Load Bearing masonry building. Similarly, the probability of an earthquake causing the RCC G+3 building to collapse over the next 50 years is found to be 1.57 %. Therefore, there is a need of detailed structural evaluation for retrofitting the Load Bearing masonry building to perform safely under any seismic activity.

- Hence, using the codal provisions of Indian Standards, the RVS guidelines of FEMA P-154(2015) can be used satisfactorily for preliminary investigation. Based on which a fair decision regarding the necessity of detailed technical evaluation can be done and the methodology will help in prioritizing the building for detailed structural evaluation and retrofitting recommendations.

6.3 FUTURE SCOPE OF THE WORK

The present study has dealt with Preliminary Investigation of buildings using RVS as tool, to assess their performance under seismic activity. However, the future scope of the work deals with detailed vulnerability assessment of the existing building structures after their prioritization using RVS tool. Using the results of detailed vulnerability assessment, a strong basis for the type of retrofitting required must be prepared to ease the process.

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LIST OF PUBLICATIONS

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