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Rapid Visual Screening of Public Buildings in Uttarakhand

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Abstract:

Himalaya has been an earthquake prone region and has seen great earthquakes such as 1991 Uttarkashi, 1999 Chamoli earthquakes in the state of Uttarakhand which have been recognized as falling under the seismic gap and is identified as a potential site for a future catastrophic earthquake.As per IS 1893: (part1) 2002, Uttarakhand lies in Seismic Zones IV&V. Thus the seismic evaluation and retrofitting of the important public buildings lying in high seismic zones is important for the initiation of disaster mitigation efforts. With this in view and as an initiative from the Uttarakhand Disaster Recovery Project (UDRP) funded by the World Bank, a Rapid Visual Screening (RVS) survey of Government buildings has been started. Primary objective of this survey is to evaluate the present condition of existing public buildings and to identify the necessary retrofitting techniques to safe guard these buildings in severe earthquakes. The examining is based on earthquake code related strength, building type and damageability grade as followed in past earthquakes and covered in Medvedev Sponheuer Karnik Macroseismic Intensity Scale (MSK) and experience gained in India. Buildings are categorized on the basis of damageability grade based on Central Building Research Institute Roorkee[2] study and Uttarakhand Disaster Recovery Project study. A new Uttarakhand Disaster Recovery Project method was developed considering more number of parameters affecting Performance Modification Factor and correlated its results with the Central Building Research Institute method. A total of 11239 public buildings were surveyed during this project which accounts to 25-30% of total buildings in the Uttarakhand state.The qualitative assessment of buildings shows almost all the Type-A houses are vulnerable and only 1-2% Type-B buildings and 64% Type-C buildings are safe. The assessment shows that buildings are recognized with overhang (76%), pounding (26%), asymmetric in plan (36%), irregular in elevation (5%), Re-entrant corners (11%), distressed and damaged (> 50%), low construction quality (37%) vulnerability parameters. The non-structural members like cladding, ceilings, improper anchorage and thin parapet walls are posing falling hazards in almost all the structures.

Keywords: Medvedev Sponheuer Karnik Macroseismic Intensity Scale; Performance Modification Factor; Simplified and Detailed Vulnerability Analysis

1. Introduction

The State of Uttarakhand is among the most earthquake-prone parts of India. The Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) are the main active features in Uttarakhand. Slippage on these faults and their partners has in the past created huge earthquakes. Since the last earthquake that's this big and important range in this area happened more than 200 years ago, this section of the Himalayan thrust zone is believed to have the greatest possibility of a future high earthquake. The area of possible danger is known as the Central Earthquake-related Gap, and underlies Uttarakhand and western Nepal. Uttarakhand falls in the category of high seismic zone and has witnessed great earthquakes such as 1991 Uttarkashi, 1999 Chamoli earthquakes and these major earthquakes will repeat. In the last six years, Uttarkashi, Chamoli, Rudraprayag and several other areas in Uttarakhand have been repeatedly jolted by earthquakes ranging from magnitudes of 4 to 5.1 on the Richter scale. By regulating the construction in the hills, we can minimize the effects of earthquake.

2. Objective of the study:

With an overall goal of increasing the State Disaster Resilience capacity in Uttarakhand, the main objectives are as follows:

- To identify, inventory and screen buildings that are potentially seismically vulnerable
- To assess the seismic vulnerability and risk of the buildings, their value in saving lives and livelihood of the region by collecting structural details of the buildings through Rapid Visual Screening hereafter (RVS)
- Identifying seismic deficient buildings and targeting priority buildings for the structural strengthening i.e. retrofitting.
- To classify various buildings based on various parameters such as building typology,construction material, etc.

3. Preparation of building Database

An RVS online form was evolved for the android platform with the usage of ODK (Open Data Kit) framework. After filling all of the required statistics in the RVS format, latitude/longitude is recorded by way of allowing in built GPS and photos of the building. Information is sent to the server by the use of internet connectivity. This information can be accessed from ukdisasterrecovery.in/rvs website everywhere using the web software. This database consists of all the technical and non-technical facts collected by this program and may be a resource for future work.

4. Seismic Vulnerability Assessment Methods

RVS is a simple and cost effective tool for preliminary identification of seismic vulnerable buildings. It makes use of a scoring machine that requires the evaluator to (1) pick out the primary structural lateral load-resisting gadget, and (2) become aware of building attributes that alter the seismic overall performance predicted for this lateral load resisting device. The screening is primarily based on numerical seismic hazard and vulnerability rating. The rankings are based at the predicted ground shaking degrees within the vicinity as well as the seismic design and construction practices for the metropolis or the location. The ratings use chance ideas and are consistent with the superior assessment strategies. The RVS may be integrated with GIS-based city planning database and can also be used with superior threat evaluation software. Essentially, RVS helps in the evaluation that a particular building needs a Simplified Vulnerability Assessment and Detailed Vulnerability Assessment or now not.

5. Methodology

The evaluation is done on the basis of building types, building geometry, frame action, pounding effect, structural irregularity, short columns, heavy overhangs, soil conditions, falling hazard, apparent building quality, diaphragm action etc. Building details provide a Basic Structural Hazard (BSH) score and Performance Modification Factors (PMF) for building type. A final Structural Score S is calculated by summation of the BSH and PMFs. The BSH, PMFs and final S all relate to the probability of the building sustaining major life-threatening damage. As per the FEMA guidelines the final S scores typically range from 0 to about 6,greater the S, safer the building and S=2 being a suggested minimum acceptable level. Score is calculated from below formula,

S (Score) = BSH (Basic Structural Hazard) + PMFs (Performance Modification Factor)

i. Basic Structural Hazard (BSH)

The Basic Structural Hazard (BSH) is depend on the type of building,

$$\mathbf{BSH = -\log_{10}[Pr\ (D \geq 60\%)]} \tag{1}$$

And,

$$\mathbf{BSH \pm PMF = S} \tag{2}$$

ii. Performance Modification Factors (PMFs)

FEMA: 154 -2002 (Second edition), performance modification factors were renamed as score modifiers.

In the RVS survey done in Uttarakhand state, the methodology used is based on the guidelines of FEMA 154. As FEMA methodology is mainly applicable for the US, so for the survey in Uttarakhand, CBRI [2] works done for the vulnerability assessment in Mega cities is used and based on their methodology RVS form is developed and analysis of result is processed. As PMF parameters considered in the CBRI study are less in numbers but the vulnerability of building can get affected by many factors. So, a new method named UDRP is developed considering more parameters vulnerable for the buildings. UDRP method only modifies the PMF score not the BSH score. There the basic concept of calculating vulnerability score is same in both UDRP and CBRI method.

iii. Score classification

$$\mathbf{Final\ score = BSH\ score \pm \sum (PMF\ score)} \tag{3}$$

Each building type is assigned with BSH score depending on earthquake forces it is likely to experience.

Table 2: Basic Hazard Score (BSH) classification

Parameter	TYPE-A	TYPE-B	TYPE-C
Basic Hazard Score (BSH)	2.0	2.5	3.0

Table 3: Comparison table of PMF score used in UDRP and CBRI method

S. No.	Parameters	UDRP method		CBRI Method	
		Specification/ Boundary	modification factor	Specification / Boundary	Modification factors
1	Total no. of stories	<2	0	upto 2	0
		2 to 5	-0.15	3 to 7	-0.2
				more than 7	-0.5
2	Minimum gap between adjacent building	<100mm per storey	-0.2	<100 mm per storey	-0.5
		otherwise	0	otherwise	0
3	Building site located at	hill top	-0.2	plain	0
		high slope of hill	-0.15	gentle	-0.1
		mild slope	-0.1	moderate	-0.2
		Plain	0	steep	-0.3
4	Building location	Isolated	0		
		Internal	-0.1		
		End	-0.15		
		Corner	-0.2		
5	Soil type	rock/hard soil	0	rock	0
		medium soil	-0.1	Cohesion-less	-0.3
		soft soil	-0.25	black cotton	-0.6
		reclaimed/ filled soil	-0.2		
		partially filled soil	-0.15		
		loose sand	-0.3		
6	Roofing material	RCC slab	-0.15		

		Tiles	-0.2		
		GI sheets	0		
		Asbestos sheet	-0.1		
		Wooden building	-0.25		
7	Parapet height	Secured against following: YES	0		
		NO	-0.2		
8	Re-entrant corner	≤15%	0		
		> 15%	-0.25		
9	Regularity/ irregularity in elevation	Regular	0		0
		L shape	-0.3		-0.5
		T shape			
		⊥ shape			
10	Soft storey exist	Yes	-0.3		-0.5
		No	0		0
11	Heavy mass at top	Yes	-0.25		
		No	0		
12	Construction type	engineered construction	0		
		non-engineered construction	-0.2		
13	Building construction quality	high	0		0
		medium	-0.1		-0.25
		Low	-0.2		-0.5
14	Building condition/ maintenance	Excellent	0		
		Good	0		
		Damaged	-0.1		

		Distressed	-0.2		
15	Overhang length(balcony) in m	Overhang length <1.5m	0		
		>1.5m	-0.2		
16	Plan irregularity	Symmetric	-0.25	Symmetric	-0.5
		Asymmetric	0	Asymmetric	0
17	Cladding	-		with	-0.5
		-		without	0

Table 4: Final vulnerability score classification

Final Score	Ranking of Building
Less than 80	Grade 5
81-160	Grade 4
161-180	Grade 3
181-200	Grade 2
Greater than 201	Grade 1

The threshold value for the final score is taken as 2. All the values of BSH and PMF are multiplied by 100 for ease of understanding because the values come in decimal form leads to some difficulty in reading and understanding of evaluation process.

6. Categorization of public buildings surveyed in all districts

Total of 11239 buildings including 18835 units are surveyed in this project duration which basically accounts to 25-30% of the total public buildings in the Uttarakhand state. All the buildings are categorized into 6 categories named as Education department, Health department, Fire department, Police station, Administrative Department and other buildings include cooperative banks, Sales Tax department, civil works department (PWD, Agriculture, Irrigation, UJVNL departments, forest department, etc).

Table 5: Department wise categorization of buildings

District	Education	Health	Fire	Thana/Police Station	Administrative	Other	Total Buildings
Almora	361	79	0	9	47	7	503
Bageshwar	609	77	1	28	174	62	951
Chamoli	1224	164	5	37	385	280	2095
Champawat	88	39	1	8	16	13	165

Dehradun	504	61	2	17	36	1	621
Haridwar	219	48	2	7	43	7	326
Nanital	196	52	0	1	8	10	267
Pauri	1004	143	0	11	45	1	1204
Pithoragarh	1049	144	0	68	260	122	1643
Rudrapraya g	531	63	1	20	118	14	747
Tehri	529	80	0	2	17	3	631
Udham Singh Nagar	305	39	3	1	2	0	350
Uttarkashi	1112	132	7	60	269	156	1736
Total	7731	1121	22	269	1420	676	11239

7. Various Parameters affecting the vulnerability of the building:

7.1 Irregularities

i. Vertical irregularity

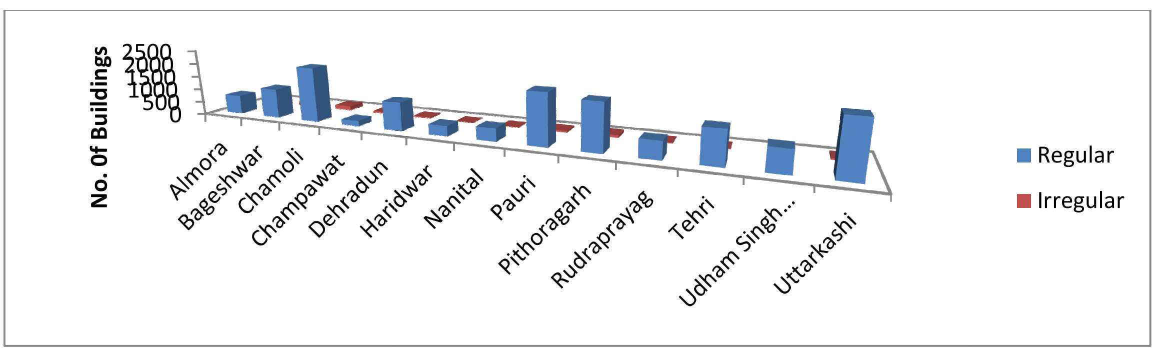

Figure 1: Representation of Regularity and Irregularity in elevation of the Masonry building

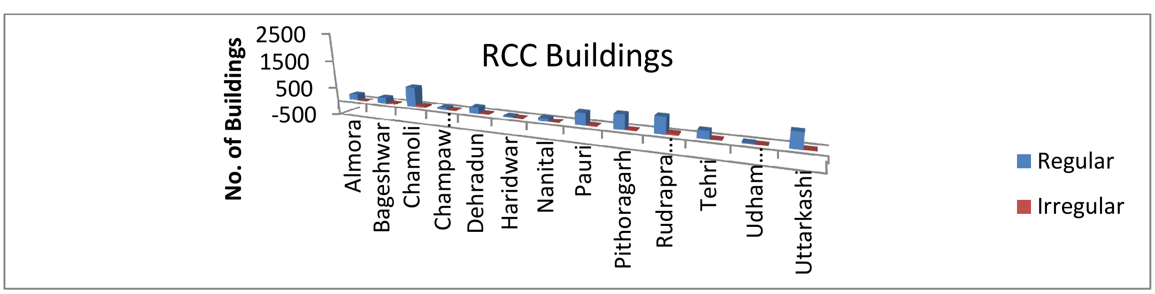

Figure 2: Representation of Regularity and Irregularity in elevation of the RCC buildings

Maximum percentages of the buildings are regular and hence they are safe during the earthquake from irregularity point of view. But some other parameters can make them vulnerable. Around 95% buildings- both RCC and masonry are regular in shape and 5% buildings are irregular in shape. Irregular shape leads to the concentration of stress at those points from where the cracks initiate and make structure vulnerable.

7.2 Re-entrant Corner

Presence of re-entrant corners are one the serious plan irregulars that results in poor seismic performance of buildings. There are two problems created by these shapes. The first is that they tend to produce differential motions between different wings of the building that result in local stress concentrations at the re-entrant corner, or "notch." The second problem of this form is torsion which is caused because the center of mass and the center of rigidity in this form cannot geometrically coincide for all possible earthquake directions. The result is rotation.

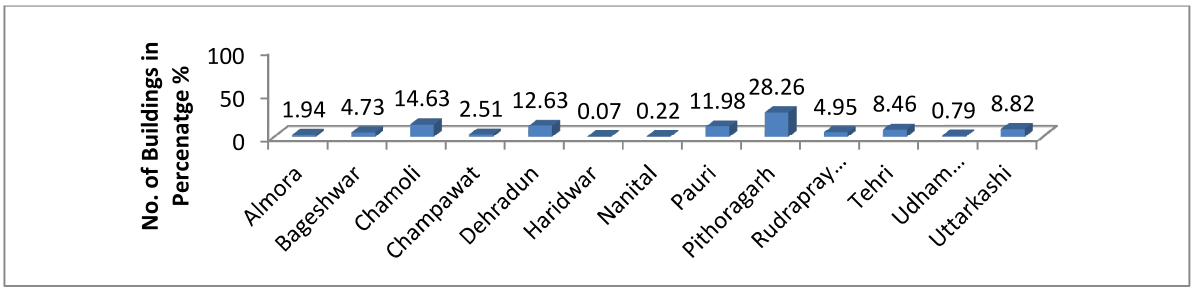

Figure 3: Percentage of Masonry building failure due to Re-entrant corner

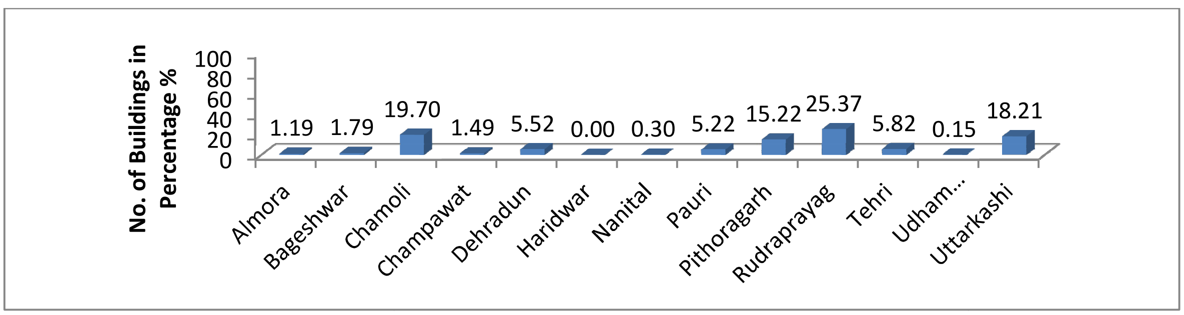

Figure 4: Percentage of RCC building failure due to Re-entrant corner

7.3 Pounding effect

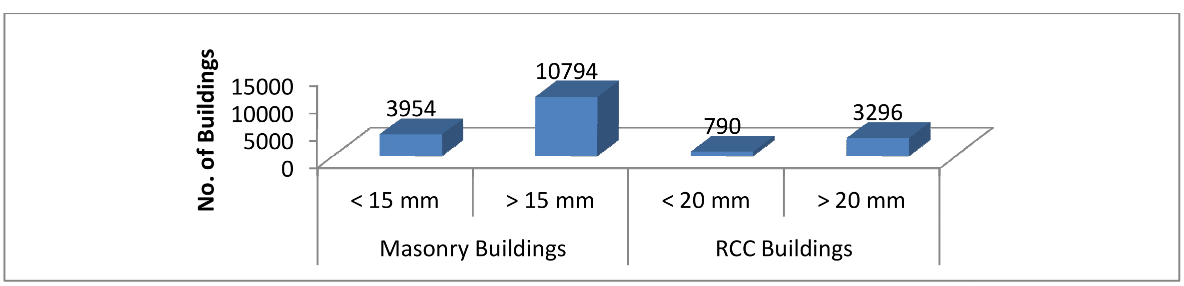

Figure 5: Representation of building typology based on pounding failure

From the present study, it is concluded that 50-55% of the masonry buildings and 20-25 % of the RCC building are vulnerable due to the pounding effect. Some of the pictures of pounding effect are shown below.

7.4 Overhang length

. width and area not exceeding 3.5 sq m. per bedroom.

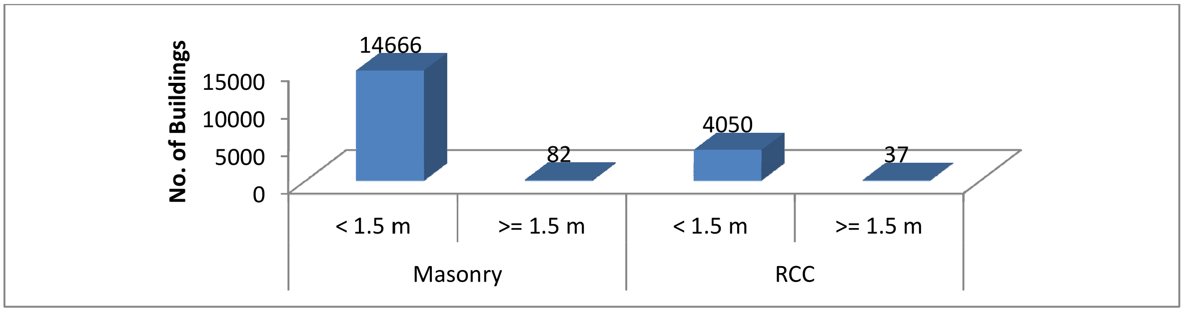

Figure 6: Percentage of buildings based on typology with overhang features

7.5 Building construction quality

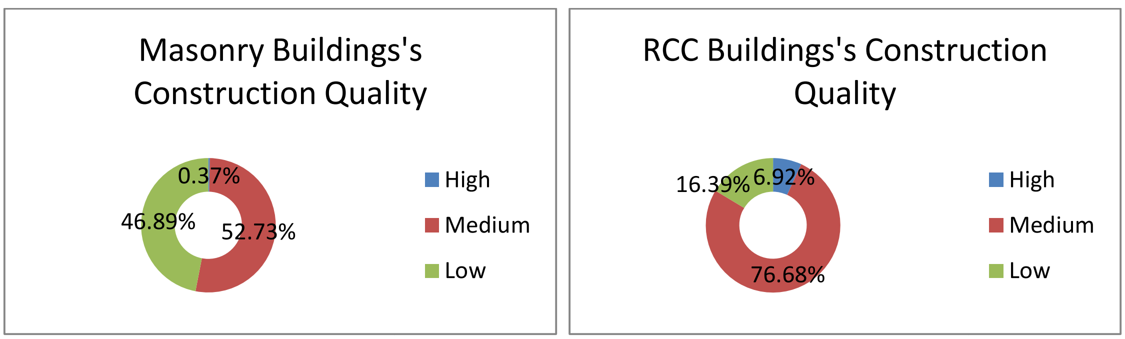

Figure 7: Representation of Building based on construction quality

From the present study we can concluded that most of the RCC and Masonry buildings construction quality is medium. Masonry buildings with 46.89% have low construction quality and about 0.37 % buildings have high construction quality.

7.6 Building condition and maintenance

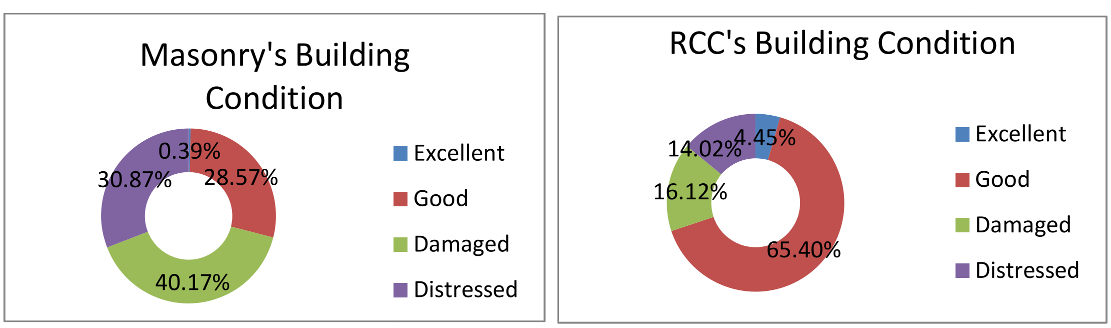

Figure 8: Representation of buildings based on building condition

Approximately 40.17% of the masonry buildings are there whose condition is damaged but only 16.12% of the RCC buildings lie in damaged condition; very few percent of buildings have excellent condition in RCC and negligible buildings in Masonry.

8. Vulnerability analysis of Buildings based on Final Score

Overall vulnerability of the Uttarakhand state is 86% calculated as per CBRI method and by UDRP method vulnerability of the state is 87%. The difference is due to the consideration of more number of parameters in UDRP method as compared to CBRI method.

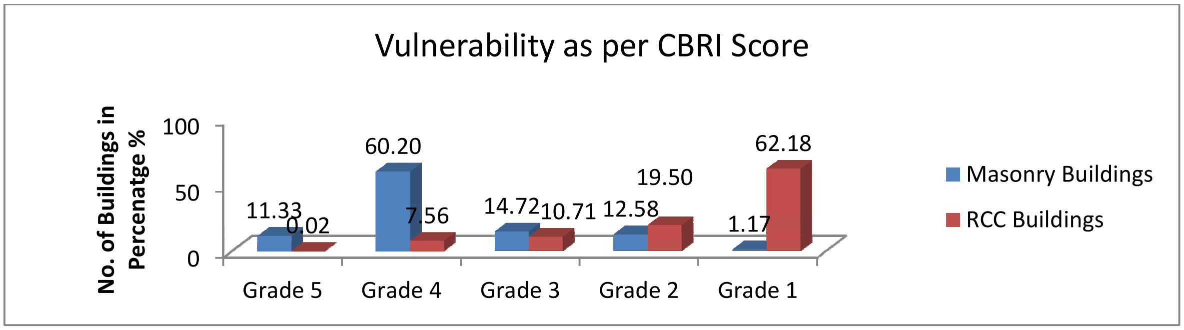

Figure 9: RCC and Masonry Building categorization based on CBRI score

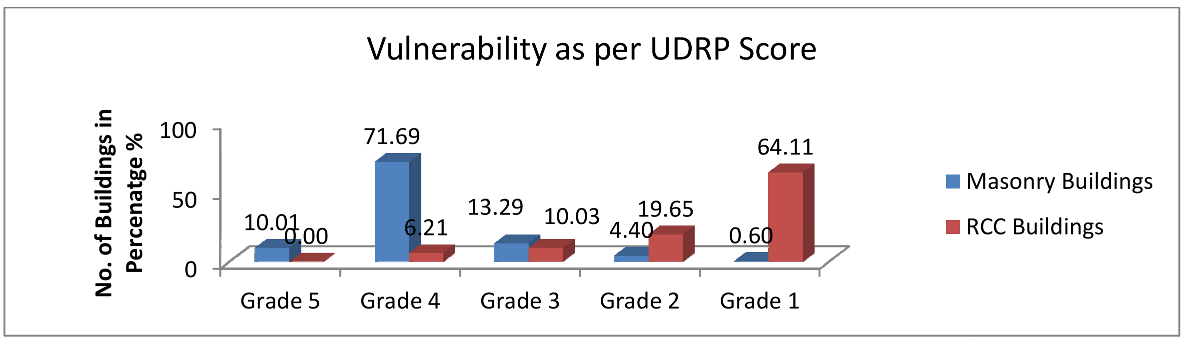

Figure 10: RCC and maonsry Building categorization based on UDRP score

64.11% RCC buildings are safe and only 0.6% Masonry buildings are safe from UDRP method and 62.18% RCC buildings are safe and only 1.17% Masonry buildings are safe from CBRI method. More number of masonry buildings falls in the Grade 4 category as 60.20% and 71.69% by CBRI and UDRP method respectively. Masonry structures will suffer very heavy damages such as heavy damages to structural components and very heavy damages to non-structural components. Overall 15% buildings are safe and other 85% buildings are vulnerable.

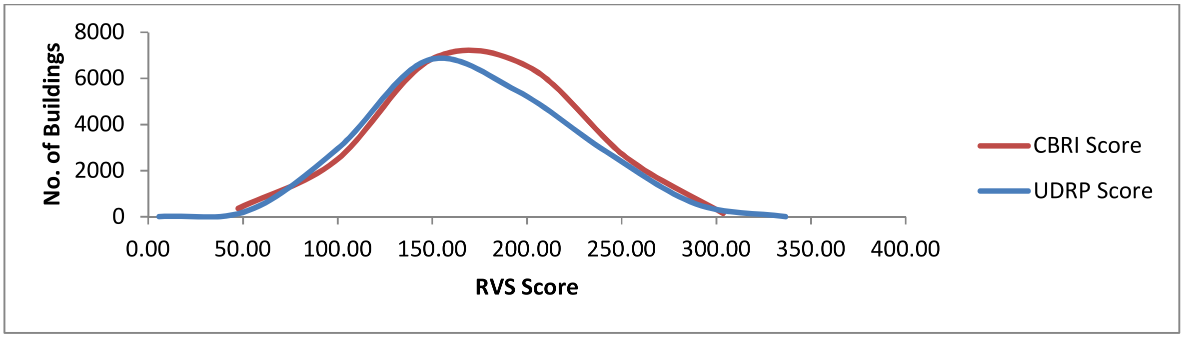

Figure 11: Normal distribution curve for buildings through RVS score

It is observed that score lies in the range of 0 to 175 for Type A, 0 to 225 for Type B, and 60 to 300 for Type C buildings. To draw normal distribution curve for CBRI and UDRP method the mean and standard deviation for both CBRI and UDRP are 149.92, 51.23, 147.44, and 47.25 respectively. Graph is plotted considering the range of damage as μ-2σ, μ-1σ, μ, μ+1σ, μ+2σ.

9. Result and Conclusion

i. Seismic vulnerability of type –A houses

It is seen that all the houses surveyed scored much less than the desirable structural score i.e. 200. Hence the houses are seismically vulnerable and likely to have damage in the event of earthquake. Therefore the damage scenario of Type-A houses deduced as that 100% of Type-A houses is likely to have extensive cracking and serious falling of walls, leading to collapse.

ii. Seismic vulnerability of Type-B houses

The evaluation of Type-B buildings makes only 1-2 % safe against earthquake. The low percentage of safe houses is due to the reasons that the qualitative study includes structural and non-structural failures as a whole, including ambience, geological/geotechnical features.

iii. Seismic vulnerability of Type-C houses

Type-C buildings are so called engineered construction and comprises of RCC framed configuration for load transfer. Hence, the qualitative assessment shows that 36% buildings are vulnerable requiring detailed investigations on their seismic resistance. The non-structural members like cladding, ceilings, improper anchorage and thin parapet walls are posing falling hazards in almost all the structures.

iv. General Conclusions

- It was found that 85% of the buildings have non-engineered construction
- 36% of the buildings are asymmetric in plan, 5% of the buildings are irregular in elevation and 11% buildings have Re-entrant corners
- 21% masonry buildings and 4-5% RCC buildings will suffer the loss due to pounding
- 76% of the buildings surveyed have overhang length > 1.5m hence they are more vulnerable to earthquakes
- 60% buildings have medium, 37% buildings have low and only 2% buildings have high construction quality. More than 50% of the buildings are distressed and damaged

- Based on RVS score, maximum buildings surveyed are lying in very bad and bad category which accounts to 49-58% and 13-14% respectively and around 7-9% buildings is worst
- Around 85% of public buildings are vulnerable.

10. Scope of further study

The present study laid emphasis on public buildings which consists of Education, Health, Administrative, Fire, Thana/Police station departments to access seismic vulnerability. Also it is require identifying the other type of private buildings which are more vulnerable and suggest them for the retrofitting. Also the results of vulnerability assessment should be integrated with hazard microzonation results to estimate risk for Uttarakhand state.

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