Nat Hazards (2017) 85:1851–1875
DOI 10.1007/s11069-016-2668-3

ORIGINAL PAPER

Rapid visual screening of different housing typologies in Himachal Pradesh, India

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Received: 10 December 2015 / Accepted: 2 November 2016 / Published online: 17 November 2016

Abstract Methods capable of assessing the vulnerability of houses for future earthquakes are of fundamental importance for the safety and development of an area. As the detailed assessment is limited to number of houses and cost, one of the appraising methods currently used for seismic vulnerability assessment is rapid visual screening (RVS). This methodology has led to determination of risk of an area subjected to an earthquake event. Many codes have limited rapid visual screening to housing typologies like reinforced concrete and Brick masonry structures. This paper delivers an approach on how to perform RVS for five varieties of buildings in Himachal Pradesh state. The RVS scores have been calculated for 9099 buildings and normal distribution curves are plotted for each typology of building to understand the distribution of buildings in Himachal Pradesh. Finally, a new modified format for performing rapid visual screening has been proposed at the end.

Keywords Rapid visual screening · Housing · Normal distribution · Building typology

1 Introduction

Structural damages in buildings during an earthquake are accepted constructively by majority of seismic codes in the world, given that there is no human loss. Undeniably many such damages have occurred due to earthquakes in the past. Many new constructions were unaffected by the improvements of codes, but the earthquake safety of existing buildings is

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under question. In case of Indian subcontinent, it faces serious earthquake threat due to rapid growth of urban population, wherein nearly 60% of landmass in India is part of moderate-to-severe earthquake prone area. However, over 80% of population is living in this 60% of the land (Pradeep and Murty 2014). In last decade, India has witnessed earthquakes like that of 2001 Bhuj earthquake of M7.7, 2004 Sumatra earthquake of M9.3, 2005 Kashmir earthquake of M7.6, 2009 Andaman Islands of M7.5, and 2011 Sikkim earthquake of M6.8, etc. and an overall of 24 moderate to severe earthquakes were experienced, where around 4.25 lakh casualties and property loss was caused (Ref. Table 1). However, similar intensity earthquakes in the US, Japan, etc., did not lead to such an enormous loss of lives, as the structures in these countries are earthquake resistant (NDMA Guidelines 2007). During the 2001 Bhuj earthquake, numerous recently built Reinforced Concrete (RC) structures collapsed in Gandidham and Bhuj areas in Gujarat (EERI Earthquake Report 2001; Murty et al. 2002). In 2005 Kashmir earthquake, significant damage was attributed for stone masonry buildings, particularly random rubble type structures, which are poor seismic performance (EERI Earthquake Report, 2005). Most of the multi storey RC buildings were non-engineered and sustained considerable damage during the 2011 Sikkim earthquake (EERI Earthquake Report 2012). So, these failures

Table 1 Major earthquake in India. *Source*: Indian Meteorological Department, IMD

S. no.	Date	Epicenter	Location	Mw	Casualties
1	1818 Jun 16	(23.60, 68.60)	Kutch, Gujarat	8.0	2000
2	1869 Jan 10	(25.00, 93.00)	Nearcachar, Assam	7.5	Unknown
3	1885 May 30	(34.10, 74.60)	Sopor, J&K	7.0	Unknown
4	1897 Jun 12	(26.00, 91.00)	Shillong plateau	8.7	1500
5	1905 Apr 04	(32.30, 76.30)	Kangra, HP	8.0	19,000
6	1918 Jul 08	(24.50, 91.00)	Srimangal, Assam	7.6	Unknown
7	1930 Jul 02	(25.80, 90.20)	Dhubri, Assam	7.1	Unknown
8	1934 Jan 15	(26.60, 86.80)	Bihar–Nepal border	8.3	10,700
9	1943 Oct 23	(26.80, 94.00)	Assam	7.2	Unknown
10	1950 Aug 15	(28.50, 96.70)	Arunachal Pradesh–China Border	8.5	1526
11	1956 Jul 21	(23.30, 70.00)	Anjar, Gujarat	7.0	Unknown
12	1967 Dec 10	(17.37, 73.75)	Koyna, Maharashtra	6.5	177
13	1975 Jan 19	(32.38, 78.49)	Kinnaur, HP	6.2	Unknown
14	1988 Aug 06	(25.13, 95.15)	Manipur–Myanmar border	6.6	1000
15	1988 Aug 21	(26.72, 86.63)	Bihar–Nepal border	6.4	1004
16	1991 Oct 20	(30.75, 78.86)	Uttarkashi, UP	6.6	2000
17	1993 Sep 30	(18.07, 76.62)	Latur-Osmanabad, Maharashtra	6.3	9748
18	1997 May 22	(23.08, 80.06)	Jabalpur,MP	6.0	38
19	1999 Mar 29	(30.41, 79.42)	Chamoli Dist, UP	6.8	100
20	2001 Jan 26	(23.40, 70.28)	Bhuj, Gujarat	7.7	20,023
21	2004 Dec 26	(03.34, 96.13)	Off West Coast of Sumatra	9.3	283,106
22	2005 Oct 08	(34.48, 73.61)	Kashmir	7.6	74,500
23	2009 Aug 10	(14.01, 92.92)	Andaman Islands, India region	7.5	Unknown
24	2011 Sep 18	(27.7, 88.2)	Sikkim Nepal border	6.8	Unknown

project the urgent need to perform the seismic vulnerability assessment of buildings and suggest possible solutions to retrofit them. Since the detailed assessment of buildings is a complex and expensive task, it cannot be performed on all the buildings in an area. Past reconnaissance survey reports suggest that a simple assessment of existing buildings is necessarily required. Most of the methods follow a three level assessment procedure, namely:

(a) Phase-I: Rapid visual screening (RVS).
(b) Phase-II: Preliminary assessment.
(c) Phase-III: Detailed evaluation.

The RVS methodology is referred to as a "sidewalk survey" in which an experienced screener visually examines a building to identify features such as the building type, seismic zone, soil conditions, horizontal and vertical irregularities, apparent quality in buildings and short column etc. that affect the seismic performance of the building. This side walk survey is carried out based on the checklists provided in a proforma for all five typologies of the buildings. Other important data regarding the building including the occupancy of the building and the presence of nonstructural falling hazards is also gathered during the screening. A performance score or RVS corresponding to these features is calculated for the building based on numerical values on the RVS form. The performance score is compared to a "cut-off" score to determine whether a building has potential vulnerability and whether it should be further evaluated by an experienced engineer. The worldwide practices on RVS are as follows.

A number of guidelines were developed by the Federal Emergency Management Agency (FEMA) in the USA for seismic risk assessment and rehabilitation of buildings. The RVS method was originally developed by the Applied Technology Council (ATC) in the late 1980s and published in the FEMA: 154 in 1988. Later, it was developed in FEMA: 178-1989, 1992 (revised), FEMA: 310-1998 developed as revised version of FEMA: 178-1992, and FEMA: 154-1988, 2002 (revised), for rapid visual screening of buildings. A different RVS procedure was developed based on fuzzy logic technique to categorize buildings into five different damage grades (OASP 2000; Demartinos and Dristos 2006). This technique was applied on 102 buildings, which were affected by 1999 Athens earthquake. At the end, damage score was evaluated through a fuzzy inference system. Another RVS method was suggested by National Research Council, Canada, which is based on a seismic priority index. This method accounts for both structural and non-structural factors including soil conditions, building occupancy, building importance, falling hazards, occupied density and the duration of occupancy (NRCC 1993).

The Japanese procedure is based on seismic index (SI) for total earthquake resisting capacity of a story which is estimated as the product of basic seismic index based on strength and ductility indices, irregularity index and time index (TI). The evaluation is based on few parameters and lacks clarity regarding the ranking of buildings based on a scoring or rating system (JPDPA 2001). The New Zealand code recommends a two stage seismic performance evaluation of buildings (NZSEE 2006). The Switzerland applies a three stage concept for evaluating seismic risk. In first stage, seismic risk of a building is roughly estimated and in second stage, seismic risk is studied in detailed. Strengthening measures are employed in the last stage of seismic risk (SIA-2018 2004). The RVS method developed was based on the ratio of roof displacement capacity to roof displacement demand determined for life safety performance criteria and collapse prevention performance criteria by Bogadici University and Istanbul Technical University. Later, this method was improved on the basis of 454 reinforced concrete buildings surveyed after the

1999 Duzce earthquake and classified into four damage grades (Sen 2010; Hassan and Sozen 1997; Ozdemir and Taskin 2006; Sucuoglu et al. 2007).

There have been some efforts in India towards developing RVS methods. Sinha and Goyal (2004) have proposed a methodology for RVS of ten different types of buildings. The procedure requires identification of the primary structural load carrying system and the building attributes that are expected to modify the expected seismic performance for the lateral load resisting system under consideration. A statistical analysis has been performed to develop Expected Performance Score (EPS) for RC buildings based on the rapid visual surveys in Ahmadabad, India (Jain et al. 2010; Keya 2008).

2 Vulnerability studies of cities

Vulnerability assessment of cities has been performed in the past based on population loss estimation and estimation of direct and indirect losses due to various disasters. Some recent vulnerability assessment studies are discussed in the following sections:

2.1 Tehran, Iran

Seismic vulnerability assessment was done in the city of Tehran based on buildings data and damage for buildings for two earthquake scenarios (Nateghi 1998, 2000; Motamed and Ashtiany 2012). Seismic building damage for earthquake scenarios was derived from HAZUS software ranging from minor to major or complete damage (FEMA 1999; HAZUS 2000). Most of the buildings in the study area were found to be vulnerable considering the two earthquake scenarios (South Ray Fault and Floating).

2.2 Dehradun, India

The vulnerability assessment in Uttaranchal was done by Singh (2005). This study developed a methodology for loss estimation based on buildings and population loss. A Geographic Information System based tool was developed for primarily population loss estimation.

2.3 Kanpur, India

Preliminary evaluation was carried out on 30 multistoried RC buildings (IIT-GSDMA Guidelines 2003). The study revealed that large openings, horizontal and vertical projections, presence of soft and weak stories and short column effects are major weaknesses in the buildings at Kanpur from seismic safety point of view (Jain 2006).

2.4 Zeytinburnu, Turkey

This study is an implementation of the earthquake master plan for Istanbul metropolitan area in the Zeytinburnu district with a population of 240,000 and more than 16,000 buildings (Ozcebe et al. 2006) as a part of seismic vulnerability of existing building, a multi stage seismic safety assessment was performed by the Middle Eastern Technical University (METU) in Ankara.

2.5 Gandhidham, India

RVS was conducted on around 20,000 buildings in Gandhidham and Adipur cities (Srikanth et al. 2010). Though there is a large variation in construction practices, about 26% of buildings were RC buildings and 74% were of brick masonry. The study observes an RVS score ranging from 60 to 120 both for masonry and concrete structures which reveals the low quality of construction in this area (Srikanth et al. 2010).

2.6 Nanded, India

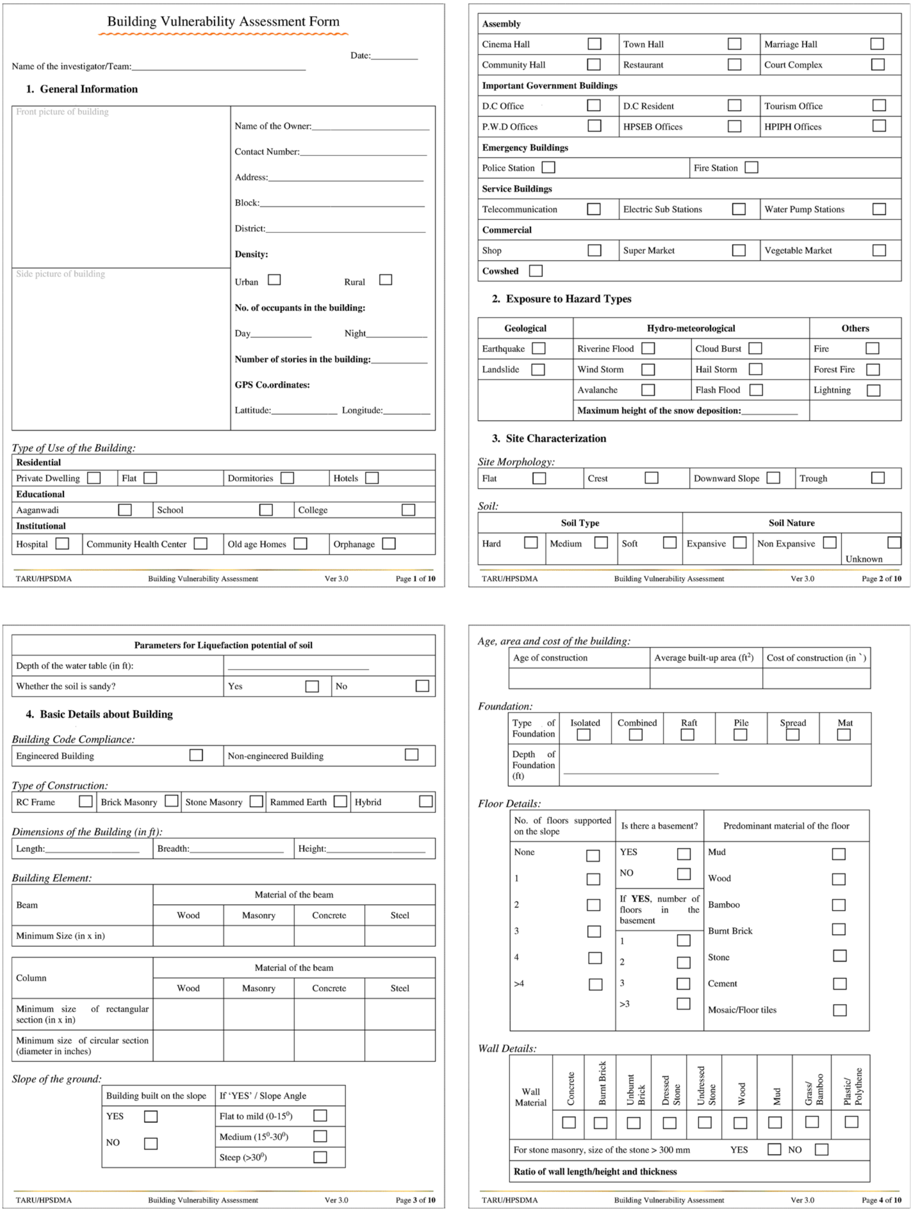
RVS was conducted on around 200 buildings in Nanded city. Initial observation reveals that there are wide variety of construction practices; however, predominantly buildings are classified as per material used, i.e., reinforced concrete, stone and brick masonry, tin shade and other buildings, about 70.39% are reinforced concrete buildings, 25.79% are stone and brick masonry, 2.54% are tin shade and 1.26% are other buildings. In RC buildings, score was varying from 40 to 145 and for brick masonry building score was varying from 113 to 130. A detailed study has been done for buildings regarding the structural aspect and effect of earthquakes (Narender 2014).

In the above literature, vulnerability studies of RC and brick masonry buildings have only been considered. An attempt has been made to do RVS for five varieties of building in the state of Himachal Pradesh. The state Himachal Pradesh consists of 1,027,788 buildings with RC, brick masonry, stone masonry, rammed earth, and hybrid building typologies, having a population of 6,856,509 in an area of 55,763 km^2. For the purpose of study, 9099 buildings were surveyed with the help of TARU Consultancy Private Limited. The above buildings were selected based on the structural irregularity, terrain condition, construction year, presence of cracks. Figure 1 shows the format of Building Vulnerability Assessment form originally prepared by TARU consultancy and Himachal Pradesh State Disaster Management Authority (HPSDMA). The RVS scores are originally calculated using RVS forms of RC and Brick Masonry. Later, these forms are modified for stone masonry, rammed earth, and hybrid buildings. Figure 2 represents a sample calculations of RVS score for five variety of buildings. As per statistics of surveyed buildings in Himachal Pradesh, around 17% (1541 out of 9099) of buildings are reinforced concrete, 48% (4363 out of 9099) of buildings are brick masonry, 15% (1341 out of 9099) of buildings are stone masonry, 5% (518 out of 9099) of buildings are rammed earth and 15% (1317 out of 9099) of buildings are hybrid. A schematic diagram of assessment of a building is shown in Fig. 3. Present study mainly focuses on RVS analysis of five varieties of buildings and the surveyed buildings distribution is shown in Fig. 4. Preliminary and detailed analyses are beyond the scope of this paper.

3 Methodology

The evaluation is based on few parameters of building like building geometry, frame action, hybrid action, pounding effect, structural irregularity, short columns, heavy overhangs, soil conditions, falling hazard, apparent building quality, diaphragm action etc. On the basis of above-mentioned parameters, performance score of the buildings has been calculated. The formula of the performance score (PS) is given in the following equation:

$$\mathrm{PS} = \mathrm{BS} + \sum [(\mathrm{VSM}) \times (\mathrm{VS})] \tag{1}$$



Building Vulnerability Assessment Form

Date:_________

Name of the investigator/Team:_______________________________

1. General Information

Front picture of building	Name of the Owner:________________
	Contact Number:________________
	Address:________________
	Block:________________
	District:________________
	Density:
Side picture of building	Urban ☐ Rural ☐
	No. of occupants in the building:
	Day__________ Night__________
	Number of stories in the building:__________
	GPS Co.ordinates:
	Lattitude:__________ Longitude:__________

Type of Use of the Building:

Residential			
Private Dwelling ☐	Flat ☐	Dormitories ☐	Hotels ☐
Educational			
Aaganwadi ☐	School ☐	College ☐	
Institutional			
Hospital ☐	Community Health Center ☐	Old age Homes ☐	Orphanage ☐

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Assembly		
Cinema Hall ☐	Town Hall ☐	Marriage Hall ☐
Community Hall ☐	Restaurant ☐	Court Complex ☐
Important Government Buildings		
D.C Office ☐	D.C Resident ☐	Tourism Office ☐
P.W.D Offices ☐	HPSEB Offices ☐	HPIPH Offices ☐
Emergency Buildings		
Police Station ☐	Fire Station ☐	
Service Buildings		
Telecommunication ☐	Electric Sub Stations ☐	Water Pump Stations ☐
Commercial		
Shop ☐	Super Market ☐	Vegetable Market ☐
Cowshed ☐		

2. Exposure to Hazard Types

Geological	Hydro-meteorological		Others
Earthquake ☐	Riverine Flood ☐	Cloud Burst ☐	Fire ☐
Landslide ☐	Wind Storm ☐	Hail Storm ☐	Forest Fire ☐
	Avalanche ☐	Flash Flood ☐	Lightning ☐
	Maximum height of the snow deposition:__________		

3. Site Characterization

Site Morphology:

Flat ☐	Crest ☐	Downward Slope ☐	Trough ☐

Soil:

Soil Type			Soil Nature		
Hard ☐	Medium ☐	Soft ☐	Expansive ☐	Non Expansive ☐	Unknown ☐

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Parameters for Liquefaction potential of soil		
Depth of the water table (in ft):	________________	
Whether the soil is sandy?	Yes ☐	No ☐

4. Basic Details about Building

Building Code Compliance:

Engineered Building ☐	Non-engineered Building ☐

Type of Construction:

RC Frame ☐	Brick Masonry ☐	Stone Masonry ☐	Rammed Earth ☐	Hybrid ☐

Dimensions of the Building (in ft):

Length:__________	Breadth:__________	Height:__________

Building Element:

Beam	Material of the beam			
	Wood	Masonry	Concrete	Steel
Minimum Size (in x in)				

Column	Material of the beam			
	Wood	Masonry	Concrete	Steel
Minimum size of rectangular section (in x in)				
Minimum size of circular section (diameter in inches)				

Slope of the ground:

Building built on the slope	If 'YES' / Slope Angle
YES ☐	Flat to mild ($0-15^0$) ☐
NO ☐	Medium (15^0-30^0) ☐
	Steep ($>30^0$) ☐

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Age, area and cost of the building:

Age of construction	Average built-up area (ft^2)	Cost of construction (in `)

Foundation:

Type of Foundation	Isolated ☐	Combined ☐	Raft ☐	Pile ☐	Spread ☐	Mat ☐
Depth of Foundation (ft)	____________					

Floor Details:

No. of floors supported on the slope	Is there a basement?	Predominant material of the floor
None ☐	YES ☐	Mud ☐
1 ☐	NO ☐	Wood ☐
2 ☐	If **YES**, number of floors in the basement	Bamboo ☐
3 ☐	1 ☐	Burnt Brick ☐
4 ☐	2 ☐	Stone ☐
>4 ☐	3 ☐	Cement ☐
	>3 ☐	Mosaic/Floor tiles ☐

Wall Details:

Wall Material	Concrete	Burnt Brick	Unburnt Brick	Dressed Stone	Undressed Stone	Wood	Mud	Grass/ Bamboo	Plastic/ Polythene
	☐	☐	☐	☐	☐	☐	☐	☐	☐
For stone masonry, size of the stone > 300 mm	YES ☐	NO ☐							
Ratio of wall length/height and thickness									

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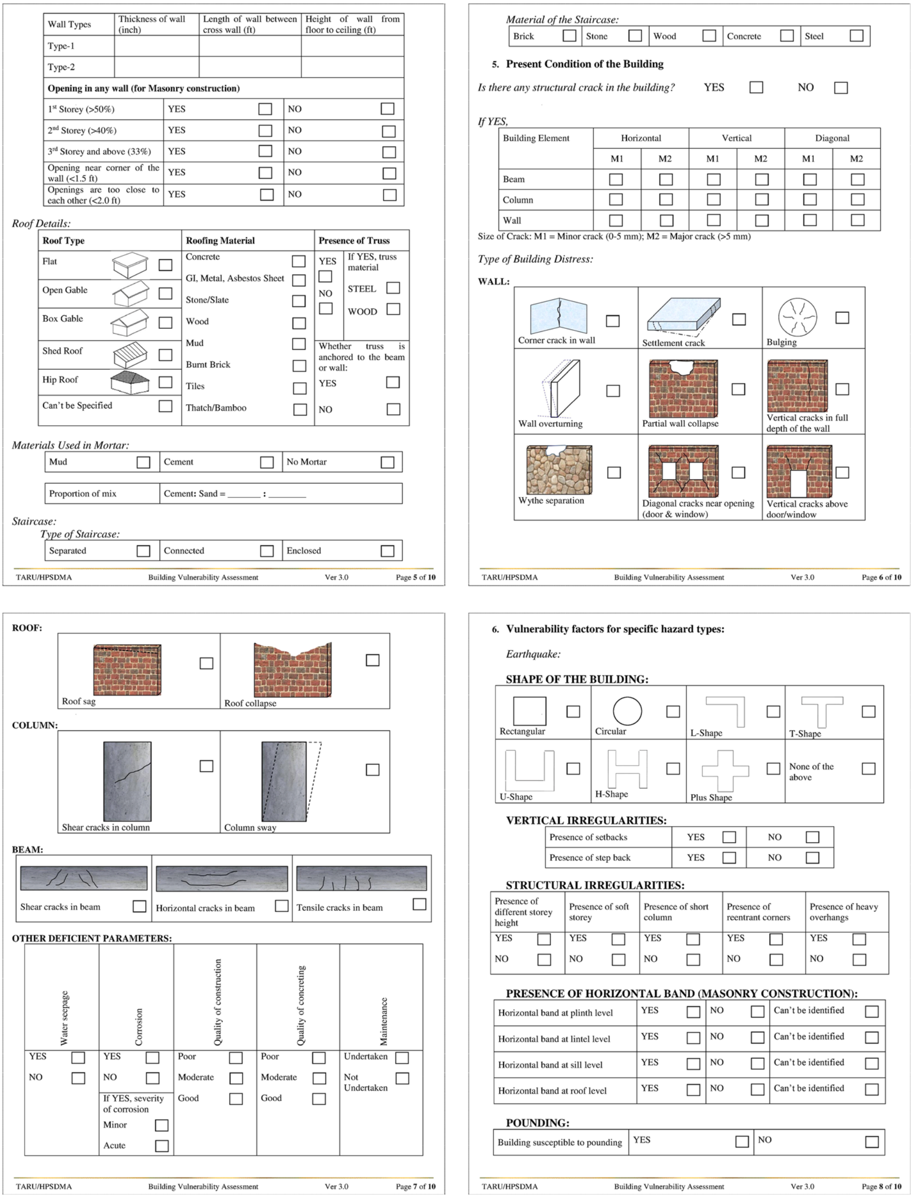
Fig. 1 Proposed format of building vulnerability assessment form prepared by TARU consultancy and HPSDMA

where VSM represents the Vulnerability Score Modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).

The RVS data of existing buildings in the region is plotted as Gaussian (Normal) distribution. This distribution is commonly used for statistical analysis of large data. A



Wall Types	Thickness of wall (inch)	Length of wall between cross wall (ft)	Height of wall from floor to ceiling (ft)
Type-1			
Type-2			

Opening in any wall (for Masonry construction)

1st Storey (>50%)	YES ☐	NO ☐
2nd Storey (>40%)	YES ☐	NO ☐
3rd Storey and above (33%)	YES ☐	NO ☐
Opening near corner of the wall (<1.5 ft)	YES ☐	NO ☐
Openings are too close to each other (<2.0 ft)	YES ☐	NO ☐

Roof Details:

Roof Type	Roofing Material	Presence of Truss
Flat ☐	Concrete ☐	YES ☐ / NO ☐; If YES, truss material: STEEL ☐ WOOD ☐
Open Gable ☐	GI, Metal, Asbestos Sheet ☐	
Box Gable ☐	Stone/Slate ☐	
Shed Roof ☐	Wood ☐	
Hip Roof ☐	Mud ☐	Whether truss is anchored to the beam or wall:
Can't be Specified ☐	Burnt Brick ☐	YES ☐
	Tiles ☐	NO ☐
	Thatch/Bamboo ☐	

Materials Used in Mortar:

Mud ☐	Cement ☐	No Mortar ☐
Proportion of mix	Cement: Sand = _______ : _______	

Staircase:
Type of Staircase:

Separated ☐	Connected ☐	Enclosed ☐

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Material of the Staircase:

Brick ☐	Stone ☐	Wood ☐	Concrete ☐	Steel ☐

5. Present Condition of the Building

Is there any structural crack in the building? YES ☐ NO ☐

If YES,

Building Element	Horizontal		Vertical		Diagonal	
	M1	M2	M1	M2	M1	M2
Beam	☐	☐	☐	☐	☐	☐
Column	☐	☐	☐	☐	☐	☐
Wall	☐	☐	☐	☐	☐	☐

Size of Crack: M1 = Minor crack (0-5 mm); M2 = Major crack (>5 mm)

Type of Building Distress:

WALL:

Corner crack in wall ☐	Settlement crack ☐	Bulging ☐
Wall overturning ☐	Partial wall collapse ☐	Vertical cracks in full depth of the wall ☐
Wythe separation ☐	Diagonal cracks near opening (door & window) ☐	Vertical cracks above door/window ☐

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ROOF:

Roof sag ☐	Roof collapse ☐

COLUMN:

Shear cracks in column ☐	Column sway ☐

BEAM:

Shear cracks in beam ☐	Horizontal cracks in beam ☐	Tensile cracks in beam ☐

OTHER DEFICIENT PARAMETERS:

Water seepage	Corrosion	Quality of construction	Quality of concreting	Maintenance
YES ☐	YES ☐	Poor ☐	Poor ☐	Undertaken ☐
NO ☐	NO ☐	Moderate ☐	Moderate ☐	Not Undertaken ☐
	If YES, severity of corrosion: Minor ☐ Acute ☐	Good ☐	Good ☐	

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6. Vulnerability factors for specific hazard types:

Earthquake:

SHAPE OF THE BUILDING:

Rectangular ☐	Circular ☐	L-Shape ☐	T-Shape ☐
U-Shape ☐	H-Shape ☐	Plus Shape ☐	None of the above ☐

VERTICAL IRREGULARITIES:

Presence of setbacks	YES ☐	NO ☐
Presence of step back	YES ☐	NO ☐

STRUCTURAL IRREGULARITIES:

Presence of different storey height	Presence of soft storey	Presence of short column	Presence of reentrant corners	Presence of heavy overhangs
YES ☐	YES ☐	YES ☐	YES ☐	YES ☐
NO ☐	NO ☐	NO ☐	NO ☐	NO ☐

PRESENCE OF HORIZONTAL BAND (MASONRY CONSTRUCTION):

Horizontal band at plinth level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at lintel level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at sill level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at roof level	YES ☐	NO ☐	Can't be identified ☐

POUNDING:

Building susceptible to pounding	YES ☐	NO ☐

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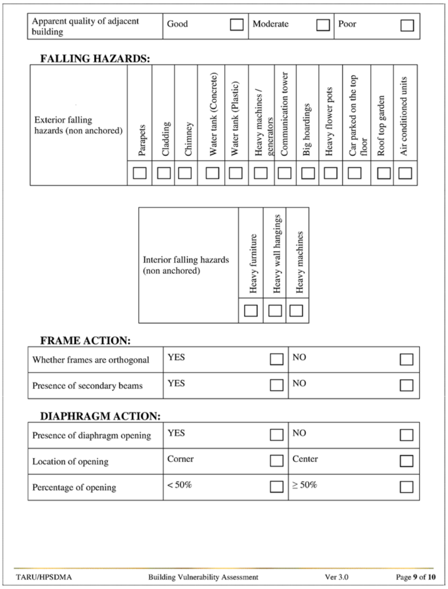
Fig. 1 continued

normal distribution in a variate X (RVS) with mean μ and variance σ is a statistical distribution with probability density function is given in Eq. 2:

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



Apparent quality of adjacent building	Good ☐	Moderate ☐	Poor ☐

FALLING HAZARDS:

Exterior falling hazards (non anchored)	Parapets	Cladding	Chimney	Water tank (Concrete)	Water tank (Plastic)	Heavy machines / generators	Communication tower	Big hoardings	Heavy flower pots	Car parked on the top floor	Roof top garden	Air conditioned units
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Interior falling hazards (non anchored)	Heavy furniture	Heavy wall hangings	Heavy machines
	☐	☐	☐

FRAME ACTION:

Whether frames are orthogonal	YES ☐	NO ☐
Presence of secondary beams	YES ☐	NO ☐

DIAPHRAGM ACTION:

Presence of diaphragm opening	YES ☐	NO ☐
Location of opening	Corner ☐	Center ☐
Percentage of opening	< 50% ☐	≥ 50% ☐

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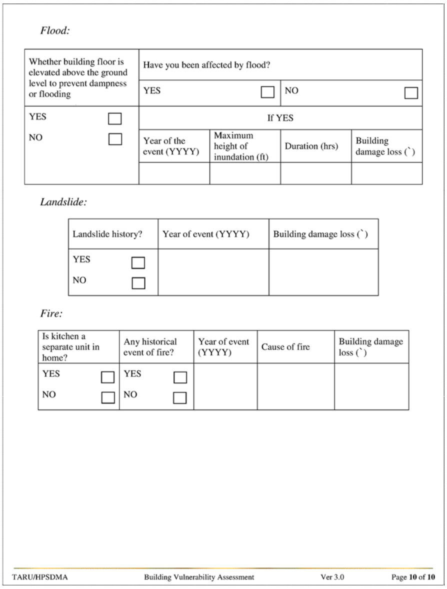

Flood:

Whether building floor is elevated above the ground level to prevent dampness or flooding	Have you been affected by flood?			
	YES ☐		NO ☐	
YES ☐	If YES			
NO ☐	Year of the event (YYYY)	Maximum height of inundation (ft)	Duration (hrs)	Building damage loss (`)

Landslide:

Landslide history?	Year of event (YYYY)	Building damage loss (`)
YES ☐		
NO ☐		

Fire:

Is kitchen a separate unit in home?	Any historical event of fire?	Year of event (YYYY)	Cause of fire	Building damage loss (`)
YES ☐	YES ☐			
NO ☐	NO ☐			

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Fig. 1 continued

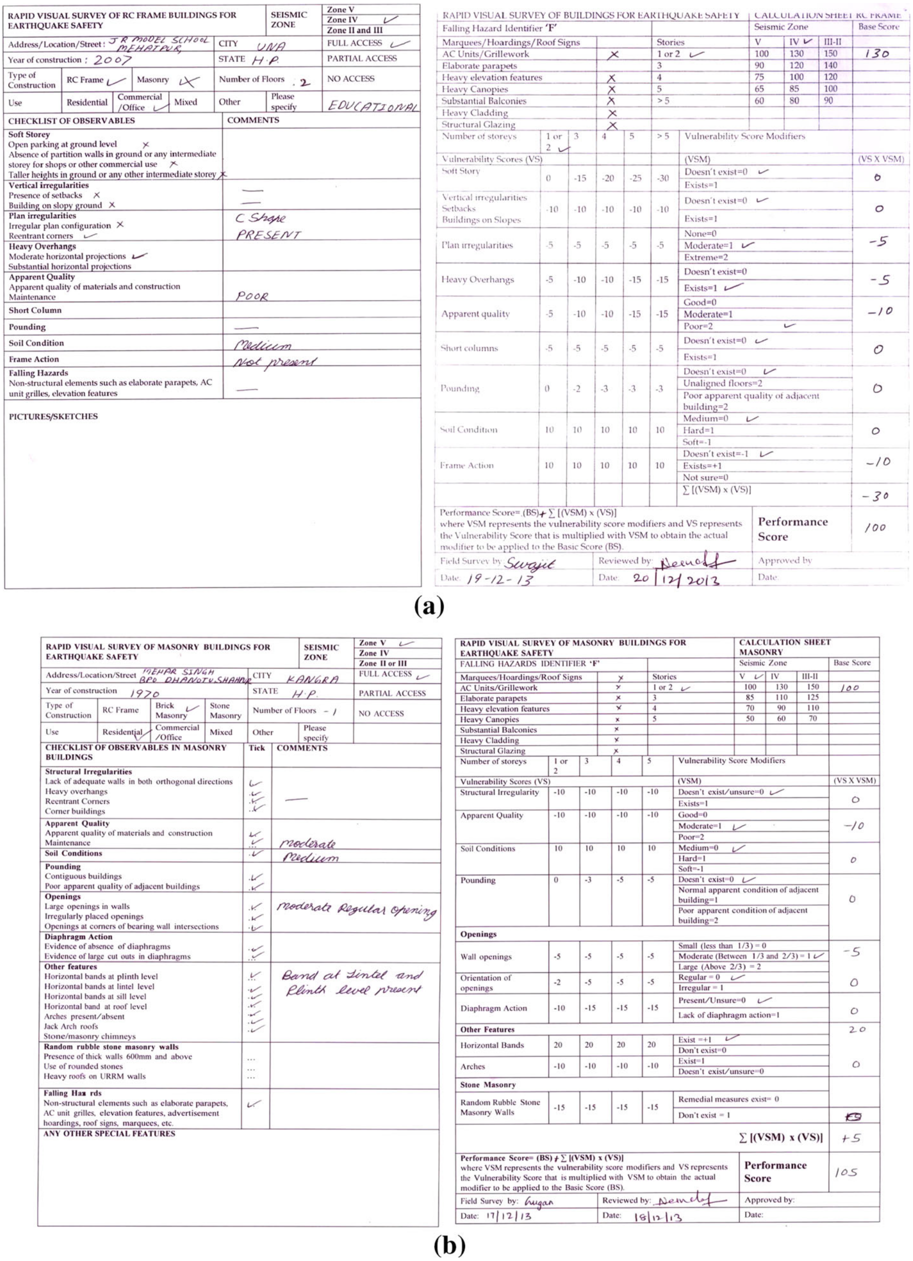
Generally, a cumulative probability refers to the probability that the value of a random variable falls within a specified range (damage range based on design). Cumulative probabilities refer to the probability that a random variable is less than or equal to a specified value. The cumulative distribution function, which gives the probability that a variate will assume a value $\leq x$, is

$$D(x) = \int_{-\infty}^{x} f(x)\mathrm{d}x = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-(x-\mu)} / 2\sigma^2 \mathrm{d}x \qquad (3)$$

In RVS survey, even non-engineers may collect data and calculate RVS score for buildings. Present study considers Himachal Pradesh as a case study to evaluate RVS score for five varieties of buildings. The description of Himachal Pradesh is given in the following section.

4 A case study of Himachal Pradesh

Himachal Pradesh state is located 31.1033°N, 77.1722°E and lies in the Himalayan Mountains, and is part of the Punjab Himalayas. Since the earthquake database in India is still incomplete, especially regarding the earthquakes prior to the historical period (before 1800 A.D.), the largest instrumented earthquake in Himachal Pradesh was 1905 Kangra earthquake (Mw7.8) (Ambraseys and Bilham 2000). The Himalayan Frontal Thrust, the Main Boundary Thrust, the Krol, the Giri, Jutogh and Nahan thrusts lie in this region. However, it must be stated that the proximity to faults does not necessarily translate into a higher hazard as compared to areas located far away. As it is located on hilly terrain, land



(a)

RAPID VISUAL SURVEY OF RC FRAME BUILDINGS FOR EARTHQUAKE SAFETY			SEISMIC ZONE	Zone V / Zone IV ✓ / Zone II and III
Address/Location/Street: J R MODEL SCHOOL MEHATPUR		CITY UNA		FULL ACCESS ✓
Year of construction: 2007		STATE H.P.		PARTIAL ACCESS
Type of Construction	RC Frame ✓	Masonry ✗	Number of Floors 2	NO ACCESS
Use	Residential	Commercial /Office ✓	Mixed / Other	Please specify EDUCATIONAL

CHECKLIST OF OBSERVABLES	COMMENTS
Soft Storey Open parking at ground level ✗; Absence of partition walls in ground or any intermediate storey for shops or other commercial use ✗; Taller heights in ground or any other intermediate storey ✗	
Vertical irregularities Presence of setbacks ✗; Building on slopy ground ✗	—
Plan irregularities Irregular plan configuration ✗; Reentrant corners ✓	C Shape PRESENT
Heavy Overhangs Moderate horizontal projections ✓; Substantial horizontal projections	
Apparent Quality Apparent quality of materials and construction; Maintenance	POOR
Short Column	
Pounding	—
Soil Condition	Medium
Frame Action	Not present
Falling Hazards Non-structural elements such as elaborate parapets, AC unit grilles, elevation features	—
PICTURES/SKETCHES	

RAPID VISUAL SURVEY OF BUILDINGS FOR EARTHQUAKE SAFETY — CALCULATION SHEET RC FRAME

Falling Hazard Identifier 'F'		Stories	V	IV ✓	III-II	Base Score
Marquees/Hoardings/Roof Signs						
AC Units/Grillework	✗	1 or 2 ✓	100	130	150	130
Elaborate parapets		3	90	120	140	
Heavy elevation features	✗	4	75	100	120	
Heavy Canopies	✗	5	65	85	100	
Substantial Balconies	✗	> 5	60	80	90	
Heavy Cladding	✗					
Structural Glazing	✗					

Number of storeys	1 or 2 ✓	3	4	5	> 5	Vulnerability Score Modifiers (VSM)	(VS X VSM)
Soft Story	0	-15	-20	-25	-30	Doesn't exist=0 ✓; Exists=1	0
Vertical irregularities Setbacks Buildings on Slopes	-10	-10	-10	-10	-10	Doesn't exist=0 ✓; Exists=1	0
Plan irregularities	-5	-5	-5	-5	-5	None=0; Moderate=1 ✓; Extreme=2	-5
Heavy Overhangs	-5	-10	-10	-15	-15	Doesn't exist=0; Exists=1 ✓	-5
Apparent quality	-5	-10	-10	-15	-15	Good=0; Moderate=1; Poor=2 ✓	-10
Short columns	-5	-5	-5	-5	-5	Doesn't exist=0 ✓; Exists=1	0
Pounding	0	-2	-3	-3	-3	Doesn't exist=0 ✓; Unaligned floors=2; Poor apparent quality of adjacent building=2	0
Soil Condition	10	10	10	10	10	Medium=0 ✓; Hard=1; Soft=-1	0
Frame Action	10	10	10	10	10	Doesn't exist=-1 ✓; Exists=+1; Not sure=0	-10
						∑ [(VSM) x (VS)]	-30

Performance Score= (BS)+∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS). Performance Score: 100

Field Survey by: Surajit; Date: 19-12-13 | Reviewed by: Neemd; Date: 20/12/2013 | Approved by; Date

(b)

RAPID VISUAL SURVEY OF MASONRY BUILDINGS FOR EARTHQUAKE SAFETY			SEISMIC ZONE	Zone V ✓ / Zone IV / Zone II or III
Address/Location/Street: MEHAR SINGH BPO DHANOTU SHAHPUR		CITY KANGRA		FULL ACCESS ✓
Year of construction 1970		STATE H.P.		PARTIAL ACCESS
Type of Construction	RC Frame	Brick Masonry ✓ / Stone Masonry	Number of Floors – 1	NO ACCESS
Use	Residential ✓	Commercial /Office / Mixed	Other	Please specify

CHECKLIST OF OBSERVABLES IN MASONRY BUILDINGS	Tick	COMMENTS
Structural Irregularities Lack of adequate walls in both orthogonal directions; Heavy overhangs; Reentrant Corners; Corner buildings	✓ ✓ ✓ ✓	—
Apparent Quality Apparent quality of materials and construction; Maintenance	✓ ✓	moderate
Soil Conditions	✓	Medium
Pounding Contiguous buildings; Poor apparent quality of adjacent buildings	✓ ✓	
Openings Large openings in walls; Irregularly placed openings; Openings at corners of bearing wall intersections	✓ ✓ ✓	moderate Regular opening
Diaphragm Action Evidence of absence of diaphragms; Evidence of large cut outs in diaphragms	✓ ✓	
Other features Horizontal bands at plinth level; Horizontal bands at lintel level; Horizontal bands at sill level; Horizontal band at roof level; Arches present/absent; Jack Arch roofs; Stone/masonry chimneys	✓ ✓ ✓ ✓ ✓ ✓ ✓	Band at lintel and Plinth level present
Random rubble stone masonry walls Presence of thick walls 600mm and above; Use of rounded stones; Heavy roofs on URRM walls	...	
Falling Hazards Non-structural elements such as elaborate parapets, AC unit grilles, elevation features, advertisement hoardings, roof signs, marquees, etc.	✓	
ANY OTHER SPECIAL FEATURES		

RAPID VISUAL SURVEY OF MASONRY BUILDINGS FOR EARTHQUAKE SAFETY — CALCULATION SHEET MASONRY

FALLING HAZARDS IDENTIFIER 'F'		Stories	V ✓	IV	III-II	Base Score
Marquees/Hoardings/Roof Signs	✗					
AC Units/Grillework	✗	1 or 2 ✓	100	130	150	100
Elaborate parapets	✗	3	85	110	125	
Heavy elevation features	✗	4	70	90	110	
Heavy Canopies	✗	5	50	60	70	
Substantial Balconies	✗					
Heavy Cladding	✗					
Structural Glazing	✗					

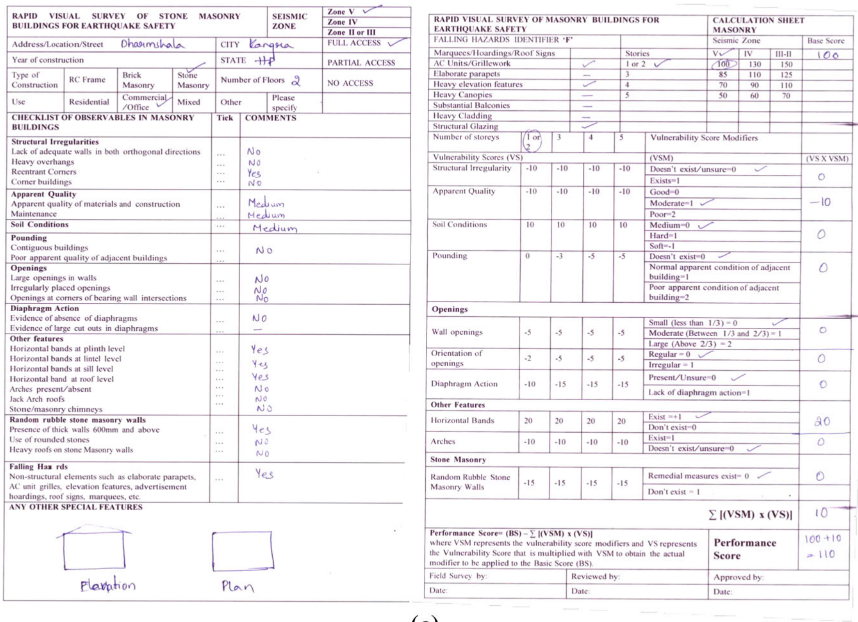
Number of storeys	1 or 2	3	4	5	Vulnerability Score Modifiers (VSM)	(VS X VSM)
Structural Irregularity	-10	-10	-10	-10	Doesn't exist/unsure=0 ✓; Exists=1	0
Apparent Quality	-10	-10	-10	-10	Good=0; Moderate=1 ✓; Poor=2	-10
Soil Conditions	10	10	10	10	Medium=0 ✓; Hard=1; Soft=-1	0
Pounding	0	-3	-5	-5	Doesn't exist=0 ✓; Normal apparent condition of adjacent building=1; Poor apparent condition of adjacent building=2	0
Openings						
Wall openings	-5	-5	-5	-5	Small (less than 1/3) = 0; Moderate (Between 1/3 and 2/3) = 1 ✓; Large (Above 2/3) = 2	-5
Orientation of openings	-2	-5	-5	-5	Regular = 0 ✓; Irregular = 1	0
Diaphragm Action	-10	-15	-15	-15	Present/Unsure=0 ✓; Lack of diaphragm action=1	0
Other Features						20
Horizontal Bands	20	20	20	20	Exist =+1 ✓; Don't exist=0	
Arches	-10	-10	-10	-10	Exist=1; Doesn't exist/unsure=0	0
Stone Masonry						
Random Rubble Stone Masonry Walls	-15	-15	-15	-15	Remedial measures exist= 0; Don't exist = 1	
					∑ [(VSM) x (VS)]	+5

Performance Score= (BS)+∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS). Performance Score: 105

Field Survey by: [illegible]; Date: 17/12/13 | Reviewed by: Neemd; Date: 18/12/13 | Approved by; Date

Fig. 2 Calculation of RVS score from RVS sheets for **a** reinforced concrete buildings, **b** brick masonry buildings, **c** stone masonry buildings, **d** rammed earth buildings and **e** hybrid buildings

by its very nature is very fragile; therefore, threat due to earthquakes or landslides is high. Hence, it has been considered as the apt study area. In total of 12 districts, Chamba, Kullu, Kangra, Una, Hamirpur, Mandi, and Bilaspur districts lie in Zone V, whereas Lahul and



RAPID VISUAL SURVEY OF STONE MASONRY BUILDINGS FOR EARTHQUAKE SAFETY				SEISMIC ZONE	Zone V ✓ / Zone IV / Zone II or III
Address/Location/Street	Dharmshala		CITY Kangra		FULL ACCESS ✓
Year of construction			STATE HP		PARTIAL ACCESS
Type of Construction	RC Frame	Brick Masonry	Stone Masonry ✓	Number of Floors 2	NO ACCESS
Use	Residential	Commercial/Office ✓	Mixed	Other / Please specify	

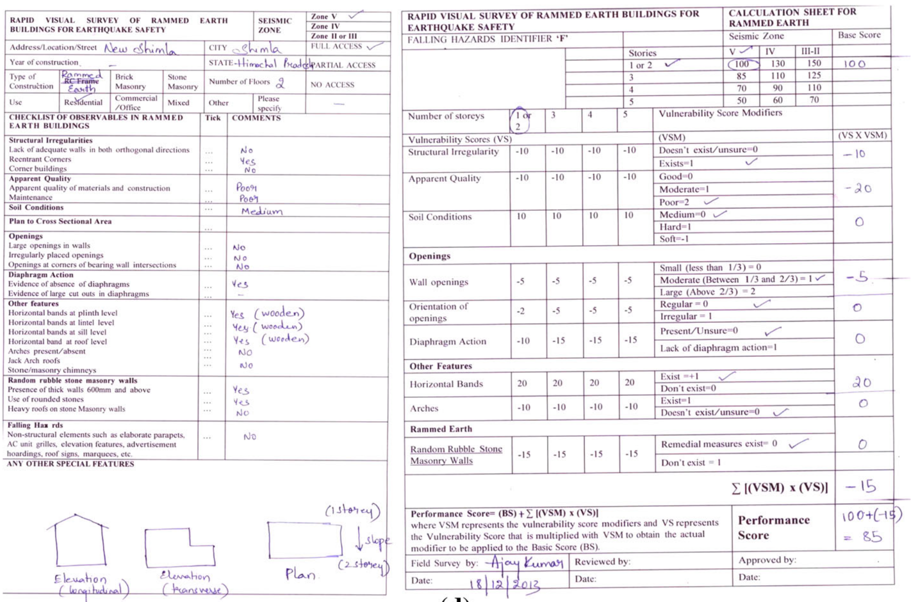
CHECKLIST OF OBSERVABLES IN MASONRY BUILDINGS	Tick	COMMENTS
Structural Irregularities		
Lack of adequate walls in both orthogonal directions	…	No
Heavy overhangs	…	No
Reentrant Corners	…	Yes
Corner buildings	…	No
Apparent Quality		
Apparent quality of materials and construction	…	Medium
Maintenance	…	Medium
Soil Conditions	…	Medium
Pounding		
Contiguous buildings	…	No
Poor apparent quality of adjacent buildings	…	
Openings		
Large openings in walls	…	No
Irregularly placed openings	…	No
Openings at corners of bearing wall intersections	…	No
Diaphragm Action		
Evidence of absence of diaphragms	…	No
Evidence of large cut outs in diaphragms	…	—
Other features		
Horizontal bands at plinth level	…	Yes
Horizontal bands at lintel level	…	Yes
Horizontal bands at sill level	…	Yes
Horizontal band at roof level	…	No
Arches present/absent	…	No
Jack Arch roofs	…	No
Stone/masonry chimneys	…	No
Random rubble stone masonry walls		
Presence of thick walls 600mm and above	…	Yes
Use of rounded stones	…	No
Heavy roofs on stone Masonry walls	…	No
Falling Hazards		
Non-structural elements such as elaborate parapets, AC unit grilles, elevation features, advertisement hoardings, roof signs, marquees, etc.	…	Yes
ANY OTHER SPECIAL FEATURES		

Elevation Plan

RAPID VISUAL SURVEY OF MASONRY BUILDINGS FOR EARTHQUAKE SAFETY					CALCULATION SHEET MASONRY			
FALLING HAZARDS IDENTIFIER 'F'					Seismic Zone			Base Score
Marquees/Hoardings/Roof Signs		Stories			V ✓	IV	III-II	100
AC Units/Grillework	✓	1 or 2 ✓			(100)	130	150	
Elaborate parapets	—	3			85	110	125	
Heavy elevation features	✓	4			70	90	110	
Heavy Canopies	—	5			50	60	70	
Substantial Balconies	—							
Heavy Cladding	—							
Structural Glazing	✓							

Number of storeys	(1 or 2)	3	4	5	Vulnerability Score Modifiers	
Vulnerability Scores (VS)					(VSM)	(VS X VSM)
Structural Irregularity	-10	-10	-10	-10	Doesn't exist/unsure=0 ✓; Exists=1	0
Apparent Quality	-10	-10	-10	-10	Good=0; Moderate=1 ✓; Poor=2	−10
Soil Conditions	10	10	10	10	Medium=0 ✓; Hard=1; Soft=-1	0
Pounding	0	-3	-5	-5	Doesn't exist=0 ✓; Normal apparent condition of adjacent building=1; Poor apparent condition of adjacent building=2	0
Openings						
Wall openings	-5	-5	-5	-5	Small (less than 1/3) = 0 ✓; Moderate (Between 1/3 and 2/3) = 1; Large (Above 2/3) = 2	0
Orientation of openings	-2	-5	-5	-5	Regular = 0 ✓; Irregular = 1	0
Diaphragm Action	-10	-15	-15	-15	Present/Unsure=0 ✓; Lack of diaphragm action=1	0
Other Features						
Horizontal Bands	20	20	20	20	Exist =+1 ✓; Don't exist=0	20
Arches	-10	-10	-10	-10	Exist=1; Doesn't exist/unsure=0 ✓	0
Stone Masonry						
Random Rubble Stone Masonry Walls	-15	-15	-15	-15	Remedial measures exist= 0 ✓; Don't exist = 1	0
					∑ [(VSM) x (VS)]	10
Performance Score= (BS) – ∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).					Performance Score	100 + 10 = 110
Field Survey by:		Reviewed by:			Approved by:	
Date:		Date:			Date:	

(c)



RAPID VISUAL SURVEY OF RAMMED EARTH BUILDINGS FOR EARTHQUAKE SAFETY				SEISMIC ZONE	Zone V ✓ / Zone IV / Zone II or III
Address/Location/Street	New Shimla		CITY Shimla		FULL ACCESS ✓
Year of construction	—		STATE Himachal Pradesh		PARTIAL ACCESS
Type of Construction	~~RC Frame~~ Rammed Earth	Brick Masonry	Stone Masonry	Number of Floors 2	NO ACCESS
Use	Residential	Commercial/Office	Mixed	Other / Please specify	—

CHECKLIST OF OBSERVABLES IN RAMMED EARTH BUILDINGS	Tick	COMMENTS
Structural Irregularities		
Lack of adequate walls in both orthogonal directions	…	No
Reentrant Corners	…	Yes
Corner buildings	…	No
Apparent Quality		
Apparent quality of materials and construction	…	Poor
Maintenance	…	Poor
Soil Conditions	…	Medium
Plan to Cross Sectional Area	…	
Openings		
Large openings in walls	…	No
Irregularly placed openings	…	No
Openings at corners of bearing wall intersections	…	No
Diaphragm Action		
Evidence of absence of diaphragms	…	Yes
Evidence of large cut outs in diaphragms	…	—
Other features		
Horizontal bands at plinth level	…	Yes (wooden)
Horizontal bands at lintel level	…	Yes (wooden)
Horizontal bands at sill level	…	Yes (wooden)
Horizontal band at roof level	…	No
Arches present/absent	…	No
Jack Arch roofs	…	
Stone/masonry chimneys	…	
Random rubble stone masonry walls		
Presence of thick walls 600mm and above	…	Yes
Use of rounded stones	…	Yes
Heavy roofs on stone Masonry walls	…	No
Falling Hazards		
Non-structural elements such as elaborate parapets, AC unit grilles, elevation features, advertisement hoardings, roof signs, marquees, etc.	…	No
ANY OTHER SPECIAL FEATURES		

Elevation (longitudinal) Elevation (transverse) Plan (1 storey) slope (2 storey)

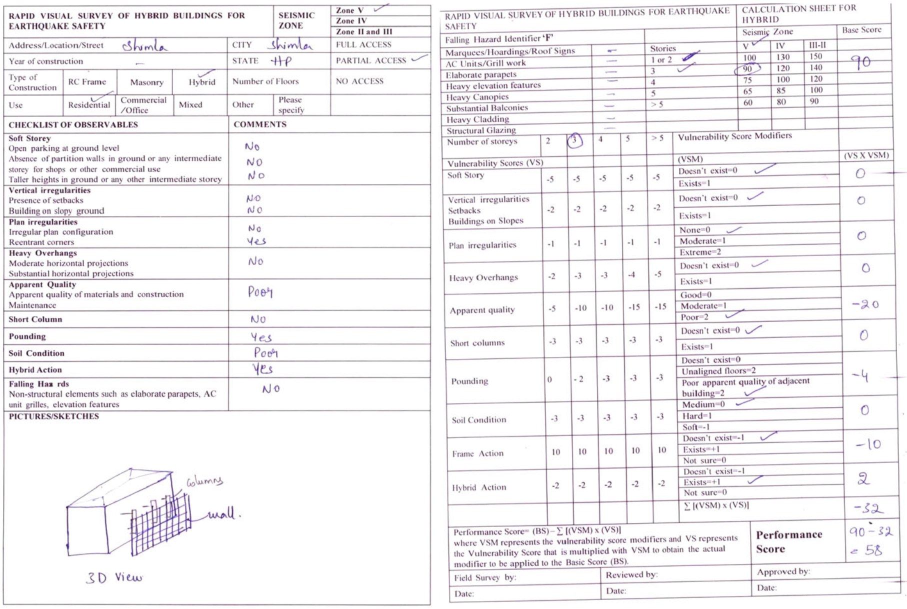
RAPID VISUAL SURVEY OF RAMMED EARTH BUILDINGS FOR EARTHQUAKE SAFETY					CALCULATION SHEET FOR RAMMED EARTH			
FALLING HAZARDS IDENTIFIER 'F'					Seismic Zone			Base Score
		Stories			V ✓	IV	III-II	100
		1 or 2 ✓			(100)	130	150	
		3			85	110	125	
		4			70	90	110	
		5			50	60	70	

Number of storeys	(1 or 2)	3	4	5	Vulnerability Score Modifiers	
Vulnerability Scores (VS)					(VSM)	(VS X VSM)
Structural Irregularity	-10	-10	-10	-10	Doesn't exist/unsure=0; Exists=1 ✓	−10
Apparent Quality	-10	-10	-10	-10	Good=0; Moderate=1; Poor=2 ✓	−20
Soil Conditions	10	10	10	10	Medium=0 ✓; Hard=1; Soft=-1	0
Openings						
Wall openings	-5	-5	-5	-5	Small (less than 1/3) = 0; Moderate (Between 1/3 and 2/3) = 1 ✓; Large (Above 2/3) = 2	−5
Orientation of openings	-2	-5	-5	-5	Regular = 0 ✓; Irregular = 1	0
Diaphragm Action	-10	-15	-15	-15	Present/Unsure=0 ✓; Lack of diaphragm action=1	0
Other Features						
Horizontal Bands	20	20	20	20	Exist =+1 ✓; Don't exist=0	20
Arches	-10	-10	-10	-10	Exist=1; Doesn't exist/unsure=0 ✓	0
Rammed Earth						
Random Rubble Stone Masonry Walls	-15	-15	-15	-15	Remedial measures exist= 0 ✓; Don't exist = 1	0
					∑ [(VSM) x (VS)]	−15
Performance Score= (BS) + ∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).					Performance Score	100+(−15) = 85
Field Survey by: Ajay Kumar		Reviewed by:			Approved by:	
Date: 18/12/2013		Date:			Date:	

(d)

Fig. 2 continued

Spiti, Kinnaur, Simla, Solan and Sirmaur districts lie in Zone IV. The building's data are collected in every district of HP and procedure for data collection is described in the following section.



RAPID VISUAL SURVEY OF HYBRID BUILDINGS FOR EARTHQUAKE SAFETY					SEISMIC ZONE	Zone V ✓ / Zone IV / Zone II and III
Address/Location/Street	Shimla			CITY	Shimla	FULL ACCESS
Year of construction	–			STATE	HP	PARTIAL ACCESS ✓
Type of Construction	RC Frame	Masonry	Hybrid ✓	Number of Floors		NO ACCESS
Use	Residential ✓	Commercial /Office	Mixed	Other	Please specify	

CHECKLIST OF OBSERVABLES	COMMENTS
Soft Storey Open parking at ground level Absence of partition walls in ground or any intermediate storey for shops or other commercial use Taller heights in ground or any other intermediate storey	No NO NO
Vertical irregularities Presence of setbacks Building on slopy ground	NO NO
Plan irregularities Irregular plan configuration Reentrant corners	No Yes
Heavy Overhangs Moderate horizontal projections Substantial horizontal projections	No
Apparent Quality Apparent quality of materials and construction Maintenance	Poor
Short Column	NO
Pounding	Yes
Soil Condition	Poor
Hybrid Action	Yes
Falling Haa rds Non-structural elements such as elaborate parapets, AC unit grilles, elevation features	NO

PICTURES/SKETCHES

RAPID VISUAL SURVEY OF HYBRID BUILDINGS FOR EARTHQUAKE SAFETY				CALCULATION SHEET FOR HYBRID		
Falling Hazard Identifier 'F'				Seismic Zone		Base Score
Marquees/Hoardings/Roof Signs	–	Stories		V ✓	IV	III-II
AC Units/Grill work	–	1 or 2	100	130	150	90
Elaborate parapets	–	3 ✓	(90)	120	140	
Heavy elevation features	–	4	75	100	120	
Heavy Canopies	–	5	65	85	100	
Substantial Balconies	–	> 5	60	80	90	
Heavy Cladding	–					
Structural Glazing	–					

Number of storeys	2	(3)	4	5	> 5	Vulnerability Score Modifiers (VSM)	(VS X VSM)
Vulnerability Scores (VS)							
Soft Story	-5	-5	-5	-5	-5	Doesn't exist=0 ✓ Exists=1	0
Vertical irregularities Setbacks Buildings on Slopes	-2	-2	-2	-2	-2	Doesn't exist=0 ✓ Exists=1	0
Plan irregularities	-1	-1	-1	-1	-1	None=0 ✓ Moderate=1 Extreme=2	0
Heavy Overhangs	-2	-3	-3	-4	-5	Doesn't exist=0 ✓ Exists=1	0
Apparent quality	-5	-10	-10	-15	-15	Good=0 Moderate=1 Poor=2 ✓	-20
Short columns	-3	-3	-3	-3	-3	Doesn't exist=0 ✓ Exists=1	0
Pounding	0	- 2	-3	-3	-3	Doesn't exist=0 Unaligned floors=2 Poor apparent quality of adjacent building=2 ✓	-4
Soil Condition	-3	-3	-3	-3	-3	Medium=0 ✓ Hard=1 Soft=-1	0
Frame Action	10	10	10	10	10	Doesn't exist=-1 ✓ Exists=+1 Not sure=0	-10
Hybrid Action	-2	-2	-2	-2	-2	Doesn't exist=-1 Exists=+1 ✓ Not sure=0	2
						Σ [(VSM) x (VS)]	-32

Performance Score= (BS) – Σ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).		**Performance Score**	90 - 32 = 58
Field Survey by:	Reviewed by:	Approved by:	
Date:	Date:	Date:	

(e)

Fig. 2 continued

4.1 Data collection

An RVS format was developed for the android platform using ODK (Open Data Kit) framework. After designing RVS format for android platform, it is stored on all the tablet computers to be used for data collection. Once it is installed, it does not require Internet connectivity to fetch the blank form. Data are collected from the field on day-to-day basis. On a regular basis, surveyors were provided maps of the marked area along with the number of buildings to be surveyed in that area. After filling all the required information in the RVS format, latitude/longitude is recorded by enabling inbuilt GPS in the tablet computer. Three photographs are taken for each building type in which first two photographs are taken as front and side elevation of the building and third photograph belongs to any major building vulnerability feature. Data are sent to the server using Internet connectivity. These data can be accessed from anywhere using the web application. Surveyors sent the data every evening or next day (in case of non-availability of signal in the remote area) after finishing the work.

Following were few challenges faced during the process of data collection.

1. More time was needed to reach the rural location due to limited travel connectivity.
2. It was difficult to get the information on few parameters such as horizontal bands in the masonry buildings for well-plastered buildings.
3. Foundation details and age of construction was difficult to obtain, if the building was not constructed by the owner.

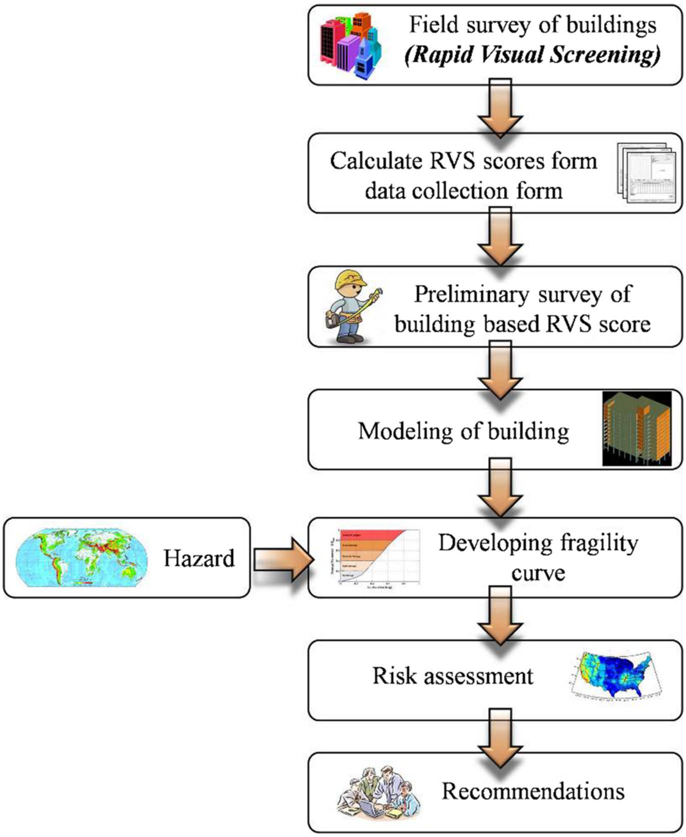


Fig. 3 Schematic diagram of assessment of a building

4.2 Housing potrayal

It has been observed that buildings in Himachal Pradesh are primarily classified into five types viz., reinforced concrete buildings, brick masonry buildings, rammed earth buildings, stone masonry and hybrid buildings from the surveyed buildings data. It also portrays varied building construction methodologies in the state. From the surveyed buildings database, it is categorized into three levels in the preliminary stage of analysis: (a) district wise, (b) type of buildings and (c) building components. Following are few observations from the database which explains the housing scenario in Himachal Pradesh.

1. Huge number of brick masonry buildings and wide variety of building construction are present in Kangra district.
2. New construction of buildings has evolved in Kangra and Solan districts.
3. Presence of medium type of soil is more in every district except Kinnaur and Lahul Spiti.
4. Existence of corner openings of buildings is more in Kangra and Solan districts and substantial openings are more in Solan district.
5. Existence of horizontal bands of a building is more in Kangra district.

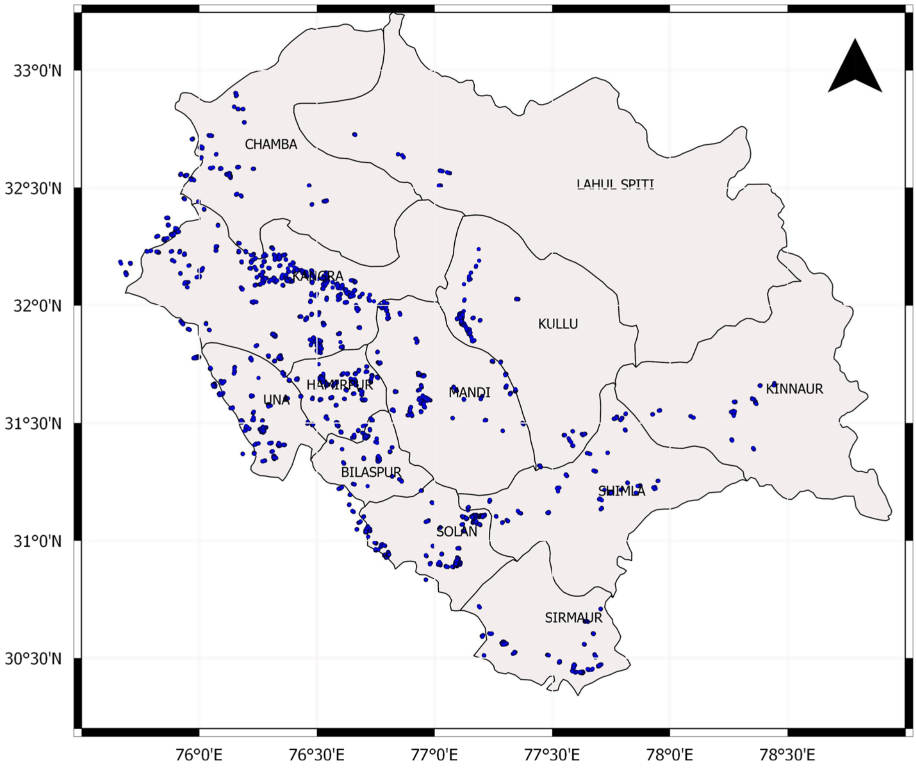


Fig. 4 Location of buildings considered in RVS analysis

6. Presence of soft story, heavy overhangs and short column is rare in most of the districts.
7. Quality of construction is moderate in all districts of Himachal Pradesh.
8. Because of its geographical conditions, only few buildings are observed to be on the flat ground, whereas large number of buildings is located on slopes.

The building parameters according to district are shown in Fig. 5. The primary observation from housing classification is the complexity involved in construction of buildings in the state.

4.3 RVS score calculation

Based on the factors given in the form, RVS scores have been calculated for the buildings present in the database. The scores for RC, brick masonry, stone masonry, rammed earth and hybrid buildings are 50–160; 40–220; 30–190; 50–160; and 60–140, respectively. Normal distribution curves are generated for each district and building variety based on RVS scores. District wise normal distribution curves for buildings are shown in Figs. 6, 7, 8, 9, 10 and 11.

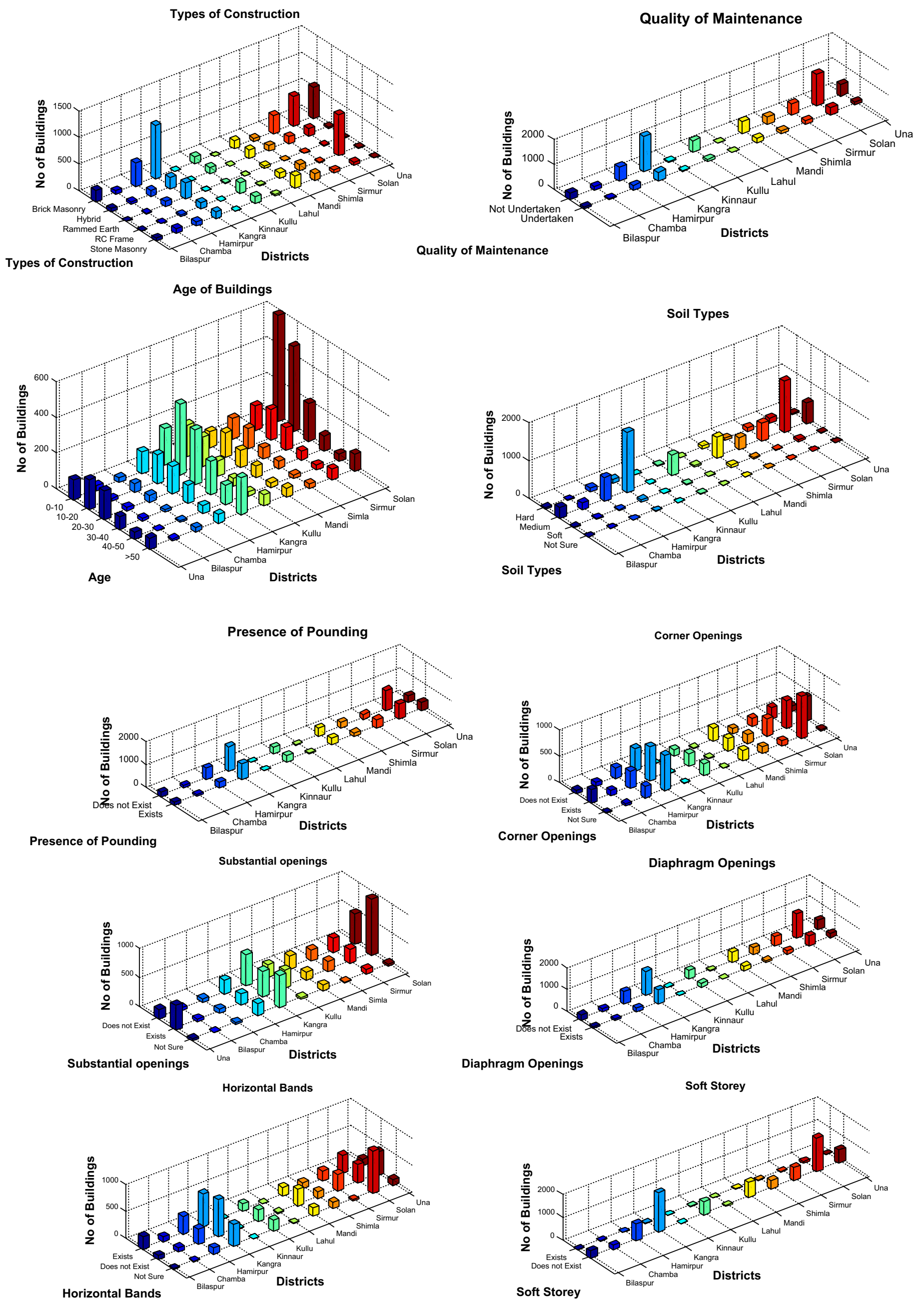


Fig. 5 Statistics of building parameters for 12 districts in HP state

1. The number of buildings surveyed in the districts of Bilaspur, Hamirpur, Kinnaur, Kullu, Lahul Spiti, Shimla, Solan, Chamba, Kangra, Mandi, Sirmaur and Una are 383, 789, 149, 619, 70, 401, 1553, 513, 1929, 692, 585 and 637, respectively.

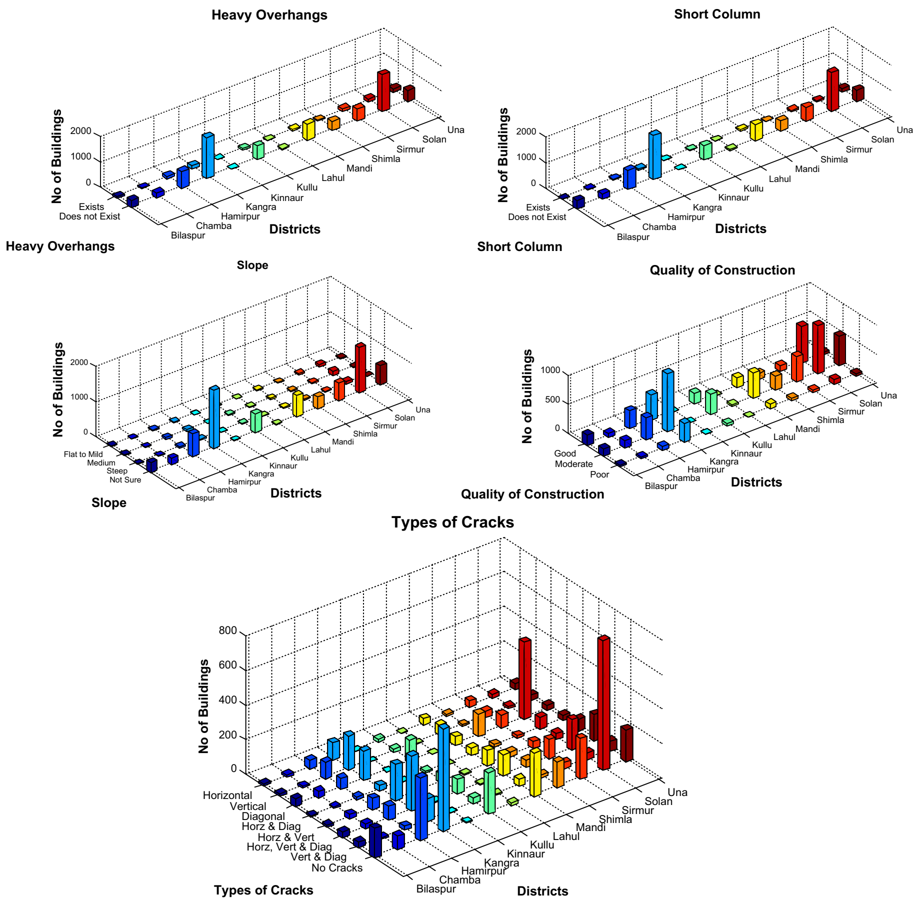


Fig. 5 continued

2. Around 62% of buildings were constructed majorly in last three decades, which indicates the developmental growth of the state. The construction of buildings rapidly increased during this period, especially in Kangra and Solan districts of HP. There were few buildings that were constructed in 1970s. Most of the surveyed buildings are single, two or three storied and a few are four and five storied. It is observed that the quality of construction was moderate for 45% of RC buildings, 63% of brick masonry buildings, 63% of stone masonry buildings, 60% of rammed earth, and 68% of hybrid buildings. The quality of construction needs to be improved for hybrid, rammed earth and stone masonry buildings. The construction practices are mostly done on hilly terrain due to unavailability of space on flat terrain, and buildings are built in close proximity to each other. Pounding effect was also observed for 55% of buildings.
3. Around 88% of RC buildings, 90% of brick masonry buildings, 80% of stone masonry buildings, 86% of rammed earth, 82% of hybrid buildings are located on medium type of soil. Around 10–15% of buildings are located on hard and soft soils. Buildings located on soft soils are more vulnerable than medium soils and hard soils.

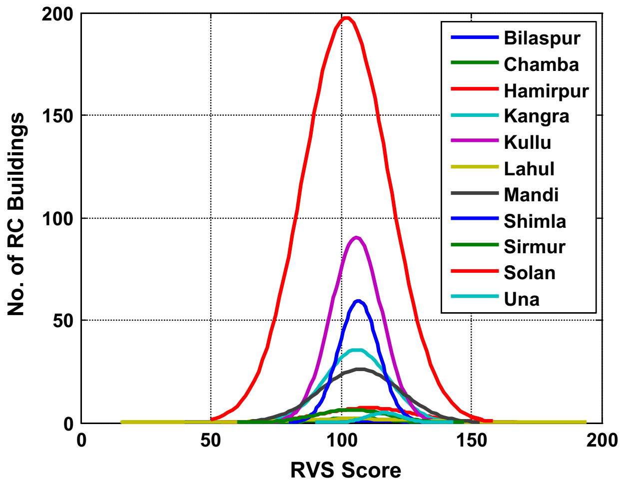


Fig. 6 Normal distribution curves for RC buildings obtained from RVS score

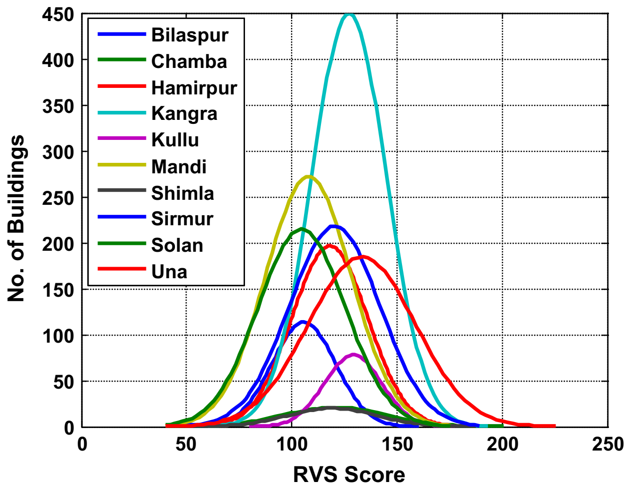


Fig. 7 Normal distribution curves for brick masonry buildings obtained from RVS score

4. Presence of horizontal bands for buildings located in zone IV and V, increase the seismic response of building. In the present survey only 32% of buildings are observed to have bands.
5. Other parameters like openings, short column effect, slope angle heavy overhangs etc. are classified district wise as shown in Fig. 5, but full access of the building is required to get overview of it. The configuration of building is either rectangle, L-shape, T-shape or U-shape for all types of buildings. It is one of the important virtues of earthquake resistant buildings. For buildings, whose configuration is irregular, should make it regular by providing expansion joints, so that, pounding effect due to earthquake can be minimized in high seismic areas.

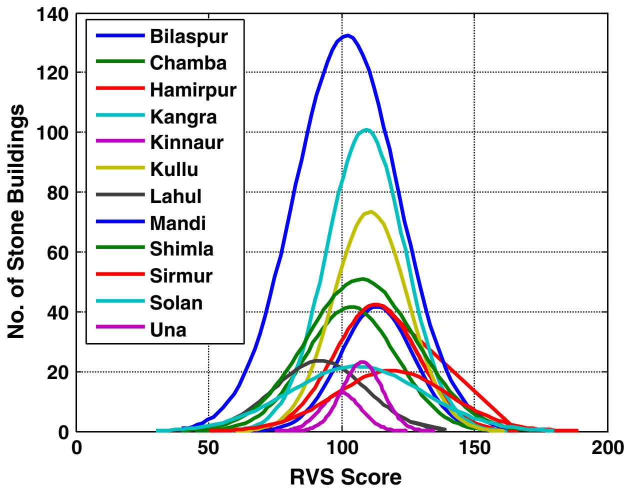


Fig. 8 Normal distribution curves for stone masonry buildings obtained from RVS score

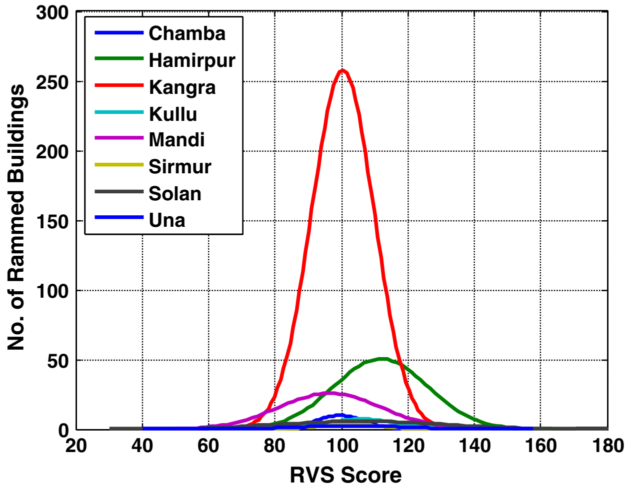


Fig. 9 Normal distribution curves for rammed earth buildings obtained from RVS score

6. Many of the buildings use less than 230 mm as column size, which is not advisable in seismic areas of zone IV and V. But, IS: 13920—2014 recommends that the minimum size of column should be 300 mm. Around 63% of brick masonry buildings used 150–250 mm, 73% of hybrid buildings used 100–150 mm, 86% of RC buildings used 100–200 mm as column size.

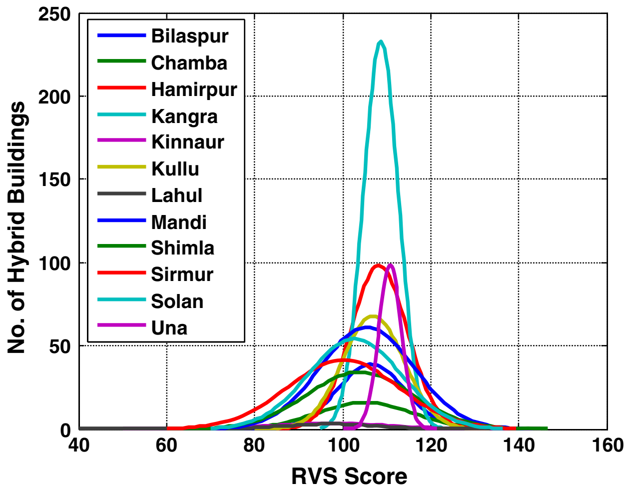


Fig. 10 Normal distribution curves for hybrid buildings obtained from RVS score

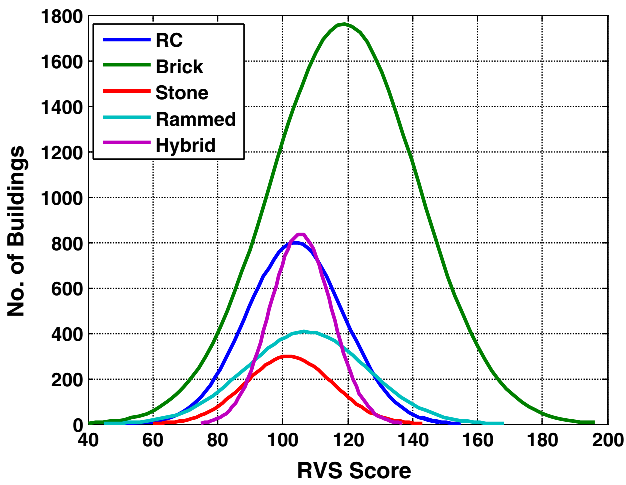


Fig. 11 Normal distribution curves as per building variety

4.4 Estimation of damage using RVS score

From literature, it is observed that the predominant RVS score lies in the range of 60–120 for both RC and brick masonry buildings in Gandhidham and Adipur cities in Gujarat (Srikanth and Pradeep 2010; Srikanth et al. 2010). The mean and median values for both RC and brick masonry buildings are 89.3, 90.0; 78.74, 80.0. Similarly, for Himachal Pradesh, the RVS score lies in the range of 50–160 for reinforced concrete and 40–220 for brick masonry buildings. For which the mean values for both RC and brick masonry buildings are 106 and 120. The analysis was also carried out for stone masonry, rammed earth and hybrid buildings. The RVS scores of five varieties of buildings were given in the

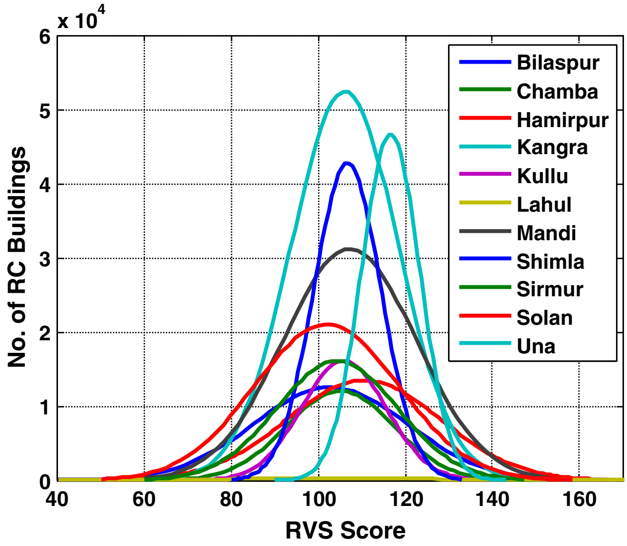


Fig. 12 Normal distribution curve for RC buildings

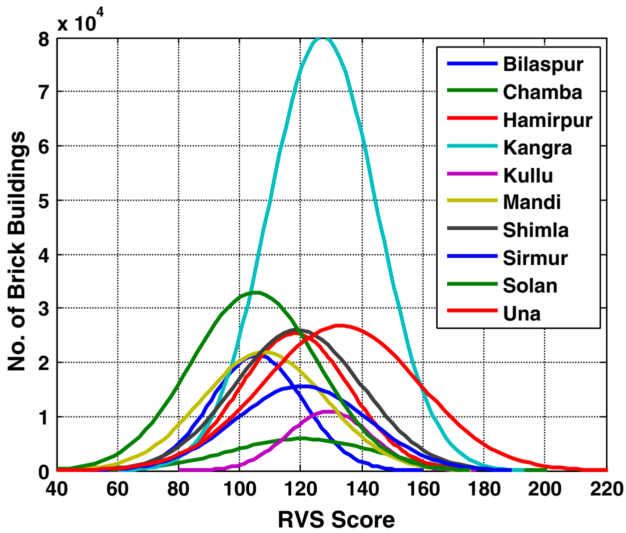


Fig. 13 Normal distribution curve for brick masonry buildings

earlier section. The mean values are slightly shifted towards right when compared to that of study done in Gandhidham and Adipur cities. It is difficult to set a benchmark for RVS score to understand the damage state of building. A normal distribution curves have been drawn for RC, Brick Masonry, Stone Masonry, Rammed Earth and Hybrid type of buildings are shown in Figs. 12–16 respectively. Also, all type of buildings is represented in single plot and is shown in Fig. 17. For this purpose, damage is classified as no damage, slight, moderate, severe and collapse based on $\mu - 2\sigma$, $\mu - 1\sigma$, μ, $\mu + 1\sigma$, and $\mu + 2\sigma$. The mean and standard deviation of all building typologies are represented in Table 2. A

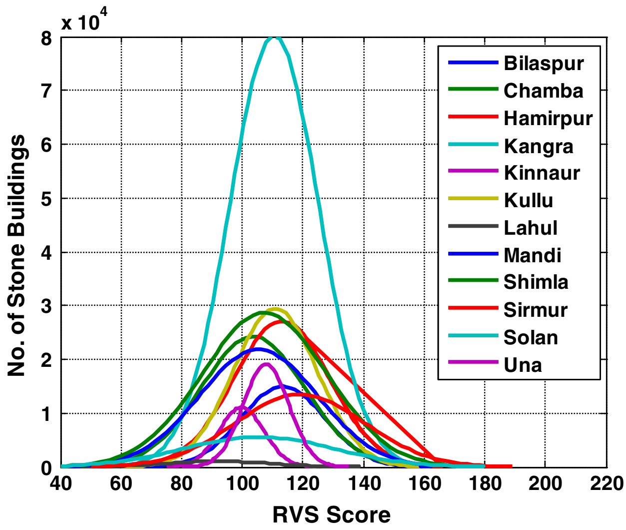


Fig. 14 Normal distribution curve for stone masonry buildings

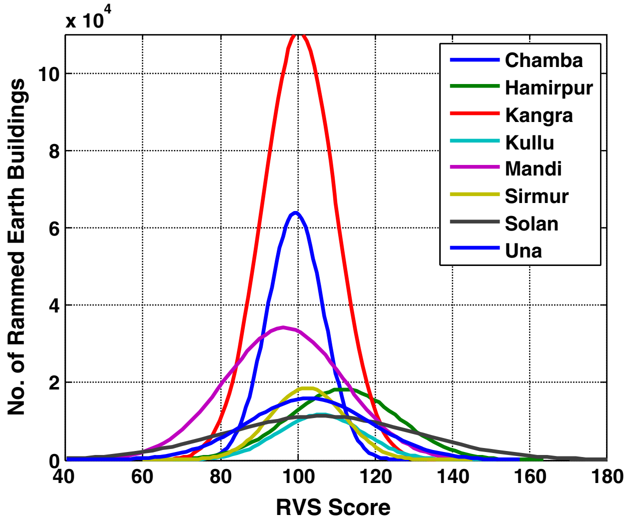


Fig. 15 Normal distribution curve for rammed earth buildings

representative diagram is shown in Fig. 18. Mean and standard deviations are calculated for each type of building and the state of damage is estimated. Table 3 represents damage state of five types of buildings and Fig. 18 shows the classification of damage of buildings in Himachal Pradesh State.

The distribution of number of buildings in each district of HP with respect to RVS score is shown in Fig. 19. The buildings whose RVS score lies between 130 and 150 are more in number in all Mandi and Sirmaur districts and RVS score lies between 105 and 110 in other districts. These buildings will suffer moderate damage as per damage classification shown in Fig. 18. It means moderate damage buildings are sparsely distributed in all

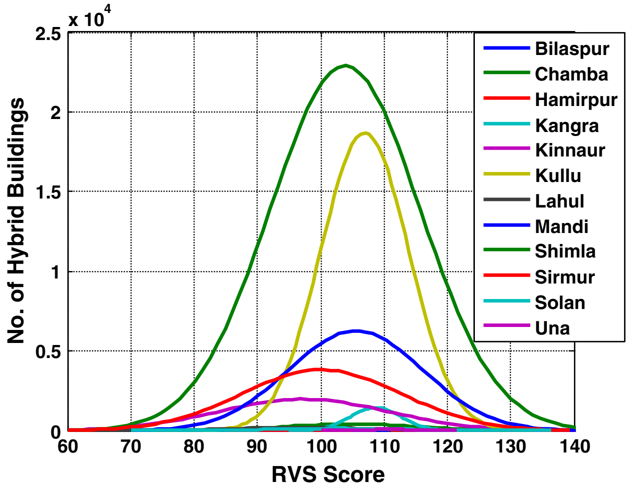


Fig. 16 Normal distribution curve for hybrid buildings

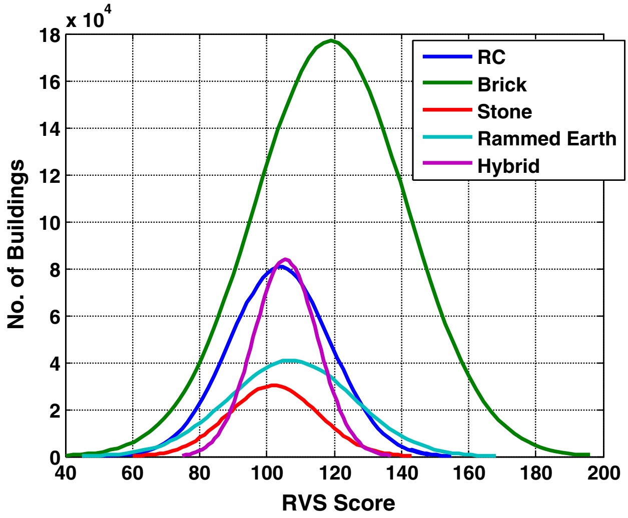


Fig. 17 Normal distribution curve as per building variety

districts. The mean and median of buildings range 110–130 and 105–135, respectively. Around 5.3% of buildings in Sirmaur district and 2% of buildings in other districts will have collapse stage. Buildings whose RVS score is less than or equal to 100 need to be analyzed in detail. These analyses are beyond scope of the paper.

5 Conclusions

An attempt has been made to perform RVS of five varieties of buildings in Himachal Pradesh state. RVS score are calculated for 9099 buildings and normal distribution curves are plotted for each typology of building to understand the distribution of buildings in

Table 2 Mean and standard deviation of buildings as per district wise and building variety wise

Name of District	RC		Brick masonry		Stone masonry		Rammed earth		Hybrid	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Bilaspur	102.8	17.72	105.73	15.09	113.43	13.78	–	–	106.45	7.7
Chamba	105	12.28	120.53	23.95	103.55	17.07	99.44	7.26	105.02	10.8
Hamirpur	110.4	17.7	118.08	17.95	113.03	15.81	111.88	14.19	108.25	6.41
Kangra	106.07	12.33	127.25	17.77	109.15	14.68	100.42	9.43	108.68	4.01
Kinnaur	–	–	–	–	99.75	7.42	–	–	97.2	13.38
Kullu	105.84	9.71	129.16	13.53	110.90	13.91	106	11	106.95	6.93
Lahul Spiti	104.77	26.18	–	–	91.88	17.28	–	–	97.12	10.65
Mandi	107.23	15.30	108	20.28	101.9	19.5	96.6	15.43	105.53	10.61
Shimla	106.7	7.7	119.17	20.82	107.31	20.57	–	–	103.86	11.86
Sirmur	104.27	13.85	120.42	21.41	115	21.68	102.5	9.57	100.12	12.59
Solan	101.87	16.5	104.75	20.74	105.45	24.95	99.21	19.43	102.73	10.53
Una	116.62	6.71	133.32	25.39	107.85	7.56	103	16.04	110.8	2.6

μ mean, σ standard deviation

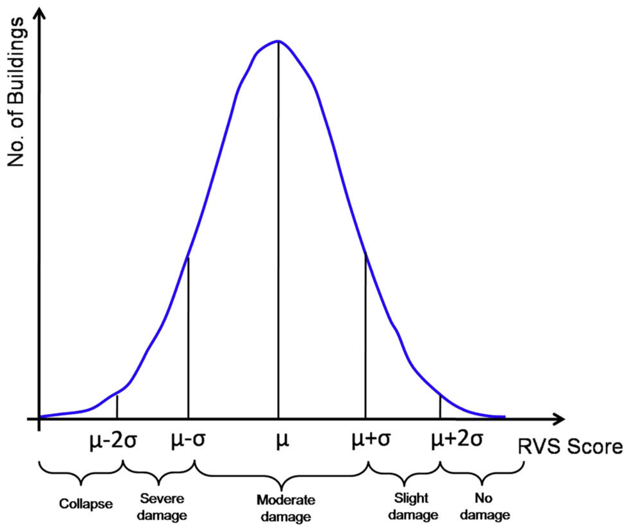


Fig. 18 Classification of damage from normal distribution curve

Himachal Pradesh state. In this study, a detailed analysis of RVS has been incorporated to that of existing one. This RVS study enables us to calculate the risk by assessing the structural vulnerability of different building typologies. It is observed that overall RVS score for different building typologies range from 30 to 220. A statistical approach has been considered to understand the building state using RVS scores. However, major buildings turn out be in middle range of damage index and hence drawing meaningful conclusion is a difficult task. However, there are low RVS score buildings which are potentially vulnerable to future earthquakes. Also it is suggested that preliminary analysis

Table 3 State of damage and number of damage buildings of RC, brick, stone, rammed earth and hybrid buildings

State of damage	Collapse	Severe damage	Moderate damage	Slight damage	No damage	Total
RCC	32	210	1051	209	39	1541
BM	107	645	2984	546	81	4363
SM	38	179	948	148	28	1341
RE	11	86	341	71	9	518
Hybrid	32	193	902	167	25	1317

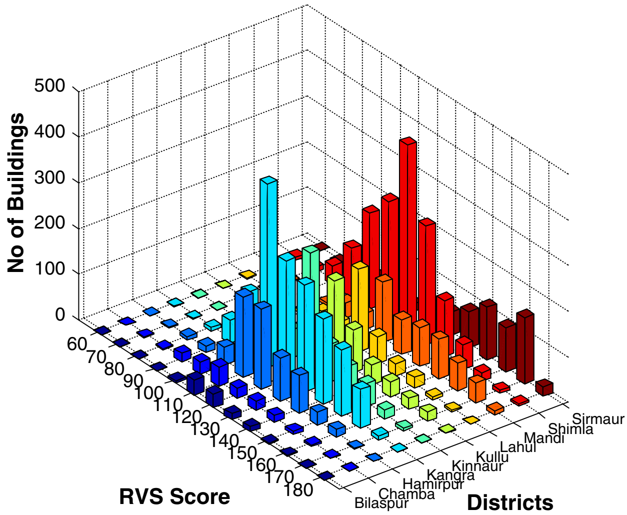


Fig. 19 Distribution of number of buildings with respect to RVS score and each district of HP

needs to be performed on few buildings and detailed analysis should be done for selected buildings for calibrating RVS scores.

5.1 Recommendations

1. Implementation of the building code regulations for rammed earth, hybrid and stone masonry buildings needs to be initiated in India.
2. Performance of the low-rise buildings constructed using locally available materials must be improved. This factor could lead to a significant reduction of casualties in future earthquakes.
3. Research is needed to investigate and improve the performance of the above buildings.

Acknowledgements The authors would like to express their gratitude to the TARU Leading Edge Private Limited, New Delhi. A special thanks goes to our colleagues Mr. Swajit Singh Goud, Mr. Gugan Vignesh Selvaraj, Mr. Bodige Narender, Ms. Bhargavi Sattar, Mr. Ravikanth Chittiprolu, Mr. Pulkit Velani, Mr. Krishna Babu, and Mr. Raju Sangam in finalizing the buildings for preliminary and detailed analysis of buildings.

References

Ambraseys N, Bilham R (2000) A note on the Kangra Ms = 7.8 earthquake of 4 April 1905. Curr Sci 79(1):45–50

Demartinos K, Dristos S (2006) First-level pre-earthquake assessment of buildings using fuzzy logic. Earthq Spectra 22:865–885

EERI Special Earthquake Report (2001) Preliminary observations on the origin and effects of the January 26, 2001 Bhuj (Gujarat, India) Earthquake. California, USA

EERI Special Earthquake Report (2005) First report on the Kashmir Earthquake of October 8, 2005. California, USA

EERI Special Earthquake Report (2012) The Mw 6.9 Sikkim-Nepal Border Earthquake of September 18, 2011. California, USA

FEMA 154 (1988) Rapid visual screening of buildings for potential seismic hazards—a handbook. Federal Emergency Management Agency, Washington

FEMA 178 (1989) NEHRP handbook for the seismic evaluation of existing buildings—a handbook. Federal Emergency Management Agency, Washington

FEMA 178 (1992) NEHRP handbook for the seismic evaluation of existing buildings—a handbook. Federal Emergency Management Agency, Washington

FEMA 310 (1998) Handbook for the seismic evaluation of buildings: a pre-standard—a handbook. Federal Emergency Management Agency, Washington

FEMA (1999) HAZUS: earthquake loss estimation methodology—a handbook. Federal Emergency Management Agency, Washington D.C. Indian Standard Criteria for Ductile Detailing of RC Structures Subjected to Seismic Forces, IS: 13920-2014, Bureau of Indian Standards, New Delhi

FEMA 154 (2002) Rapid visual screening of buildings for potential seismic hazards—a handbook. Federal Emergency Management Agency, Washington

Hassan AF, Sozen MA (1997) Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes. ACI Struct J 94(1):31–39

HAZUS (2000) Estimated annualized earthquake losses for the United States, FEMA 366, Sept 2000

IITK-GSDMA (2003) IITK-GSDMA guidelines for seismic evaluation and strengthening of buildings. NICEE, Kanpur

Jain CK (2006) Seismic vulnerability of buildings and population in India with a case study of Kanpur, Master of Technology Dissertation, Department of Civil Engineering, Indian Institute of Technology, Kanpur

Jain SK, Mitra K, Manish K, Mehul S (2010) A proposed rapid visual screening procedure for seismic evaluation of RC-frame buildings in India. Earthq Spectra 26(3):709–729

JPDPA (2001) Seismic evaluation and retrofit. The Japan Building Disaster Prevention Association, Tokyo

Keya M (2008) Assessing urban fabric against natural disasters: a case study of seismic vulnerability of Kolkata. Ph.D Thesis, Department of Architecture, Town and Regional Planning, Bengal Engineering and Science University, Shibpur, India

Motamed H, Ashtiany MG (2012) An index for evaluating urban earthquake risk. In: Proceedings of the U.S-Iran seismic workshop, Tehran, Iran

Murty CVR, Goel RK, Goyal A, Jain SK, Sinha R, Durgesh CR, Jaswant NA, Rainer M (2002) Reinforced concrete structures. Earthq Spectra 18(S1):149–186

Narender B (2014) Development of a comprehensive seismic risk assessment model for built environment: a case study on Nanded-Waghala City, Maharashtra. Ph.D Thesis, Department of Civil Engineering, Earthquake Engineering Research Centre, International Institute of Information Technology, Hyderabad

Nateghi F (1998) Earthquakes, vulnerabilities and earthquake disaster management. IIEES Publications, Tehran

Nateghi F (2000) Seismic vulnerability of the Mega City of Tehran. In: Proceedings of 12th world conference on earthquake engineering, Auckland, New Zealand

National Disaster Management Authority of India (2007) National disaster management policy and guidelines—earthquakes

NRCC (1993) Manual for screening of buildings for seismic investigation by institute for research in construction. National Research Council Canada, Ottawa

NZSEE (2006) Assessment and improvement of the structural performance of buildings in earthquakes. Recommendations of a NZSEE Study Group on Earthquake Risk Buildings, June 2006, New Zealand

OASP (2000) Provisions for pre-earthquake vulnerability assessment of public buildings (Part A). Greek Earthquake Planning and Protection Organization, Athens

Ozcebe G, Sucuoglu H, Yucemen MS, Yakut A, Kubin J (2006) Seismic risk assessment of existing building stock in Istanbul, a pilot application in Zeytinburnu District. In: Proceedings of 8th US national conference on earthquake engineering, San Fransisco

Ozdemir R, Taskin B (2006) Seismic safety screening method for Istanbul Metropolitan City. In: Proceedings of 10th international East Asia Pacific conference on structural engineering and construction, Bangkok, Thailand

Pradeep KR, Murty CVR (2014) Earthquake safety of houses in India: understanding the bottlenecks in implementation. Indian Concr J 88(9):51–63

Sen Z (2010) Rapid visual earthquake hazard evaluation of existing buildings by fuzzy logic modeling. Expert Syst Appl 37(8):5653–5660

SIA-2018 (2004) Assessment of existing buildings with respect to earthquakes (in German). Technical note 2018. Swiss Society of Civil Engineers and Architects, Zurich, Switzerland

Singh P (2005) Population vulnerability for earthquake loss estimation using community based approach with GIS: urban infrastructure management. Master of Science Thesis, International Institute for Geo Information Science and Earth Observation, Netherlands

Sinha R, Goyal A (2004) A national policy for seismic vulnerability assessment of buildings and procedure for rapid visual screening of buildings for potential seismic vulnerability. Department of Civil Engineering, Indian Institute of Technology Bombay, Bombay

Srikanth T, Pradeep KR (2010) Rapid visual survey of existing buildings in Gandhidham and Adipur Cities, Kachchh, Gujarat. In: Proceedings of international symposium on the 2001 Bhuj earthquake and advances in earth sciences and engineering, Gujarat, India

Srikanth T, Pradeep KR, Ajay PS, Rastogi BK, Santosh K (2010) Earthquake vulnerability assessment of existing buildings in Gandhidham and Adipur Cities, Kachchh, Gujarat (India). Eur J Sci Res 41(3):336–353

Sucuoglu H, Yazgan U, Yakut A (2007) A screening procedure for seismic risk assessment in urban building stocks. Earthq Spectra 23(2):441–458