

# Seismic Vulnerability Assessment of City Regions Based on Building Typology



Dharsana Satish, E. Lalith Prakash, and K. B. Anand

**Abstract** Over half of India's territory zone is prone to seismic tremors, and the Indian subcontinent has encountered many earthquakes in the past. This study focuses on the vulnerability assessment of buildings by Rapid Visual Screening (RVS) in selected regions of Tier II city of south India—Coimbatore. The building typologies present in various city regions (normally designated as Corporation wards) and potential seismic vulnerability of buildings in each city region (ward) is determined by RVS methodology. The RVS vulnerability scores obtained for all the wards included in this study are low, indicating that these city regions are potentially vulnerable with substantial to very heavy damages in the event of an earthquake. The outcome of the study is useful in preparing efficient earthquake policies at the local level. Further assessment and strengthening are recommended for the buildings in these selected wards with high seismic hazard.

**Keywords** Building typology · Rapid visual screening · Damage grades · Seismic vulnerability

## 1 Introduction

In the preceding 70 years, the country experienced 29 seismic events with a death toll of 51,915 and an economic loss of nearly 5297 million US Dollars according to the International disaster database. Over 75% of seismic tremor-related human setbacks are brought about by the failure of structures [1]. The general construction practices in India are greatly influenced by locally available materials, traditional construction practices, topography, etc. The application of Indian standard codes is not widely implemented in the construction of residential buildings [2]. This trend in residential building construction is a matter of concern in terms of seismic resistance.

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The Federal Emergency Management Agency (FEMA) developed the Rapid Visual Screening (RVS) method [3] to determine the buildings that may be potentially hazardous under Maximum Considered Earthquake (MCE) at the site of the building. The procedure for Rapid Visual Screening was refined and used by Srikanth [4], Jain et al. [5], Pathak [6], Sarmah et al. [7], Chanu [8]. The RVS scheme can be implemented relatively quickly and inexpensively to determine potentially seismically hazardous buildings. The building score reflects the probability of collapse or partial collapse of the building during an earthquake. Hence this method is adopted for the study.

## 2 Details of Study Region

As per the 2014 annual Indian city survey, Coimbatore is the second largest city (details in Table 1) and urban agglomeration in the South Indian state of Tamil Nadu.

Coimbatore lies in the peninsular shield region and significant research was done on the seismic hazard and risk estimation. Future probable earthquake zones were located considering subsurface rupture phenomena and hazard values are estimated at rock level in the City of Coimbatore [9]. The seismic risk was assessed for the Coimbatore city by overlaying the land-use and deterministic seismic hazard map [10]. An Earthquake readiness index tool was developed for the Indian subcontinent and its reliability was tested and evaluated by conducting a field survey at the City of Coimbatore [11]. Therefore hazard and preparedness study is carried out in previous studies and there is a research gap where vulnerability of building types is not assessed for the study region.

As per Municipal city corporation delimitation 2011, following the Coimbatore City Municipal Corporation Act, 1981, the government of Tamil Nadu divides the City of Coimbatore into seventy-two territorial divisions (Fig. 1). The boundary data of each ward in the city were collected from Coimbatore City Corporation [12] and the study area was validated with GPS (global positioning system) coordinates.

As per Census 2011, around 85% of total buildings in Coimbatore City Corporation are residential buildings. Therefore the scope of the study is limited to the vulnerability assessment of typical corporation wards based on residential buildings.

Coimbatore city is placed in Seismic Zone III (pga 0.16 g) as per the latest release of IS 1983 [13]. The collision process of the Indian plate with the Eurasian plate is still underway at a rate of 45 mm/year inducing an anticlockwise rotation of the plate throughout southwest Peninsular India [14].

**Table 1** Details of the study region

Latitude	Longitude	Area	Elevation	Population
10°10'–11°30'	76°50'–77°30'	105.5 km <sup>2</sup>	432 from MSL	1.6 million

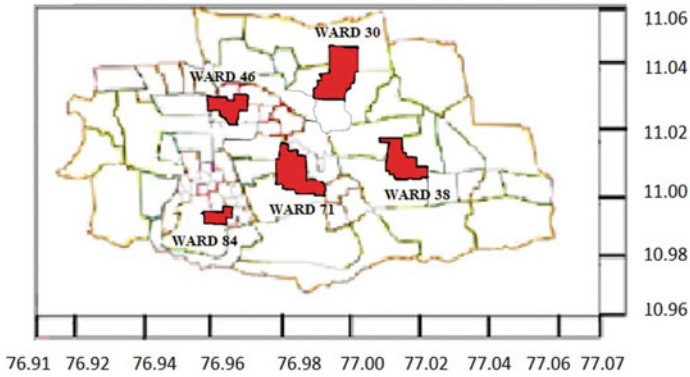


Fig. 1 Delimitation map of 72 territorial divisions with selected wards

### 3 Methodology

This study aims to determine the seismic vulnerability of residential buildings in the high seismic hazard zone at the city of Coimbatore through the rapid visual screening method and also to represent it as a ward-wise RVS vulnerability score. The methodology indicated in Fig. 2 is elaborated in subsequent sections.

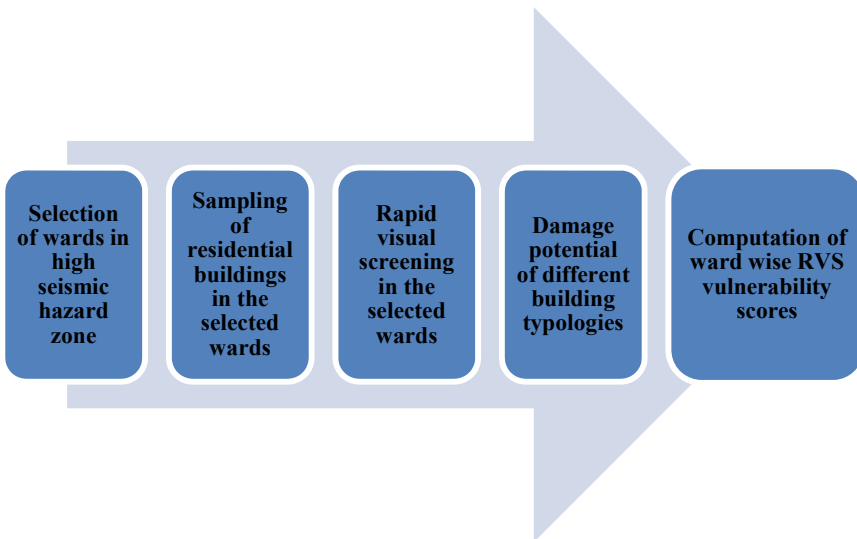


Fig. 2 Methodology of the Work

### 3.1 Selection of Wards

A hazard map for Coimbatore City Corporation by considering various factors, predominantly Peak Ground Acceleration, Amplification factor, Soil thickness, Shear wave velocity has been generated in an earlier study by Gopalakrishnan [15]. For the present study, five wards belonging to very high hazard zone alone were selected as a representative sample, for determining the seismic vulnerability of buildings on a much conservative side.

The above Deterministic seismic hazard map [15] has been developed using the formula:

$$\begin{aligned}
 DSM = & (PGA_w DPGAr + DAF_w DAFr + DST_w DSTr \\
 & + DSS_w DSSr + DPF_w DPFr + DPP_w DPPr + DLL_w DLLr \\
 & + DEL_w DELr + DDR_w DDRr + DGG_w DGGr) / \sum w \quad (1)
 \end{aligned}$$

PGA, AF, ST, SS, PF, PP, LL, EL, DR and GG represent Peak Ground Acceleration, Amplification factor, Soil thickness, Shear wave velocity, Predominant frequency, Population, Land use/Land cover, Elevation, Drainage & Geology and Geomorphology respectively. w and r represent assigned ranks and normalized weights for each factor.

### 3.2 Sampling

The number of residential buildings in each ward is obtained from the delimitation proposal of Coimbatore Corporation. Yamane [16] provided a simplified formula for determining the sample size.

For a confidence level of 95%, with 10% error:

$$n = N / (1 + N(e^2)) \quad (2)$$

where n, N and e represent the number of samples, total population and level of precision respectively.

The number of samples from each ward is computed from the above expression (Table 2). The rapid visual screening was carried out for the sample size of ninety nine in each of the selected wards.

**Table 2** Sample size in the different selected wards

Ward number	Corporation zone	Number of residential buildings in the proposed ward	Sample size (95% CL, 10% Error)
30	North	4425	97
38	West	5015	98
46	Central	3960	98
71	West	3360	97
84	Central	3994	98

### 3.3 Rapid Visual Screening

For visual surveys, the buildings are categorised based on construction material, performance during the past earthquake, horizontal and vertical framing system, etc. The present study area predominantly consists of six model building types (as adapted from Prasad et al. 2009) and presented in Table 3.

Sinha [17] suggest a procedure for rapid visual screening of buildings to determine potential seismic vulnerability for all the four zones in India. Since Coimbatore fall under Seismic zone III, a refined RVS matrix was framed including adobe building type (Table 4) as per IS 1893(2016). Three vulnerability parameters are considered for determining the potential vulnerability of building, viz., soil type, vertical irregularity and plan irregularity.

**Table 3** Predominant model building types in the study region

SL No	Label	Wall/framing type	Stories
1	Adobe	Rammed mud/stone masonry with lime or cement mortar	1–2
2	C1 L	Concrete moment-resisting frame	1–3
3	C1 M	Concrete moment-resisting frame	4–7
4	C2 M	Concrete shear wall	4–7
5	C3 L	RC frame with URM infills	1–3
6	URML	Burnt clay/concrete blocks with lime or cement mortar	1–2

**Table 4** Matrix for calculation of RVS score

Scores	Building types					
	Adobe	C1 L	C1 M	C2 M	C3 L	URML
Base score (BS)	2.4	3	3.2	4	3.2	3
Vertical irregularity (VI)	–1.5	–2	–2	–2	–2	–1.5
Plan irregularity (PI)	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5
Medium soil (S)	–0.4	–0.6	–0.6	–0.8	–0.6	–0.4

**Table 5** Expected damage level as a function of the RVS score

RVS scores	Damage potential
$S < 0.3$	High probability of Grade 5 damage; Very high probability of Grade 4 damage
$0.3 < S < 0.7$	High probability of Grade 4 damage; Very high probability of Grade 3 damage
$0.7 < S < 2.0$	High probability of Grade 3 damage; Very high probability of Grade 2 damage
$2.0 < S < 3.0$	High probability of Grade 2 damage; Very high probability of Grade 1 damage
$S > 3.0$	Probability of Grade 1 damage

Source: Sinha et al. [17]

Base Score has been computed for each Building type based on available damage and loss estimation functions that reflects the estimated likelihood that building will collapse if the building is subjected to the maximum considered earthquake (MCE) ground motion similar to the work done by Sinha et al. [17]. The final scores are computed by deducing performance score, based on soil type, plan irregularities and vertical irregularities from the base score.

The vertical and plan irregularities in framed buildings are assessed as per 1893(Part 1) 2016 and that of Unreinforced Masonry structures (URML) is assessed as per methodology adopted by Dogangun [18]. The soil type of entire city belongs to stiff soil Type D as per NEHRP [15] and the same has been considered for the final score calculation.

Since the seismic vulnerability of the adobe is extreme, the vertical irregularity and plan irregularity is assumed to be present in all adobe buildings in Coimbatore city.

Final RVS Score of a building:

$$S = (BS + VI + PI + S) \quad (3)$$

The damage potential of buildings is determined based on the final RVS score (S). Table 5 represents the damage potential level of building as a function of the final score.

## 4 Results and Discussions

The visual survey, as well as the data accumulation of selected five wards shown in Fig. 3, viz., ward numbers 30, 38, 46, 71 and 84, was carried out. Final RVS scores for each of the 99 samples are computed based on building typology, presence of irregularities and soil type. The presence of both vertical and plan irregularity will contribute to the seismic vulnerability of the building. The results of RVS shows that both plan and vertical irregularities are present in more than 50% of buildings in almost all the wards (Table 6). The percentage of buildings without irregularity is almost less than 5% in all the wards. Buildings with plan irregularity alone in all

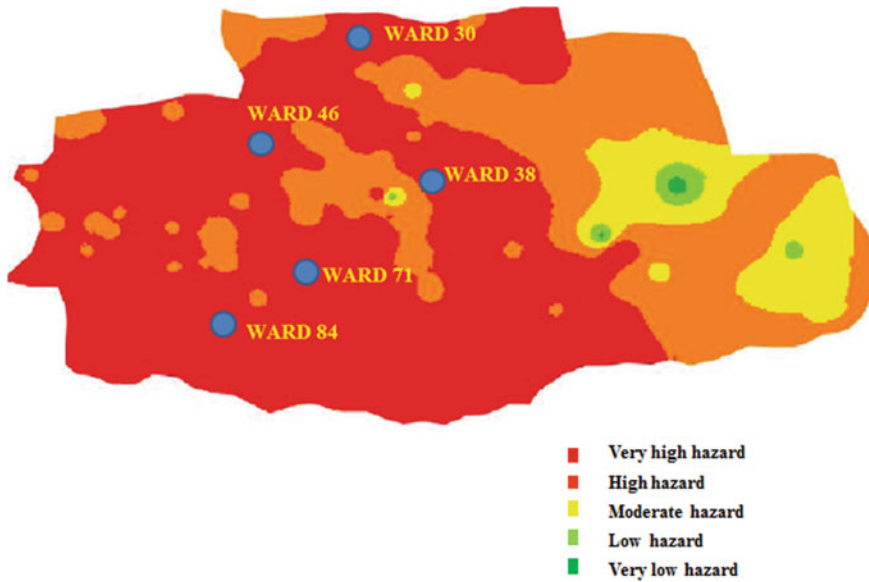


Fig. 3 Selected wards in the highest seismic hazard zones

Table 6 The percentage of buildings with irregularity across the samples in selected wards

Wards	Plan and vertical irregularity (%)	Plan irregularity (%)	Vertical irregularity (%)	Without irregularity (%)
Ward 30	62.62	4.04	27.27	6.06
Ward 38	57.57	5.05	31.31	5.05
Ward 46	68.68	1.01	27.27	3.03
Ward 71	31.31	4.04	58.58	6.06
Ward 84	53.53	1.01	41.41	4.04

the wards are lesser than 5% which indicates that construction practices in the city generally avoid irregularities in the plan. Vertical irregularity in buildings is greater than 30% in almost all the wards. In all the selected wards only a minor percentage of buildings are planned without any type of irregularity.

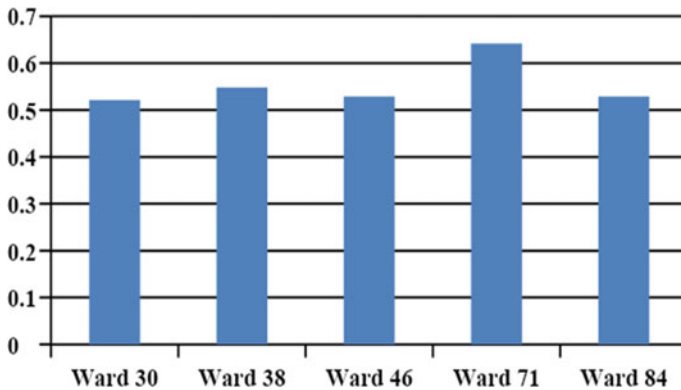
The RVS vulnerability score is estimated as the weighted average of RVS scores in each ward and is computed (Table 7) by accounting the number of buildings in each building typology as per the following equation.

RVS Vulnerability score of a ward

$$= \frac{\sum No : of\ model\ building\ type \times Average\ scores\ of\ model\ building\ type}{Number\ of\ samples\ in\ ward} \tag{4}$$

**Table 7** Computation matrix for RVS vulnerability score of each ward

Building type	Average RVS score	Number of buildings in each building typology corresponding to				
		Ward 30	Ward 38	Ward 46	Ward 71	Ward 84
Adobe	0	10	11	10	6	10
C1 L	0.876	10	4	8	11	15
C1 M	0.316	4	7	12	16	6
C2 M	0.921	8	7	4	16	6
C3 L	0.551	40	53	55	40	51
URML	0.761	16	17	10	16	5



**Fig. 4** RVS Vulnerability scores of the selected wards

The RVS vulnerability score for each of the selected wards is shown in Fig. 4. The wards with greater scores are least vulnerable and that of lesser scores are highly vulnerable to a seismic event. The RVS vulnerability scores of ward 71 are high due to the greater distribution of C2 M and C1 L buildings. The RVS vulnerability scores obtained for all the selected wards is less than 0.7, hence the selected wards are highly vulnerable to earthquake.

## 5 Conclusion

The rapid visual screening was performed in the city of Coimbatore to identify the seismic vulnerability of selected wards. Five representative wards belonging to very high hazard zone were selected with the help of available literature. Around a hundred residential buildings were surveyed in each of the selected wards. Six building typologies were predominantly distributed across the selected wards. More than 90% of the residential buildings are observed to have some form of irregularity



making them vulnerable to seismic damage. The RVS vulnerability scores of all wards range between 0.5 and 0.6, hence buildings in the selected wards are susceptible to heavy damage. Since the RVS vulnerability scores obtained for the selected wards is less than 0.7, the regions are potentially vulnerable to earthquake damages. A quick vulnerability assessment procedure for populated settlements has been illustrated through this case study for the city of Coimbatore.

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