"Seismic Vulnerability Assessment of Reinforced Concrete Structure Buildings of Indore City Using RVS Methodology"

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ABSTRACT
Seismic safety covers intricate technical, supervisory, social, and financial issues encompassing infrastructural development and spreading earthquake risk mitigation provisions. The existing structures need an evaluation for seismic performance assessment, to ensure the safety and well-being of the residents. The study evaluated 500 randomly selected buildings in ward number 55 of Indore City, Madhya Pradesh, India. The Rapid Visual Screening survey technique and US FEMA 154 adopted for Indian conditions are used for data collection and evaluation. The evaluation of the buildings is based on building characteristics and geographical details. Out of the evaluated buildings, it was observed that 110 residential, 171 commercial,105 mixed (residential with commercial), and 9 other buildings passed the Indian cut-off score and a total of 101 buildings failed the Indian Rapid Visual Screening. On applying Exploratory data analysis approximately 5% of buildings were considered for detailed evaluation for vulnerability analysis.

Keywords: RVS, FEMA, Seismic performance, Concrete Structure, US FEMA 154.

1. INTRODUCTION
Infrastructural development in any geographical region demands the need of seismic safety. Existing structures are prone to earthquakes, causing destruction and loss. To ensure structural safety it is necessary to undergo evaluation and follow safety protocols in the defined seismic zones(Fan & Li 2022). The techniques like Rapid Visual Screening help in assessing the earthquake risks of existing building environments. RVS has gained momentum among the decision-makers in India (Singh 2014). It is used for determining vulnerabilities using Pre-Earthquake Assessment and Post-Earthquake Assessment of occupied damaged buildings. It is usually done to understand the potential threats to the life of residents or understand the state of the building's potential after the earthquake (Shah et.al., 2018) (Kanti, Manik, & Kumar, 2013). The findings of RVS are documented in the FEMA-155 report, to assess the performance score of the building (Rapid Visual Screening of Buildings for Potential Seismic Hazard supporting documentation FEMA 155, Edition 2 U.S Dept. Of Homeland Security" 2009). The assessment is done concerning the building parameters like Building Identification information, Geographical coordinates, building characteristics, Number of stories, Construction year, Code year, Floor Area, Building Occupancy, Soil type, Geographical Hazards, Adjacency, Irregularities and Exterior failing hazards (Kaseem, Nazri &Farsangi 2020) (Ningthoujam& Nanda 2018). The study is conducted on the ward 55 of Indore, Madhya Pradesh, India.

2. LITERATURE REVIEW
The Rapid Visual Screening process is intended to be carried out without performing any structural calculations. The technique uses a damageability grading system that needs the evaluator to identify the main structural lateral load-resisting system, and find building attributes that modify the seismic performance (Chaudhary 2018). It takes into consideration the load-resisting system along with non-structural as well as structural components of the buildings.
Shah &Ghamadi (2008) Demonstrated the use of RVS and its improvised versions for the evaluation of over 1000 structures in two districts of Jeddah, Saudi Arabia. The research was based on the typical building structures of Jeddah City and the Saudi Building codes available. The investigation results helped in identifying the use of typical building structure and the current state of the buildings. The evaluation

was based on construction-related information and structural data of the building(Vicente et.al., 2008). This evaluation gives a clear distinction of building state for further seismic assessments.

Sarmah and Das (2017) utilized RVS to study five wards with the highest population density and tall building structures in the most vulnerable seismic zones of Guwahati, Assam. A selected sample size of 100 buildings was on nine crucial vulnerability parameters based on Indian references. A structured survey led to comprehensive results, scoring and ranking the buildings in terms of seismic vulnerability. The buildings passed the preliminary score (Score>0.3) and were considered for further refinement (Kanti, Manik, & Kumar, 2013). The study complemented the earthquake-resistant building codes and Indian guidelines. The study also helped in formulating local level policies to prioritize building stock for relevant remedial measures.

Various research conducted by Chaudhary (2018), Bhalkikan& Ramcharan (2017), and Nath and Adhikari (2015) has embarked on the importance of structural parameter-based RVS for various building types in different seismic zones. They considered demographics, land cover, building type, and construction age to define score values for the vulnerability exposure of the buildings. Minsker et al. (2015), Kamat(2015), and Singh (2014) integrated guidelines like FEMA-154 and FEMA-155, Bureau of Indian Standards to fit in the standard criteria of evaluation to manage disaster prevention. Researchers have given recommendations for the development of tools and technologies for integrating performance-based approaches in the design cycle for better full-suite evaluation of infrastructural development costs and benefits to ensure higher seismic performance (Altindal et.al. 2021).

3. Study Area

Indore is the most populous and the largest city in Madhya Pradesh, India. It is located on the southern edge of the Malwa plateau, at an average altitude of 553 meters above sea level(Lende and Ambadkar 2024). Being the most densely populated major city in the central province, the buildings are residential, commercial, and for other purposes. The mass construction and existing structures demand the need of seismic safety to ensure quality standards and prolonged structural safety (Shukla & Solanki 2021). The area selected for the research is the ward no. 55 of Indore City, having a population of 22167 and 13644 properties, out of which 500 randomly selected buildings were surveyed.

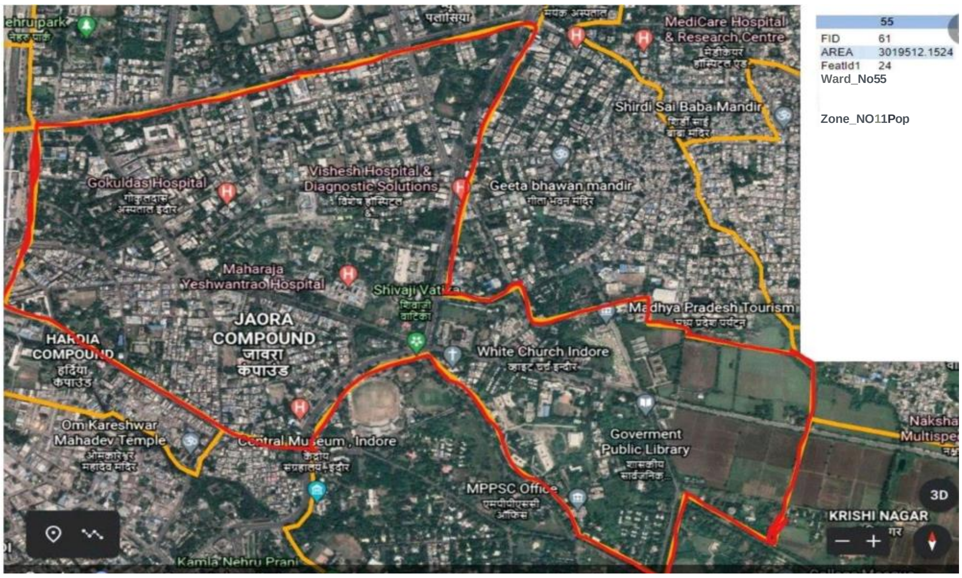

Figure 3.1. Survey Area- Ward 55 in Indore

4.METHODOLOGY

4.1 Rapid Visual Screening

RVS is used to assess the structural vulnerabilities of the buildings to seismic hazards. The major aim of the procedure is to order buildings for comprehensive structural evaluation and probable retrofitting. The procedure initializes with Pre-screening preparation, field survey, and data collection(Patil & Swami 2017). Later the performance score is collected and analyzed under the FEMA-155 standards(Alam, Khan & Paul 2008). The buildings are then ranked to identify the buildings that require immediate attention or further detailed evaluation.

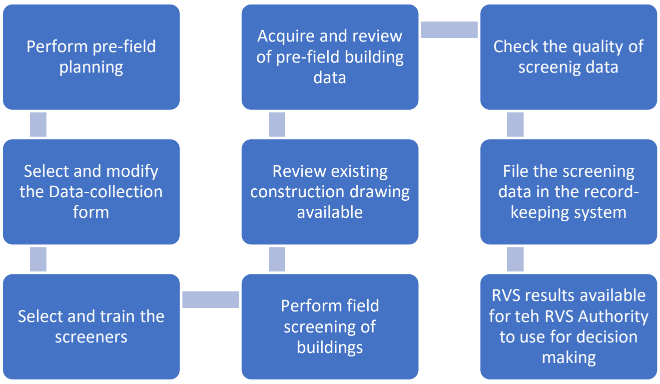

Figure 1. RVS Procedure Outline

The parameters to be evaluated for the RVS procedure as per Singh (2014) Sinha and Goyal (2004) Seismic zone, Year of construction, Type of Construction: (RC frame, Masonry) Use (residential, commercial, mixed), No. Of floors, Access to the Building , Soft story, Open parking at ground level, Absence of partition wall in-ground or any intermediate story for hops or other commercial use, Taller height in-ground or any other intermediate story, Vertical irregularity, Presence of setback, Building on slopy ground, Plan irregularity, Irregular plan configuration, Re-entrant corners, Heavy overhangs Moderate horizontal projection, Substantial horizontal projection, Apparent quality of materials and construction maintenance, Short column, Pounding, Soil condition, Frame action, Falling hazards. Additionally, Non-structural elements such as elaborate parapets, AC unit grills, elevation features, and unbraced chimneys are evaluated under a rapid visual screening process.

4.2 Performance Score according to Indian Form

By screening the aforesaid parameters, the Performance Score PS is calculated by the given formula.

PS= (BS)+ L[(VSM) x (VS)] (1)

Where, VSM is the Vulnerability Score Modifiers and VS is the Vulnerability Score thatis multiplied by VSM toobtain the actual modifier to beappliedtotheBSorBasicScore (Ajay et.al., 2017).

4.3 RVS Score using FEMA form.

Building characteristics that positively affect the performance of the building have positive Score Modifiers and increase the score. Building characteristics that negatively affect the performance of the building have negative Score Modifiers and decrease the score. (Federal Emergency Management Agency (US) ed., 2017)

Table 4.3.1 Score Modifier for FEMA

BASIC SCORE, MODIFIERS, AND FINAL LEVEL1 SCORE,SL1																	
FEMABUILDINGTYPE DoNot Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (UR MINF)	C1 (MRF)	C2 {SW)	C3 (UR MINF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score	4.1	3.7	3.2	2.3	2.2	2.9	2.2	2.0	1.7	2.1	1.4	1.8	1.5	1.8	1.8	1.2	2.2
Severe Vertical Irregularity, Vu	-1.3	-1.3	-1.3	-1.1	-1.0	-1.2	-1.0	-0.9	-1.0	-1.1	-0.8	-1.0	-0.9	-1.0	-1.0	-0.8	NA
Moderate Vertical Irregularity ,Vu	-0.8	-0.8	-0.8	-0.7	-0.6	-0.8	-0.6	-0.6	-0.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6	-0.5	NA
Plan Irregularity, Pu	-1.3	-1.2	-1.1	-0.9	-0.8	-1.0	-0.8	-0.7	-0.7	-0.9	-0.6	-0.8	-0.7	-0.7	-0.7	-0.5	NA
Pre-Code	-0.8	-0.9	-0.9	-0.5	-0.5	-0.7	-0.6	-0.2	-0.4	-0.7	-0.1	-0.4	-0.3	-0.5	-0.5	-0.1	-0.3
Post-Benchmark	1.5	1.9	2.3	1.4	1.4	1.0	1.9	NA	1.9	2.1	NA	2.1	2.4	2.1	2.1	NA	1.2
Soil Type A or B	0.3	0.6	0.9	0.6	0.9	0.3	0.9	0.9	0.6	0.8	0.7	0.9	0.7	0.8	0.8	0.6	0.9
Soil Type E(1-3stories)	0.0	-0.1	-0.3	-0.4	-0.5	0.0	-0.4	-0.5	-0.2	-0.2	-0.4	-0.5	-0.3	-0.4	-0.4	-0.3	-0.5
Soil Type E{>3stories)	-0.5	-0.8	-1.2	-0.7	-0.7	NA	-0.7	-0.6	-0.6	-0.8	-0.4	NA	-0.5	-0.6	-0.7	-0.3	NA
Minimum Score,S1.11N	1.6	1.2	0.8	0.5	0.5	0.9	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.2	1.4
FINAL LEVEL1 SCORE, SL1SMIN:																	

The severity of the structural performance varies with the FEMA building type, Score Modifiers associated with each building characteristic are indicated in the scoring matrix on the Level 1 Data Collection Form. The attributes that do not apply to a specific building type are indicated as NA.

4.4 Cut-Off Score

The cut-off score for FEMA is set to a predefined value as '2'. The Cut Off Score for Indian RVS is determined by the difference of mean(μ) and standard deviation(cr) of all observed buildings.

4.5 Methodology

The selected 500 buildings are given abbreviations. They are surveyed by evaluating the FEMA form data under the attributes like Building Name, Utility, FEMA Building Type, Base Score, Severe Vertical Irregularity, Moderate Vertical Irregularity, Plan Irregularity, Precode, Post Benchmark, and Final Score. The data is tabulated under the headings for Indian Form as Building Name, Utility, Number of floors, Soft Story, Vertical Irregularities, Plan Irregularities, Heavy Overhangs, Apparent Quality, Short Column, Pounding, Frame Action, and Performance Score (PF).

The buildings were randomly selected and geo-tag images of each were captured. The details of the visual screening were filled in the Indian RVS and FEMA forms. One of the examples from the sample is shown below.

Figure: 4.5.1 Sample building

The Indian RVS and FEMA forms for the selected buildings are shown below.

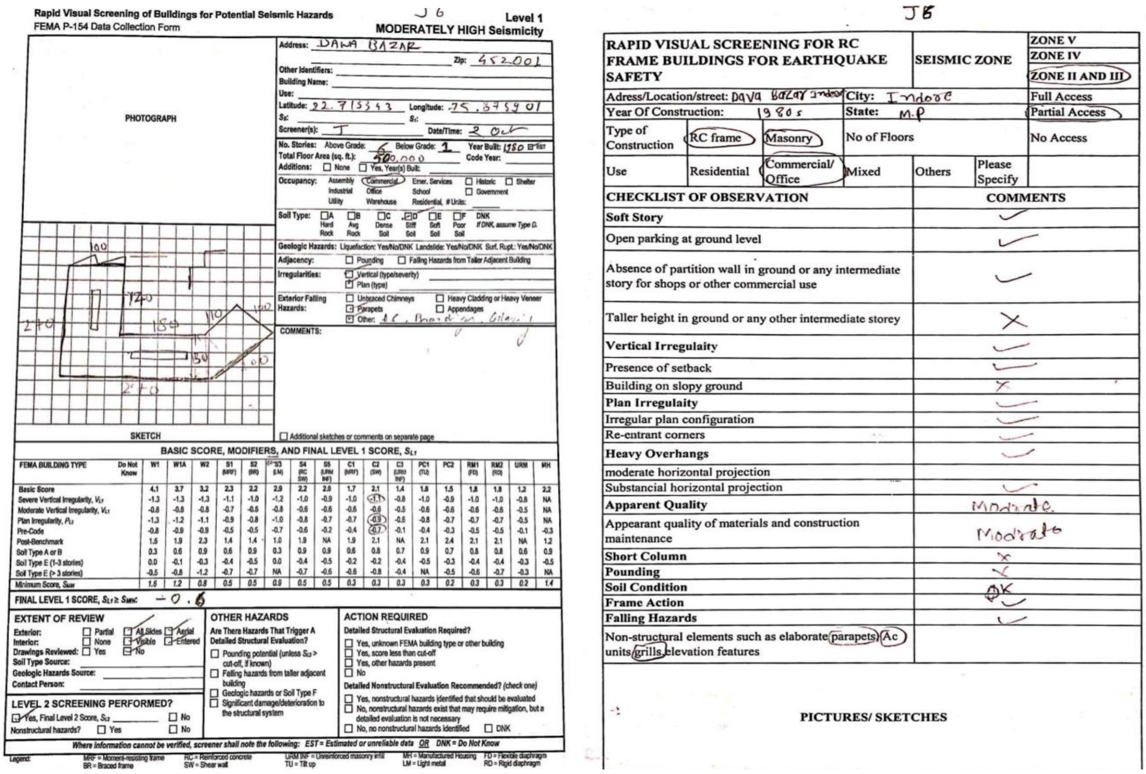

Figure 4.5.2 FEMA Sample Form Level 1&Sample Indian RVS form

Once the evaluation under the form and screening is done the determination of vulnerable buildings is done by cut-off scores of both FEMA and Indian RVS forms. The data evaluation is done using the Gaussian Distribution method. The statistical distribution with probability density function is given as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)}{2\sigma^2}} \tag{2}$$

Cumulative probabilities are calculated using the cumulative Distribution function, which gives the probability that a variate will assume a value <= x, which is then given by,

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{\frac{-(x-\mu)}{2\sigma^2}} dx \tag{3}$$

5 Data Analysis

A Rapid visual screening process was done on 500 buildings of Indore (M.P), comprising residential, commercial, a combination of residential and commercial, and others such as hospitals, educational buildings, and temples. Figure 5.1 demonstrates the distribution of 500 properties based on utility.

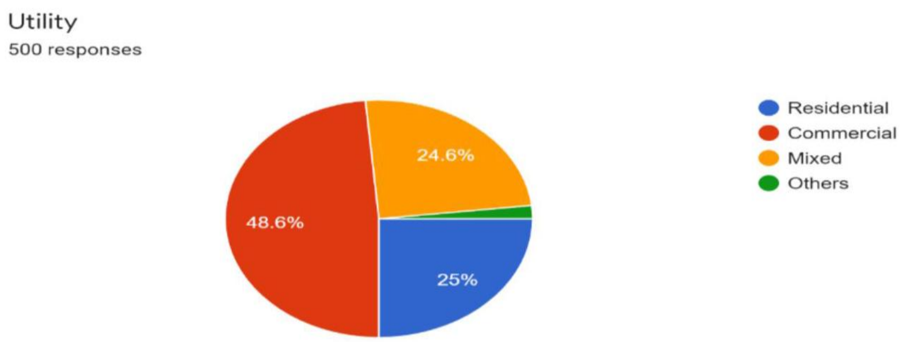

Figure 5.1 Representation of properties based on utility

The form data is evaluated to get the performance score and final Score for the Indian form and FEMA form respectively. This is done to assess the seismic vulnerabilities of the selected buildings. Figure shows the performance score and basic score of some buildings of the selected sample size.

Building Name Abbreviation	Performance Score based on Indian Form Data	Final Score FEMA form data
BI	91	0.5
B2	64	0.5
B3	101	0.5
B4	111	0.8
B5	111	0.5
B6	140	0.8
B7	160	1.3
B8	111	0.3
B9	140	0.5
BIO	105	0.7
BII	115	0.5
B12	125	0.6
B13	90	0.6
B14	70	3.1
B15	30	3.6
B16	55	-0.1

Figure 5.2 Score Evaluation of Buildings

The figure below depicts the RVS and FEMA scores for all the buildings in the survey

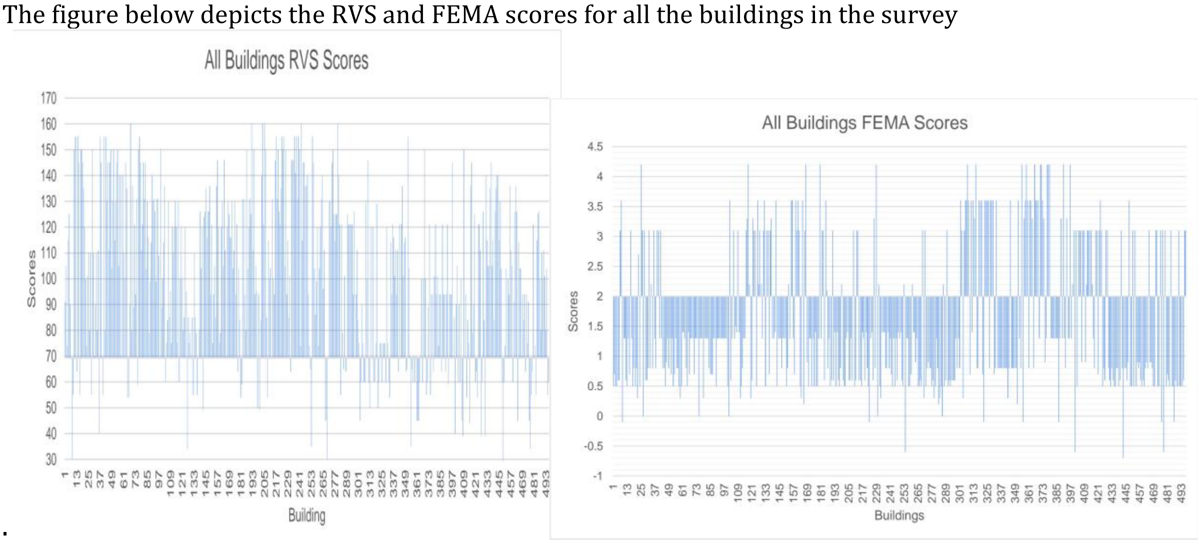

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Figure 5.2.1 and 5.2.2 RVS and FEMA score of all buildings

6.Findings

Under the study of 500 buildings in a seismic zone, the drawbacks of the FEMA and RVS Forms are analysed. The major characteristics of the building cannot be analyzed under the parameters set by the forms. After successful evaluation of the performance and base score of the selected buildings, the distribution curves for the FEMA and Indian RVS scores were obtained.

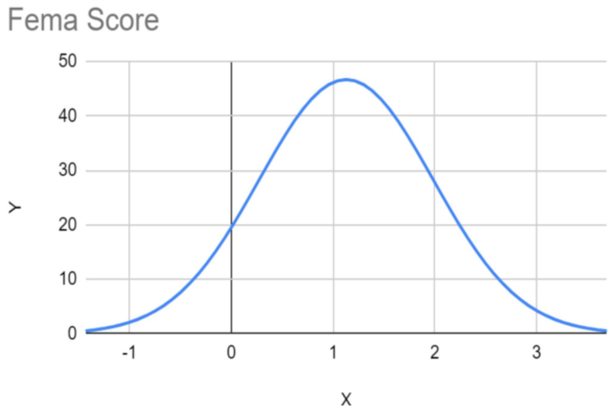

Figure 6.1 Normal distribution curve for FEMA Scores

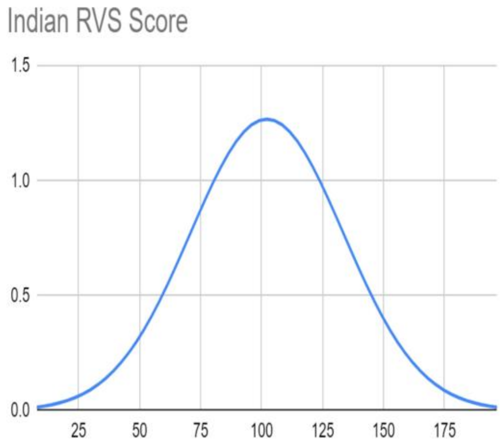

Figure 6.2 Normal Distribution Curve for Indian RVS Scores.

The table below gives the details of the parameters and drawbacks that existing systems have.
Drawbacks in FEMA forms

Table 6.1: Drawbacks in the FEMA forms

S.No.	Parameter	Description	Drawback
1	Pounding Effect	The pounding effect is considered a score modifier. Pounding is the result of irregular responses of adjacent buildings of different heights and different dynamic characteristics.	In the case of buildings with height differences, the roof of the shorter building may pound at the mid-height of the columns leading to story collapse.
2	Irregularities	Properly distributed lateral load-resisting elements within the building lead to regular structural configuration and better seismic performance.	In real cases, only two descriptions of vertical irregularities are shown as severe or moderate. Else are ignored, and results are approximated for the actual cases. Improper structures due to narrow frontages and commercial visibility make buildings prone to seismic hazards.
3	Apparent material quality	The performance score assumes that the construction materials used are of designed standards.	The deterioration of structural elements can have a huge impact on the building.
4	Number of stories	The Number of stories must be impacted by building height.	In calculation, the number of stories is not accounted for in the calculation of the final level 1 score.

Drawbacks in Indian RVS forms

Table 6.2 Drawbacks in RVS form

S.No.	Parameter	Drawback
1	Type of buildings	No shear wall type building for Indian RVS Separate forms are given which could be merged for data acquisition
2	Pre-Post Benchmarks	The standard benchmarks are not available as score modifiers in The RVS Forms. So, it is difficult to know whether or not the building was designed and constructed before or after the initial adoption of the seismic codes.
3	Location of buildings	The exact location of buildings cannot be known as the details about latitude and longitude are not mentioned.

Suggestions for better seismic evaluation: A new RVS form could be used for better analysis of Indian buildings that are improvised for the above drawbacks. This new RVS form should include the following points:

Table 6.3 Suggested Improvements

S.No.	Parameter	Improvements
1	Building Identifier	All information related to the location of buildings should be entered such as address, area code, latitude and longitude, No. of floors, year of construction, occupancy/use, type of building, and floor area.
2	Typeof building	Different Indian regions should have different building types like Brick-Masonry Buildings, Reinforced Concrete Structures, Stone-Masonry Buildings, Rammed Earth Buildings, Hybrid Buildings, Shear Wall structures, Steel Structures, and Wooden Frame Structures. All these are constructed on different frame actions and different base scores should be analysed.
3	Vertical Irregularity	Score modifiers should be analysed for all the vertical irregularities like Weak or Soft Story, Sloping Site, Out-of-Plane Setback, In-Plane Setback, Short Column/Pier, and Split Levels.
4	PlanIrregularity	Score modifiers should be analyzed for plan irregularities like Torsion, Non-Parallel Systems, Reentrant Corners, Diaphragm Openings, Beams that do not align with columns, Mass Irregularity
5	ApparentQuality	The Score modifier for the apparent quality of the building should also be analyzed for each type of building Additional checks should be added for the Quality of material used.
6	Pre/PostCode	The precode Score Modifier is applicable if the building being screened was designed and constructed before the initial adoption and enforcement of seismic codes (IS:13920-1993). Post Benchmarks Score Modifier is applicable if the building being screened was designed and constructed after significantly improved seismic codes.
7	Pounding	Modifier score for pounding should be given for different heights or number of floors of buildings.
8	SoilConditions	Score modifiers of different kinds of soil (hard rock, average hard rock, dense soil, stiff soil, soft soil, and poor soil) should be accounted to consider the number of stories of the building as the load on soil increases with no. of floors.
9	Falling Hazards	Falling hazards such as Unbraced Chimneys, Parapets, Appendages, Heavy Cladding, and elevation features should be analysed to attain a high-performance score.

7. RESULT

Rapid visual screening of a total 500 buildings in Indore city was conducted which included Residential, Commercial, Residential with Commercial, Hospital, Educational Buildings, and Temples. Out of the selected samples 110 residential, 171 commercial,105 mixed (residential with commercial), and 9 other buildings passed the Indian cutoff score and a total of 101 buildings failed in Indian Rapid Visual Screening. Additionally, it observed that 27 residential, 101 commercial, 15 mixed (residential with commercial), and 4 other buildings passed the FEMA cutoff score and a total of 349 buildings failed in FEMA Rapid Visual Screening. Around 5% of buildings were found to be considered for detailed evaluation for vulnerability analysis. On detailed evaluation, a clear estimation of the risk and loss of life and property can be studied.

8. CONCLUSION AND FUTURE SCOPE

The risks associated with seismic vulnerabilities demanded the need of seismic performance assessment for the existing structures. Rapid Visual screening has emerged as a preliminary step to assess the structures more effectively pre-earthquake as well as post-earthquake. Building characteristics, geographical location and Seismic severity all play a crucial role in the seismic performance of the building. For a comprehensive evaluation detailed structural analysis can be done using the Non-Destructive Testing of the failed building. Post-analysis suitable retrofitting methods can be suggested for earthquake-prone buildings.

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