Journal of Disaster & Emergency Research
http://jder.ssu.ac.ir
eISSN: 2588-6150
2021; 4(2): 93-110
10.18502/jder.7963

Seismic Vulnerability of Primary Response Agencies in the Himalayan Province of Uttarakhand in India

Piyoosh Rautela [1*], Girish Chandra Joshi [1], Shailesh Ghildiyal [1]

[1] *Uttarakhand State Disaster Management Authority, Uttarakhand Secretariat, Dehtradun – 248 001, Uttarakhand, India*

ARTICLE INFO

ORIGINAL ARTICLE

Article history:
Received: 6 Feb 2021
Revised: 13 Jul 2021
Accepted: 28 Jul 2021

***Corresponding author:**
Rautela, Piyoosh

Address:
Uttarakhand State Disaster Management Authority, Uttarakhand Secretariat, Dehradun – 248 001, Uttarakhand, India

Email:
rautelapiyoosh@gmail.com

Tel:
+91-94120 54085

ABSTRACT

Seismic vulnerability assessment of nearly 67%, 60%, and 18% of buildings of the first responders (Fire and Emergency Service, Police, and local administration, respectively) in the Himalayan province of Uttarakhand in India suggests 14.12% collapse, and 67.19% damage, and put to disuse immediately after an earthquake. This is to seriously limit emergency response capability of the state, and enhance sufferings and trauma of the affected community. US$ 95.27 is estimated as the cost of seismic safety of emergency response infrastructure, and this is to save building contents worth US$ 10.00 million. Prioritised demolition and reconstruction of Grade 5 buildings, detailed vulnerability assessment and phased retrofitting of Grade 4 and Grade 3 buildings, effective and strict compliance of building bye-laws, stringent punitive measures for lapses in lifeline buildings, mechanism for routine vulnerability assessment, and corrective maintenance are recommended for ensuring smooth and uninterrupted functioning of the emergency response agencies in the aftermath of an earthquake.

Keywords: Uttarakhand; Himalaya; Rapid Visual Screening; Seismic Gap

Introduction

Prompt and effective response is universally accepted as the key to saving human lives, and minimising loss of property and infrastructure due to disaster incidences. Therefore, dedicated response units have been raised, trained, and equipped by both federal and provincial governments in India since the enactment of Disaster Management Act in 2005. However, deployment of these units is delayed due to the constraints of weather and accessibility. This is particularly so in the Himalayan region, where landslides as well as toe erosion often disrupt surface connectivity by fast flowing streams and rivers; while weather conditions make aerial operations difficult and risky (20, 21). In order to overcome this handicap some provinces of India, including Uttarakhand, have initiated schemes for training and capacity building of the volunteers at the grassroots level in search, rescue, and first aid. These volunteers together with state functionaries available in the proximity of the disaster site play an important role in search and rescue, as well as relief in the aftermath of a disaster incidence.

Having evolved from routine policing disaster response in India requires adherence to some medico-legal formalities in accordance with the guidelines of State/National Disaster Response Fund (15), particularly before providing relief to next of kin of those killed in the incidence. Local administration, Police, and Fire and Emergency

***This paper should be cited as*: Rautela P, Joshi GC, Ghildiyal S. Seismic Vulnerability of Primary Response Agencies in the Himalayan Province of Uttarakhand in India.** Journal of Disaster & Emergency Research. 2021; 4(2): 93-110.

Service are recognised as the first responders in case of both accident and disaster incidences and most state sponsored post-disaster rescue and relief operations are primarily carried out by them. After the initial response phase, these services also provide various sort of relief to the affected population in addition to maintaining law and order.

Disruption or reduced response capability of these services in the aftermath of a disaster can therefore severely cripple post-disaster search, rescue, and relief operations which in turn can result in a state of confusion amongst the masses. This will certainly enhance sufferings, trauma, and misery of the affected population many times over. Therefore, it becomes necessary to ensure smooth functioning of these services even at the face of the biggest likely hazard in the region.

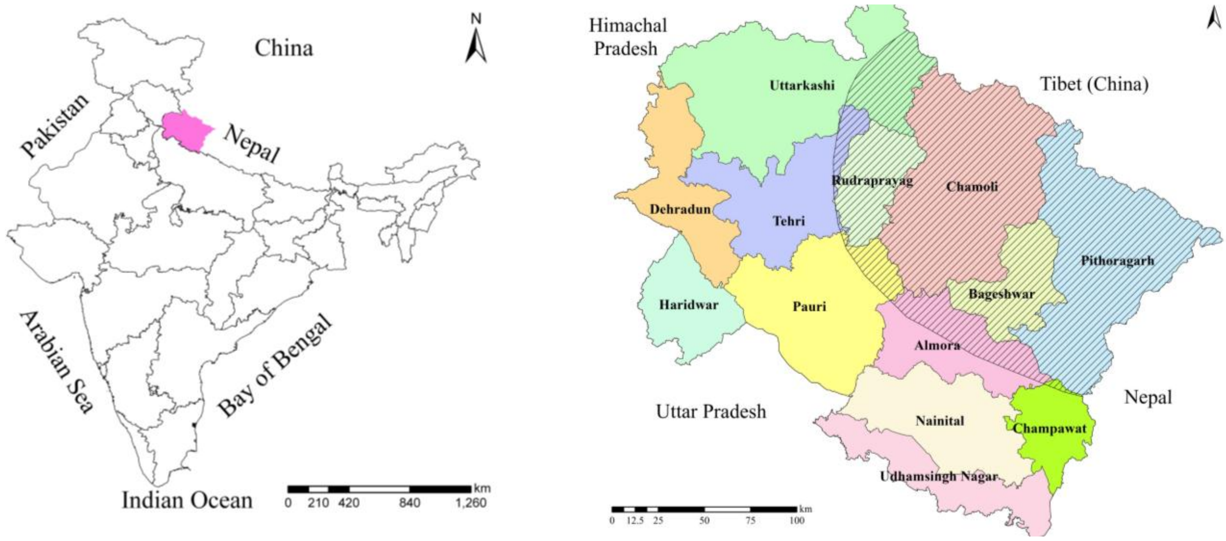

Figure 1. Location map of the study area. Hatched area in the map of the province (right) represents Zone V of earthquake zoning map of India while unhatched area represents Zone IV

Tectonic set up, and continuing tectonic movement make earthquake a major hazard for the Himalayan region, and particularly so for the province of Uttarakhand in India located in the central sector of the Himalayan orogen to the west of Nepal. Despite witnessing two moderate magnitude seismic events in the recent past; Mw~6.7 Uttarkashi Earthquake of October 20, 1991 and Mw~6.4 Chamoli Earthquake of March 29, 1999, Uttarakhand Himalaya is located in the seismic gap of Mw~7.8 Kangara Earthquake of April 4, 1905 and Mw~8.2 Bihar–Nepal Earthquake of January 15, 1934 and there has been no major seismic activity since Mw~7.5 Garhwal Earthquake of September 1, 1803. Falling in Zone IV and V of Earthquake zoning map of India (Fig. 1; IS1893 2002); therefore, Uttarakhand Himalaya is assessed as the likely location to host next devastating earthquake (Rajendran et al. 2015 7, 18). It is very important to review seismic safety of public infrastructure in the province, and undertake timely corrective measures to minimise the seismogenic losses.

Given the high vulnerability to multiple hazards, including landslide, flash flood, and earthquake, the provincial government has raised a well-equipped State Disaster Response Force (SDRF) in Uttarakhand. Moreover, given the large geographical area affected with likely severe disruption of connectivity and limited strength of SDRF, the primary response in the aftermath of a major earthquake should be made by locally available provincial government functionaries; local administration, Police, and Fire and Emergency Service, particularly in the initial phase of response. Moreover, specialised response forces are responsible for taking care of medico-legal formalities.

Poor seismic performance of buildings housing the first responders could cripple post-disaster response capability of the state. Vulnerability assessment of the response agencies could help in timely mitigation measures to ensure smooth functioning of these agencies. However, no attempt has been made to assess the vulnerability of these important service providers, and most seismic vulnerability related studies have covered small geographical areas with no focus on these services (21, 22, 23, 24 and 25). The previous studies at the same time do not provide structural details resulting in vulnerability of the built environment. This is the first study focusing on the vulnerability of response agencies, and covers a significant proportion of these cases over a large geographical area.

Around 67% Fire and Emergency Service stations, 60% Police stations, and 18% local administration buildings across the province have been covered by the present study to (i) assess their seismic vulnerability, (ii) prioritise the buildings for detailed assessment, demolition, reconstruction, and retrofitting, and (iii) estimate the cost of seismic safety.

In addition to informing policymakers of this important issue, this study aimed to help the relevant authorities in developing phased plan for improving seismic performance of the buildings housing emergency response agencies.

Methodology

Of the several vulnerability assessment and classification methodologies (8), Rapid Visual Screening (RVS) has been utilized for the present study. Fast, easy, and economic implementation are the advantages of RVS that is based on visual evaluation of buildings utilising predefined forms. RVS is performed without structural calculations, and uses a scoring system in which the evaluator has to identify the primary structural lateral load-resisting system of the surveyed building. It also modifies seismic performance expected for the identified system using building attributes. The screening is based on numerical seismic hazard and vulnerability scores that are probability functions compatible with sophisticated evaluation methodologies.

On the basis of identified building parameters, Basic Structural Hazard (BSH) score, and Performance Modification Factors (PMF) for the surveyed building are determined, and integrated subsequently to generate the final structural score (S). BSH, PMF, and S are related to the probability of the building sustaining major life-threatening damage.

For the purpose of the present study, RVS methodology proposed for the Indian context by Agarwal and Chourasia (2007) was used with some modifications in PMF scores. Based upon damage data of Mw~6.2 September 29, 1993 Killari, Mw~5.8 May 22, 1997 Jabalpur and Mw~7.6 January 26, 2001 Bhuj earthquakes Agrawal and Chourasia (2007) modified BSH scores of ATC-21 (1988) and ATC-21-1 (1988) of FEMA to suit the building stock in India, and assigned BSH score of 3.0 and 2.5 to reinforced concrete (RCC) frame buildings with unreinforced masonry infill walls and unreinforced masonry (URM) buildings respectively (1, 4, 5).

PMF is related to deviation from normal structural practice or conditions and Agrawal and Chourasia (2007) considered (i) number of stories, (ii) minimum gap between adjacent buildings, (iii) building site location, (iv) soil type, (v) irregularity in elevation, (vi) soft storey, (vii) vertical irregularity, and (viii) cladding for assigning PMF scores based on damage surveys undertaken after previous earthquakes (1).

Furthermore, the present study evaluated parameters, including (i) roofing material, (ii) parapet height, (iii) re-entrant corners, (iv) heavy mass at the top, (v) construction quality, (vi) building condition/maintenance, (vii) earthquake resistance measure adopted, and (viii) overhang length, to make the assessment better suited to the building stock in the region. The present study accordingly used PMF values of Joshi, et al (14).

The building stock

RVS of 1,856 buildings of the three identified emergency response agencies; local administration (85.45%), Police (12.93%), and Fire and

Emergency Service (1.62%), across the province of Uttarakhand (Fig. 2) was undertaken using a form prepared in android platform by Open Data Kit (ODK) framework. A team of 28 field engineers was trained and deployed for data collection.

Building typology: 24.68% of the surveyed buildings were observed to be RCC while the rest (75.32%) were masonry buildings (Table 1).

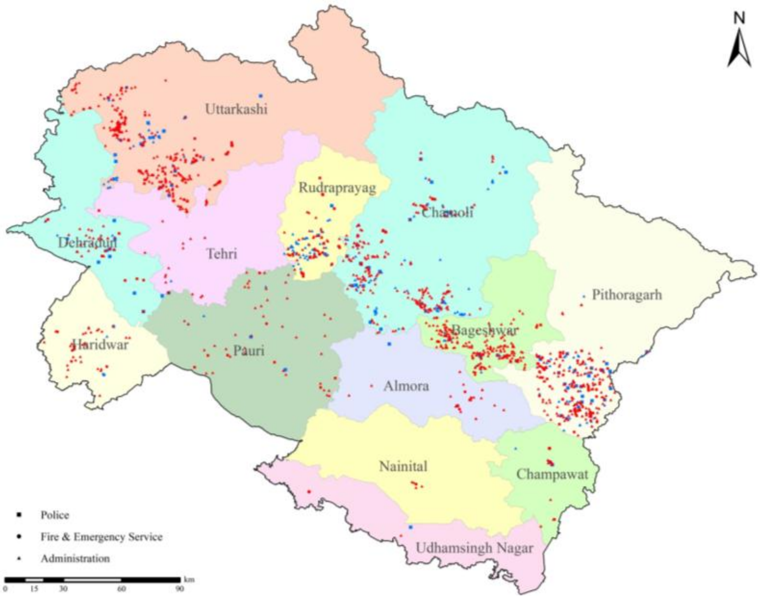

Figure 2. Spatial distribution of the surveyed buildings of local administration, Police and Fire, and Emergency Service (Masonry buildings are depicted in red and RCC buildings in blue)

Table 1. District wise details of the surveyed buildings of emergency response agencies in the province

Sl. No.	District	Masonry		RCC		Total
		Number	%	Number	%	
1.	Almora	60	86.96	9	13.04	69
2.	Bageshwar	202	88.60	26	11.40	228
3.	Chamoli	312	71.40	125	28.60	437
4.	Champawat	28	70.00	12	30.00	40
5.	Dehradun	45	67.16	22	32.84	67
6.	Haridwar	46	86.79	7	13.21	53
7.	Nainital	7	77.78	2	22.22	9
8.	Pauri Garhwal	57	78.08	16	21.92	73
9.	Pithoragarh	281	74.14	98	25.86	379
10.	Rudraprayag	86	53.42	75	46.58	161
11.	Tehri Garhwal	24	80.00	6	20.00	30
12.	Udhamsingh Nagar	6	66.67	3	33.33	9
13.	Uttarkashi	244	81.06	57	18.94	301
Total		1,398	75.32	458	24.68	1,856

Fig 3 reveals that 56.67%, 66.25%, and 77.05% of the surveyed buildings (Fire and Emergency Service, Police, and local administration, respectively) were masonry buildings.

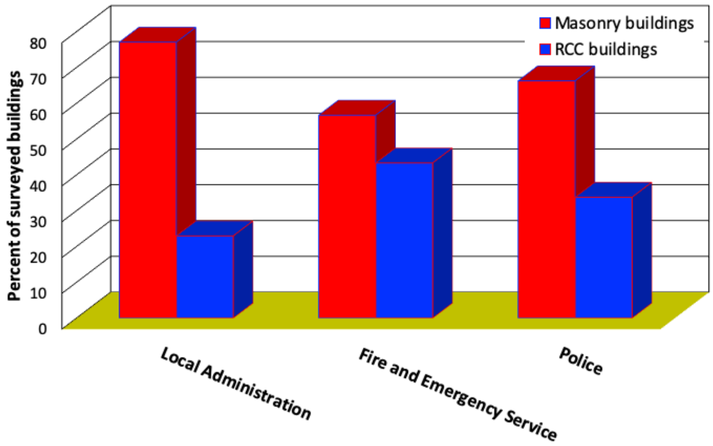

Figure 3. Surveyed building types of local administration, Police, and Fire and Emergency Service

Building height: Most of the surveyed buildings were low-rise; 49.34% of RCC and 62.95% of masonry buildings were single-story (Fig. 4); while 49.34% of RCC and 36.91% of masonry buildings were double-story (Fig. 5). Only 02 of masonry and 06 of RCC buildings were triple-story.

Figure 4. Single-story Police Station building at Harsil in Uttarkashi district built on stilts

Figure 5. Double-story RCC Block Development Office building at Joshimath (Chamoli district)

Of the surveyed buildings 58.39% of local administration, 66.25% of Police, and 70% of Fire and Emergency Service were single-story; while 23.23%, 33.75%, and 41.25% (respectively, Fire and Emergency Service, Police, and local administration) were double-story (Fig. 6).

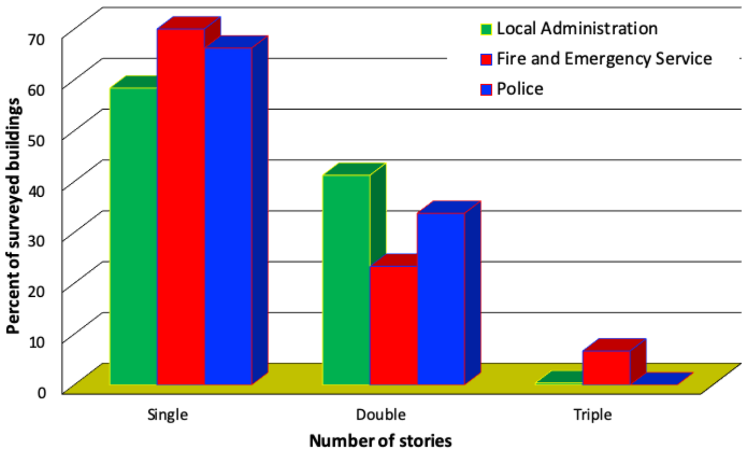

Figure 6. Surveyed building types of local administration, Police, and Fire and Emergency Service

Age of buildings: The surveyed buildings were classified according to changes in building codes in India, and 2.86% of buildings were constructed before 1962, i.e. the time of introduction of seismic code in India. They accounted for 2.78%, 3.33%, and 3.35% of the surveyed buildings (respectively, local administration, Fire and Emergency Service, and Police) (Fig. 7).

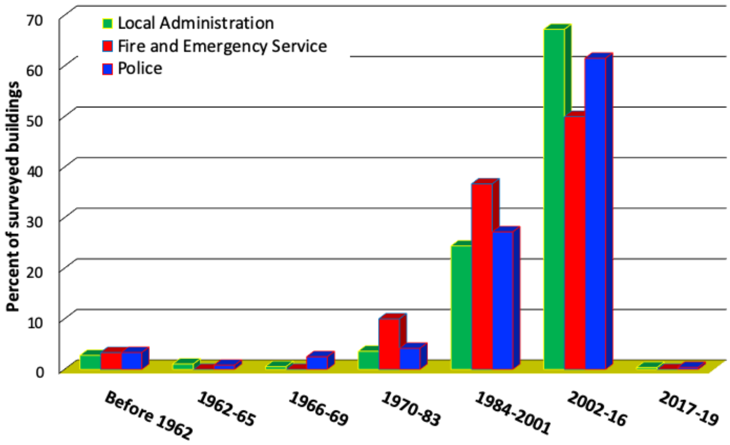

Figure 7. Time of construction of the surveyed buildings of emergency response agencies

Most buildings (66.20%) comprising 86.65% of RCC and 59.51% of masonry were constructed between 2002 and 2016. Moreover, 24.96% of the buildings comprising 11.60% of RCC and 29.33% of masonry buildings were constructed between 1984 and 2001. Large proportion of buildings of all the three departments; 50.00% of Fire and Emergency Service, 61.51% of Police, and 67.21% of local administration were constructed between 2002 and 2016 (Fig. 7).

Roofing material: Roofs of 90.83% of buildings comprising 99.34% of RCC and 88.05% of masonry buildings were RCC slab (Figs. 4 and 5) while majority of the remaining (0.66% RCC and 11.52% masonry) were Corrugated galvanised iron (CGI) sheets. Only a few buildings had tiles, wooden, and asbestos sheets as roofing material.

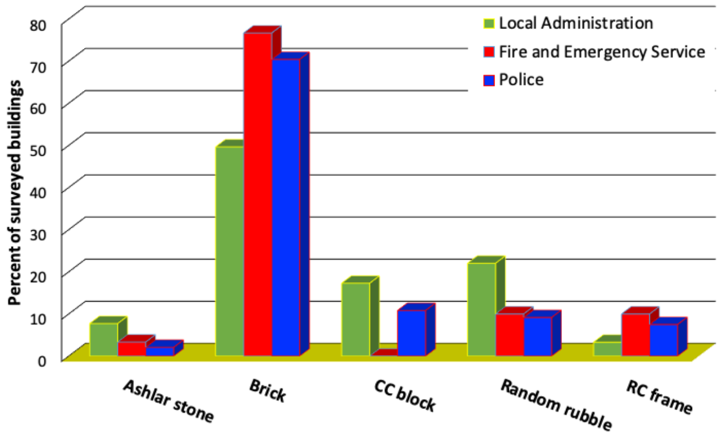

Figure 8. Walling material observed in the surveyed buildings of emergency response agencies

Walling material: Walls of the surveyed buildings were built using dressed stone (Ashlar stone), brick, and CC block, also random rubble while cement, lime surkhi, and mud were utilised as mortar (Table 2). Stones used in random rubble masonry walls were either undressed or roughly dressed while the ones used in Ashlar masonry were finely dressed with courses of uniform height, and all joints were regular, thin, and uniform in thickness.

Of the surveyed buildings 9.17% of Police, 10.00% of Fire and Emergency Service, and 22.04% of local administration were built using random rubble masonry; while 2.08, 3.33, and 7.72%, respectively, of Police, Fire and Emergency Service, and local administration were constructed using Ashlar masonry.

Despite stone, and wood being traditional building materials of the region (18, 24), majority of the surveyed buildings (52.79%) had brick masonry walls in cement mortar. Even non-load bearing walls of RCC buildings were built using bricks. Moreover, 68.96% of the surveyed buildings were observed to be built using brick and CC block (Fig. 8).

However, 19.30%, 15.94%, 13.79%, 11.20%, and 10.45% of the surveyed buildings of Bageshwar, Almora, Tehri Garhwal, Pithoragarh, and Pauri Garhwal districts were built with Ashlar stone; and 37.53%, 30.43%, 19.93%, and 19.88% of buildings of Chamoli, Almora, Uttarkashi, and Rudraprayag districts were built with random rubble.

Table 2. District wise details of walling material (in %) of the surveyed buildings of emergency response agencies in the province of Uttarakhand

Sl. No.	District	Ashlar stone		Brick masonry		CC Block	Random rubble			RC frame building
		In cement mortar	In lime surkhi	In cement mortar	In mud mortar		In cement mortar	In lime surkhi	In mud mortar	
1.	Almora	1.45	14.49	53.62	0.00	0.00	11.59	0.00	18.84	0.00
2.	Bageshwar	17.54	1.75	64.04	0.44	3.07	9.65	0.00	3.07	0.44
3.	Chamoli	0.23	0.00	40.50	0.00	21.05	16.48	0.00	21.05	0.69
4.	Champawat	0.00	0.00	95.45	0.00	4.55	0.00	0.00	0.00	0.00
5.	Dehradun	0.00	0.00	97.01	0.00	0.00	1.49	1.49	0.00	0.00
6.	Haridwar	0.00	0.00	79.25	18.87	0.00	0.00	1.89	0.00	0.00
7.	Nainital	0.00	0.00	88.89	0.00	0.00	11.11	0.00	0.00	0.00
8.	Pauri Garhwal	2.99	7.46	73.13	0.00	1.49	7.46	0.00	4.48	2.99
9.	Pithoragarh	10.67	0.53	37.87	0.27	20.27	4.53	0.53	8.80	16.53
10.	Rudraprayag	0.00	0.00	45.34	0.00	34.78	3.11	0.00	16.77	0.00
11.	Tehri Garhwal	13.79	0.00	72.41	0.00	3.45	6.90	0.00	3.45	0.00
12.	Udhamsingh Nagar	0.00	0.00	55.56	0.00	0.00	0.00	0.00	0.00	44.44
13.	Uttarkashi	6.31	0.00	52.16	0.00	21.26	8.64	0.00	11.30	0.33
Total		5.79	1.14	52.14	0.65	16.17	8.60	0.22	11.36	3.95

Most building materials (brick, cement, iron bars, and sand) are transported from the plains using locally available stones for construction, particularly in remote hill districts, thus it can be interpreted as an effort to save the transportation cost.

Foundation type: Most of the surveyed buildings (71.30%) had stripped foundation that accounted for 81.68% of masonry and 39.29% of RCC buildings. Moreover, 26.32% buildings; 17.47% masonry and 53.64% RCC, had isolated column foundation; while 0.27% and 2.11%, respectively, had raft and combined foundation.

Of the surveyed buildings, 23.99%, 33.33% and 40.83% (respectively, local administration, Fire and Emergency Service, and Police) had isolated column foundation; while 73.61%, 53.33%, and 58.33%, respectively, had stripped foundation.

Foundation material: Stone is economically and abundantly available in the hills; therefore, foundation of most buildings (82.16%) were built using stone that accounted for 54.08% RCC and 91.27% masonry buildings. RCC foundation accounted for 9.46% that includes 38.63% RCC buildings. Brick (4.22%) and cement concrete (4.16%) were other foundation materials used in the surveyed buildings (Fig. 9).

Foundation of 50.00%, 68.75%, and 84.81%, respectively, of the surveyed buildings of Fire and Emergency Service, Police, and local administration were built using stones; while 16.67%, 7.08%, and 3.35% were respectively built using bricks (Fig. 9).

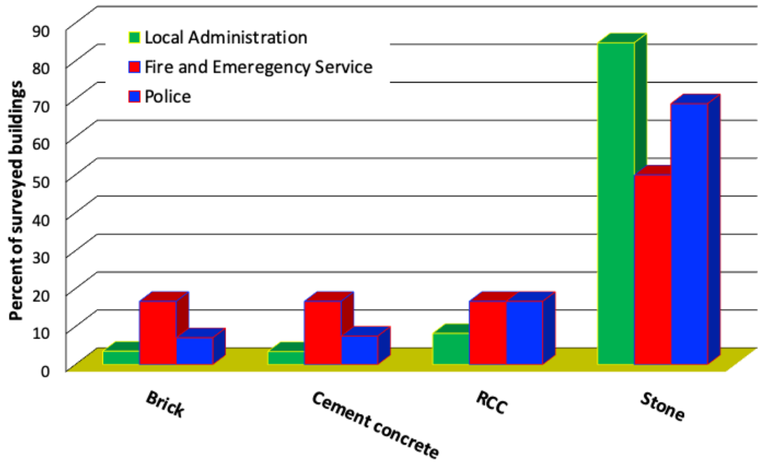

Figure 9. Foundation materials of the surveyed buildings

Building location: Location of the structure affects the amplification of the ground motion during seismic shaking. For the purpose of present study, building location was categorised, including (i) plain where the ground slope is less than 5 degree, (ii) hill top or crest, (iii) mild slope, (iv) high slope of hill where the location is at the narrow depression between two downward sloping hills, and (v) river bed.

The reviews showed that 42.63% of the buildings (44.56% masonry and 37.57% RCC) were located in mid slope; while 20.23% and 32.95% were, respectively, located in plain area and high slope of hill.

Furthermore, 28.30%, 40.00% and 45.55% of the surveyed buildings (respectively, Police, Fire and Emergency Service, and local administration) were located in mid slope; while 40.57%, 46.67%, and 15.65%, respectively, were located in plain area.

Soil type: Soil is the ultimate load carrying element, and its nature can either intensify or abate seismic vulnerability of a structure as the density of soil has a direct bearing on the amount of ground motion during an earthquake. Six soil types were identified for the purpose of the present study; (i) rock/hard soil, (ii) soft soil, (iii) reclaimed/filled land, (iv) partially filled land, (v) loose sand, and (vi) medium soil.

Most masonry buildings (82.95%) were constructed over medium soil while 1.65% were over soft soil, 3.94% over partially filled land, and 10.32% over rock/hard soil. Of the RCC buildings 1.99% was constructed on soft soil, 3.31% on partially filled land, 5.08% on rock/hard soil, and 87.86% on medium soil. Only 0.49% and 0.81% of the buildings were located over loose sand and reclaimed land, respectively.

Of the surveyed buildings 82.92%, 84.17%, and 93.33% of Police, local administration, and Fire and Emergency Service were constructed over medium soil, respectively; while 9.17%, 9.06%, and 6.67% were constructed over rock/hard soil, respectively.

Ground slope: Codal provisions in India (IS 1904, 1986) recommend footing to be placed adjacent to a sloping ground when base of the footing is at different levels. To avoid damage to an existing structure, the code recommends (i) footing at a minimum distance S from the edge of the existing footing, where S is the width of larger footing and (ii) the line from the edge of the new footing to the edge of the existing footing makes an angel of less than 45^{o}. Moreover, 2.57% masonry and 4.36% RCC buildings were respectively built over ground having slope more than 45^{o}.

Table 3. Attributes used for assessing the quality of construction of the surveyed buildings

Type of construction	Quality High	Quality Medium	Quality Low
Masonry	Workmanship is visually judged as high quality. Openings in the wall less than half the distance between adjacent cross walls. Absence of mortar cracks. 1. Efflorescence nil or slight.	Workmanship is visually judged as medium quality. 1. Openings in the wall equal to half the distance between adjacent cross walls. 2. Few mortar cracks. 3. Efflorescence moderate.	Workmanship is visually judged visually as low quality. Openings in the wall more than half the distance between adjacent cross walls. Prevalence of mortar cracks. Efflorescence heavy or serious.
RCC	Uniform sized and shaped columns and beams without any structural defect or damage. 1. Uniform non-segregated concrete with smooth finishing.	Minor non-structural cracks in columns and beams. 1. No tilting of building elements.	Structural cracks in columns and beams. Non-uniform building elements. 1. Honeycombing in concrete.

Quality of construction: Attributes summarised in Table 3 were utilised for the purpose of the present study to assess the quality of construction of the surveyed hospital buildings on a 3-point scale (high, medium, and low) (25).

The results showed that 50.89% and 48.68% of the masonry buildings showed medium and low construction quality; while amongst the RCC buildings 7.89% depicted high quality of construction. Large proportion of the buildings of all the three departments depicted medium quality of construction. Only 2.08%, 3.33%, and 3.35% of the local administration, Fire and Emergency Service, and Police exhibited high quality of construction, respectively. While majority of buildings; 53.16%, 70.00%, and 73.22% of these buildings, respectively, depicted medium quality of construction (Fig. 10).

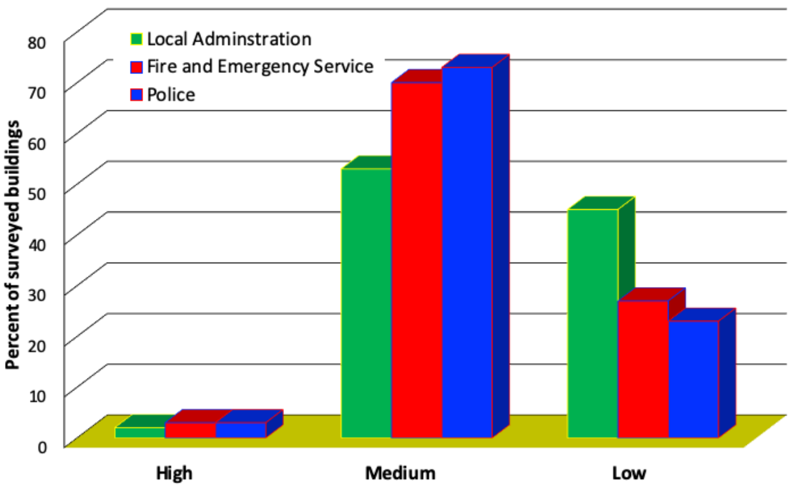

Figure 10. Construction quality of the surveyed buildings

Building condition: Lack of maintenance, faulty design, poor quality of construction, corrosion of reinforcement, settlement of foundation, and extreme loading were the main causes of vulnerability in the surveyed buildings, which were observed as cracks in the building elements.

Condition of the surveyed buildings was assessed on a 4 point scale (excellent, good, damaged and distressed), in which the condition of masonry buildings was particularly vulnerable; 33.92% were damaged, and 31.44% were distressed. Only 16.11% and 16.78% of RCC buildings were damaged and distressed, respectively (Fig. 11).

Of the surveyed buildings only 1.87% and 3.33% of local administration and Police buildings were in excellent condition, respectively; while 37.52%, 50.00%, and 60.00% of local administration, Fire and Emergency Service and Police were in good condition, respectively and 30.82%, 23.33%, and 21.67% of these departments were in damaged condition, respectively (Fig. 11).

Cracks in the wall or roof resulted in the corrosion of reinforced steel bars due to their exposure to rainwater, moisture, and air; while corroded reinforcement in columns, and beams resulted in vertical and horizontal cracks in these elements. The surveyed buildings had problems relating to seepage of water caused largely by defects in water supply line, sanitary fitments, and drainage pipes. In some cases seepage of water was through roof and exterior walls resulting in dampening of the concrete that could threaten structural safety of the buildings.

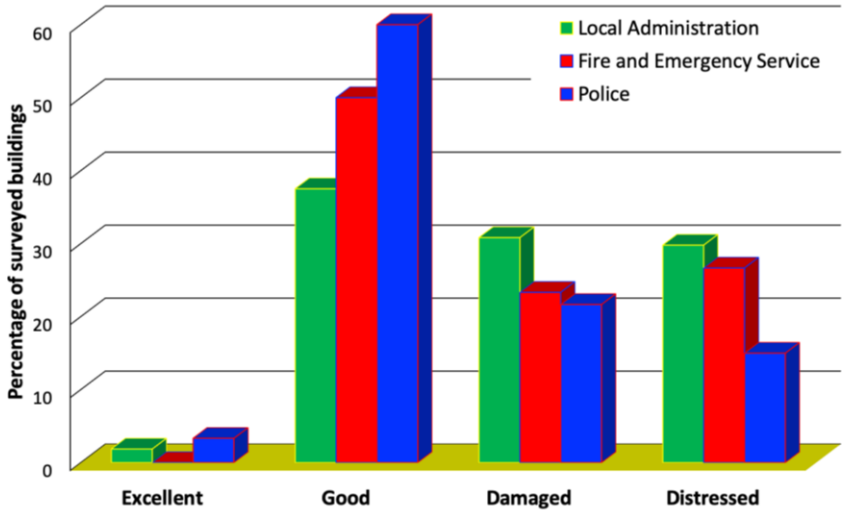

Figure 11. Building condition of the surveyed buildings

Irregularities: Buildings are sometimes designed irregular due to architectural, functional, and economic considerations. However, it has adverse impact on their seismic performance due to concentration of demand in certain structural elements from where cracks initiate and make the structure vulnerable.

Most surveyed buildings were free of vertical irregularities, but 20.77% had irregularity in shape. Building irregularities are classified as L, T, and Reverse-T type. L-type irregularities were observed in 22.21% of masonry and 12.47% of RCC buildings. Only 0.92% and 0.05% of the surveyed buildings had Reverse-T and T-type irregularity.

Of the surveyed buildings 6.09%, 16.67%, and 21.84% of Police, Fire and Emergency Service, and local administration had L-shaped irregularity, respectively; while 6.09%, 83.33%, and 77.21% of these buildings were regular, respectively.

Pounding: Based on the codal provisions on pounding in India, it is recommended to separate adjacent buildings by a distance which is equal to the amount response reduction factor (R) times the sum of calculated story displacements, so as to avoid damage to the structures when they deflect towards each other during seismic shaking (IS 1893, 2002). When two buildings are at the same elevation level, the factor R may be replaced by R/2. Safe separation distance or gap as recommended by the code between two buildings is 15, 20, and 30 mm for masonry, RCC frame, and steel structure, respectively. Moreover, 25.76% and 31.61% of the surveyed RCC and masonry buildings were vulnerable to pounding, respectively.

Overhang length: Overhangs are generally provided to shade the open spaces from undesired solar radiation to protect exterior walls, doors, and windows from rainwater while keeping the foundation dry. Building bye-laws permit 1.5 meter wide balcony at roof slab level with area not exceeding 3.5 sq m per bedroom but not exceeding 3 in a flat. In the surveyed buildings vulnerability relating to overhang length was insignificant. Only the non-structural elements like parapet wall were vulnerable and this vulnerability was universal for all the surveyed buildings.

Engineering input: Engineered buildings are the ones designed, and constructed according to desired codes while non-engineered buildings are spontaneously, and informally constructed without any engineering input (3). In the present study, 89.06% of buildings were non-engineered, and most of them were masonry buildings. Only 6.15% of masonry and 40.17% of RCC buildings engineered.

Heavy mass at the top: The presence of heavy mass on the rooftop increases the seismic forces in the members of a building and thus increases vulnerability of the building. In the surveyed buildings water tanks on the rooftop accounted for this vulnerability.

Seismic vulnerability of the emergency response infrastructure

For assessing vulnerability of the surveyed buildings, scores assigned to various surveyed constituents (BSH and PMF) were integrated, and the buildings were classified into five damageability grades based on the final structural score (S); ≤ 0.80 = Grade 5, 0.81-1.60 = Grade 4, 1.61-1.80 = Grade 3, 1.81-2.00 = Grade 2 and > 2.00 = Grade 1 (Fig. 12).

The province of Uttarakhand is located in Zone IV and V of Earthquake zoning map of India (Fig. 1) and the assessed damage grades depict earthquake intensity expected in these zones; VIII or more on MSK Scale (IS 1893, 2002).

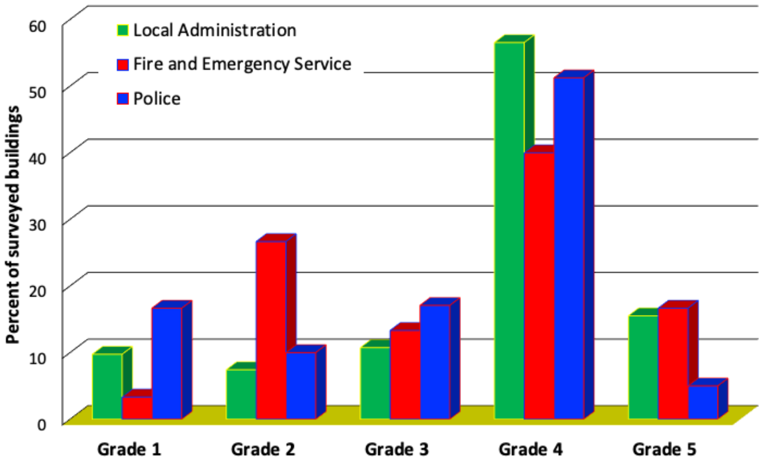

Figure 12. Damageability of the surveyed buildings

The damage likely to be incurred to the buildings falling in different damageability grades (Table 4) is related to the expected intensity of earthquake in the area, as provided by European Macroseismic Scale, EMS-98 (12).

Grade 1 and Grade 2 denote no and slight structural damage and therefore buildings falling under these values are considered safe in an earthquake event. Only 16.68% of the surveyed buildings (accounted for 17.19%, 26.67%, and 30.00% of local administration, Police, and Fire and Emergency Service, respectively) fall in Grade 1 and Grade 2. Large proportion of the masonry buildings (83.32%) accounted for 78.62%, 82.35%, and 88.68% of masonry buildings (Police, Fire and Emergency Service, and local administration respectively) were likely to sustain major damage in a seismic event.

Table 4. Damage likely to be incurred to the buildings falling in different damageability grade in a likely earthquake event (Grunthal, 1998)

Damageability Grade	Masonry	RCC
	Negligible to slight damage (No structural damage, slight non-structural damage)	
Grade 1	Hair-line cracks in very few walls	Fine cracks in plaster over frame members or in walls at the base
	Fall of small pieces of plaster only	Fine cracks in partitions and infills
	Fall of loose stones from upper parts of buildings in few cases	
	Moderate damage (Slight structural damage, moderate non-structural damage)	
Grade 2	Cracks in many walls	Cracks in column and beam of frames and in structural walls
	Fall of fairly large pieced of plaster	Cracks in partition and infill walls; fall of brittle cladding and plaster
	Partial collapse of chimneys	Falling mortar from the joints of wall panels
	Substantial to heavy damage (Moderate structural damage, heavy non-structural damage)	
Grade 3	Large and extensive cracks in most walls	Cracks in column and beam column joints of frame at the bases and at the joints of coupled walls
	Roof tiles detach	
	Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls)	Spalling of concrete cover, buckling of reinforced rods
		Large cracks in partition and infill walls, failure of individual infill panels
	Very heavy damage (Heavy structural damage, very heavy non-structural damage)	
Grade 4	Serious failure of walls; partial structural failure of roof and floors	Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bar; tilting columns
		Collapse of a few columns or of a single upper floor
	Destruction (Very heavy structural damage)	
Grade 5	Total or near total collapse	Collapse of ground floor or parts (e.g. wings) of buildings

Table 5. District wise distribution (in %) of the surveyed masonry buildings on the basis of damageability

Sl. No.	District	Surveyed buildings	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
1.	Almora	60	6.67	11.67	8.33	60.00	13.33
2.	Bageshwar	202	3.47	5.45	9.90	63.86	17.33
3.	Chamoli	312	6.41	4.17	10.58	61.54	17.31
4.	Champawat	28	7.14	10.71	10.71	60.71	10.71
5.	Dehradun	45	13.33	15.56	15.56	53.33	2.22
6.	Haridwar	46	2.17	15.22	6.52	65.22	10.87
7.	Nainital	7	14.29	42.86	14.29	28.57	0.00
8.	Pauri Garhwal	57	20.00	30.00	40.00	10.00	0.00
9.	Pithoragarh	281	9.41	7.84	9.02	61.18	12.55
10.	Rudraprayag	86	12.79	8.14	19.77	48.84	10.47
11.	Tehri Garhwal	24	13.04	13.04	8.70	56.52	8.70
12.	Udhamsingh Nagar	6	0.00	0.00	16.67	83.33	0.00
13.	Uttarkashi	244	0.82	0.00	3.28	63.52	32.38
	Total	1398	6.27	6.34	9.59	60.57	17.22

Table 5 reveals that 9.59%, 60.57%, and 17.22% of the masonry buildings, respectively, fall in Grade 3, Garde 4, and Grade 5 and were likely to be damaged during the seismic event. The vulnerability of the masonry buildings was particularly high in Uttarkashi district where 32.38% fall in Grade 5 while 63.52% fall in Grade 4 (Fig. 13).

In this study, 81.67%, 82.14%, 82.61%, 82.75%, 89.42%, 91.09%, 99.18%, and 100.00% of the surveyed masonry in Almora, Champawat, Haridwar, Pithoragarh, Chamoli, Bageshwar, Uttarkashi and Udhamsingh Nagar districts fall in Grade 5, Grade 4, and Grade 3, respectively; therefore, masonry buildings in these districts require an immediate intervention.

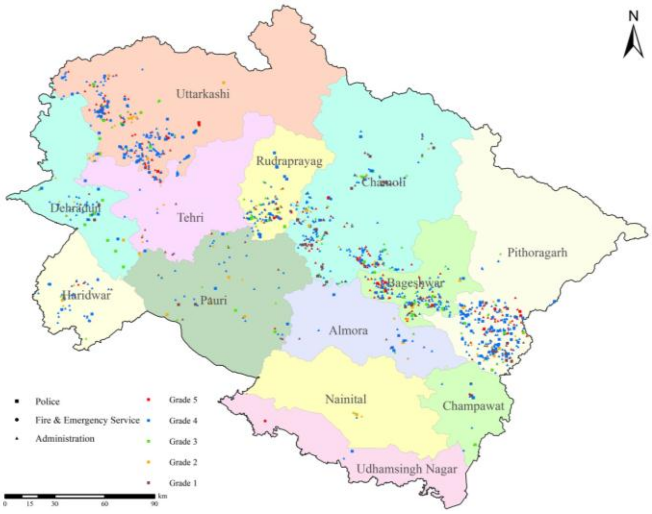

Figure 13. Spatial distribution of surveyed buildings with different damageability grade

When 36.43% of the surveyed buildings fall in Grade 1 and Grade 2, the state of RCC buildings is relatively better but not satisfactory; 63.57% of the RCC buildings are unsafe (Table 6).

Moreover, 17.66%, 40.84%, and 5.08% of the surveyed RCC buildings fall in Grade 3, Grade 4, and Grade 5, respectively, indicating damages of various degree during a seismic event. Of the surveyed RCC buildings 53.85%, 62.96%, and 64.07% of Fire and Emergency Service, Police, and local administration were thus likely to be damaged during an earthquake event, respectively.

Table 6. District wise distribution (in %) of the surveyed RCC buildings on the basis of damageability

Sl. No.	District	Surveyed buildings	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
1.	Almora	9	33.33	0.00	11.11	44.44	11.11
2.	Bageshwar	26	23.08	15.38	23.08	23.08	15.38
3.	Chamoli	125	42.40	16.80	11.20	28.00	1.60
4.	Champawat	12	18.75	0.00	18.75	62.50	0.00
5.	Dehradun	22	22.73	22.73	22.73	27.27	4.55
6.	Haridwar	7	0.00	0.00	0.00	85.71	14.29
7.	Nainital	2	0.00	50.00	0.00	50.00	0.00
8.	Pauri Garhwal	16	9.09	18.18	36.36	36.36	0.00
9.	Pithoragarh	98	17.02	4.26	15.96	56.38	6.38
10.	Rudraprayag	75	12.00	10.67	13.33	53.33	10.67
11.	Tehri Garhwal	6	16.67	16.67	0.00	66.67	0.00
12.	Udhamsingh Nagar	3	33.33	0.00	0.00	66.67	0.00
13.	Uttarkashi	57	12.28	24.56	38.60	24.56	0.00
	Total	458	23.18	13.25	17.66	40.84	5.08

The vulnerability of RCC buildings of the emergency response agencies was particularly high in Rudraprayag, Almora, Haridwar, and Bageshwar districts where 10.67, 11.11%, 14.29%, and 15.38% of the buildings fall in Grade 5; while 53.33%, 44.44%, 85.71%, and 23.08% fall in Grade 4, respectively. Particular attention is thus required to be paid on these districts.

Of all the surveyed buildings 14.12% falling in Grade 5 were likely to collapse during an earthquake event. Moreover, 5.00%, 15.53%, and 16.67% of the surveyed buildings of Police, local administration, and Fire and Emergency Service fall in Grade 5, respectively; while 51.25%, 56.54%, and 40.00% fall in Grade 4 (Table 7).

The buildings in Grade 5 have to either sustain heavy structural damage or collapse; while those in Grade 4 and Grade 3 have to sustain major structural and non-structural damages to render these incapable of delivering routine services immediately after an earthquake.

The earthquake induced damage is thus to decapacitate responders, resulting in the loss of search and rescue equipment required after the earthquake event for saving human lives. The study thus suggests that 81.31% of the emergency response facilities are likely to become non-functional in an earthquake event, which is a serious issue warranting immediate corrective action.

Table 7. Damageability of the surveyed buildings of the emergency response agencies

Sl. No.	Damageability	Response agency			Total
		Administration	Fire and Emergency Service	Police	
1.	Grade 1	9.75	3.33	16.67	10.58
2.	Grade 2	7.43	26.67	10.00	8.10
3.	Grade 3	10.75	13.33	17.08	11.65
4.	Grade 4	56.54	40.00	51.25	55.54
5.	Grade 5	15.53	16.67	5.00	14.12

Cost of seismic safety

Only earthquake induced direct economic loss is considered in the present study and it is assumed to be the value of collapsed buildings and contents therein (Grade 5) together with cost of repair and restoration of damaged buildings (Grade 4 and Grade 3).

Researchers have assessed the cost of retrofitting and reconstruction of the surveyed buildings using different approaches. Nasrazdani and others (2017) have estimated the retrofitting cost based on 167 school retrofits in Iran using Bayesian linear regression technique. Age of the building and the retrofit ratio are concluded as dominant parameters by Arikan et al. (2005) after assessing reconstruction and retrofitting alternatives and comparing them economically using life cycle cost analysis approach (17, 2). Bhakuni (2005) utilised visual assessment tool to determine structural performance modification factors that help assess the vulnerability of school buildings and provide a basis for necessary mitigation actions (6). Mora et al. (2015) have assessed seismic resilience requirements based on seismic demand associated to specific return periods. Ferreira and Proenca (2008) assessed seismic safety requirements of public educational buildings in Bucharest after studying building structure, pre-existing damage, non-structural hazards and their aggravating factors and thereby simulating building vulnerability and earthquake risk expressed in terms of the Mean Damage Grade – varying from slight (1) to total collapse (5) (11). The present study also categorises buildings into five damage grades like Ferreira and Proenca (2008) based on different observed parameters (11).

The cost of improving seismic performance of buildings in Grade 5 was high; therefore, it is recommended to demolish and reconstruct them. Retrofitting of the buildings in Grade 4 and Grade 3 is recommended as this can be done with an average investment of around 20% of their replacement value (10).

The losses were estimated in terms of reconstruction cost of the collapsed or damaged building of similar dimension calculated using prevailing schedule of rates of Public Works Department (PWD) of the provincial government; Rs. 19,418 per sq m for masonry and Rs. 23,810 per sq m for RCC buildings. Prevalent conversion rate was used to assess the reconstruction/ retrofitting cost (1 US$ = Rs. 70) (16).

The value of contents likely to be lost in collapsed buildings (Grade 5) was estimated 25% of the reconstruction cost; while the cost of repair and restoration of damaged buildings (Grade 4 and Grade 3) was estimated equal to the cost of retrofitting, i.e. 20% of the cost of reconstruction (10). The covered area of individual buildings, calculated on the basis of the data collected during the field survey, was utilised for assessing these losses (Table 8).

Direct economic loss to the surveyed emergency response facilities was estimated US$ 21.64 million. It was estimated that masonry emergency response buildings cost US$ 6.97 million would collapse; while repair of the damaged masonry buildings would cost US$ 6.03 million. The value of collapsed RCC buildings was estimated US$ 0.78; while the cost of repair of damaged RCC buildings was estimated US$ 5.93 million. The value of contents likely to be lost in collapsed buildings was estimated US$ 1.94 (Table 8).

An investment of US$ 19.70 million was estimated for ensuring seismic resilience in the surveyed emergency response buildings. The proposed demolition, reconstruction, and retrofitting programs were to save US$ 1.94 million that would otherwise be lost by an earthquake in Grade 5 buildings.

Table 8. Economic loss likely to be incurred to the surveyed infrastructure of emergency response agencies

Sl. No.	Head	Building type			
		Grade 5		Grade 4 and Grade 3	
		Masonry	RCC	Masonry	RCC
1.	**Covered area** (in sq m)				
1.1	Administration	23,402	1,423	84,594	65,075
1.2	Fire and Emergency Service	470	0	493	8,889
1.3	Police	1,271	883	23,545	13,139
2.	**Reconstruction cost** (in million US$) RCC @ Rs. 23,810 / sq m Masonry @ Rs. 19,418 / sq m				
2.1	Administration	6.49	0.48	23.47	22.13
2.2	Fire and Emergency Service	0.13	0	0.14	3.02
2.3	Police	0.35	0.30	6.53	4.47
2.4	Total	6.97	0.78	30.14	29.62
3.	**Repair / restoration cost** (in million US$) 20% of reconstruction cost				
3.1	Administration	-	-	4.69	4.43
3.2	Fire and Emergency Service	-	-	0.03	0.6
3.3	Police	-	-	1.31	0.89
3.4	Total	-	-	6.03	5.92
4.	**Content loss** (in million US$) 25% of reconstruction cost			-	-
4.1	Administration	1.62	0.12	-	-
4.2	Fire and Emergency Service	0.03	0.00	-	-
4.3	Police	0.09	0.08	-	-
4.4	Total	1.74	0.20	-	-
5.	**Total loss** (in million US$) Reconstruction of G5 + Content lost in G5 + Restoration of G4 and G3				
5.1	Administration	8.11	0.60	4.69	4.43
5.2	Fire and Emergency Service	0.16	0.00	0.03	0.6
5.3	Police	0.44	0.38	1.31	0.89
5.4	Total	8.71	0.98	6.03	5.92

Estimates suggest that the surveyed buildings constitute around 67%, 60%, and 18% of the Fire and Emergency Service stations, Police stations, and local administration buildings, respectively, in the province. US$ 0.76, 2.85, and 16.09 million were the assessed cost of reconstruction and retrofitting of the surveyed Fire and Emergency Service, Police, and local administration buildings, respectively. The investment required for ensuring seismic safety of the entire infrastructure of these services in the province was estimated US$ 1.13, 4.75, and 89.39 million, respectively. This investment of US$ 95.27 would in turn ensure safety of building contents worth US$ 0.05, 0.27, and 9.68 million in the buildings of these agencies, respectively; net saving of US$ 10.00 million. The investment on seismic safety resulted in savings to the tune of 10.50%.

Conclusion

The study suggested that around 14.12% of the surveyed buildings of the provincial government response agencies (accounted for 16.67% of Fire and Emergency Service, 15.53% of local administration, and 5.00% of Police) were likely to collapse in an earthquake incidence; while 67.19% were likely to be damaged. The magnitude of the estimated loss can totally disrupt post-earthquake search, rescue, and relief operations. Collapse of these buildings might at the same time jeopardize life, and safety of the responders besides damaging critical search and rescue equipment.

In view of the escalated hardships and misery of the affected population, it is recommended that the buildings in Grade 5 be demolished, and reconstructed. In view of particularly high vulnerability of masonry buildings in Uttarkashi district, and RCC buildings in Bageshwar, Haridwar, Almora, and Rudraprayag districts, it is recommended that these districts be accorded high priority while implementing corrective measures.

Large proportion of the response infrastructure was observed to be housed in Grade 4 and Grade 3 buildings that are likely to be damaged in an earthquake event. In view of its adverse impact on post-disaster operations, it is recommended that the buildings in Grade 4 and Grade 3 be examined using advanced vulnerability assessment techniques, and accordingly be retrofitted.

Reconstruction and retrofitting measures for the surveyed building of the emergency response agencies were estimated to cost the public exchequer US$ 21.64 million. Rather than just the surveyed buildings, it is recommended to ensure seismic safety of the entire emergency response infrastructure in the province that was estimated to cost around US$ 95.27 million and save building contents worth US$ 10.00 million. This could be taken up in a phased manner over 5 years, and managing funds to the tune of US$ 15 – 20 million annually should not be a major issue for the state.

Despite being constructed by engineering departments of the provincial government having qualified, trained, and experienced engineers, 93.85% masonry and 59.83% RCC buildings were non-engineered, which is a major cause of concern. This assertion was however corroborated by other findings of the study that includes 48.68% masonry, and 20.39% RCC buildings, depicting low quality of construction, irregularities in 23.00% masonry and 14.00% of RCC buildings, 31.61 and 25.76% of masonry and RCC buildings, respectively. They were vulnerable to pounding and placement of heavy mass at the top of many buildings.

This highlights the issue of non-compliance of seismic safety codes, and flaunting of established engineering norms in the construction of these buildings. Stringent punitive measures are therefore recommended for ruling out omission of standards and codes.

Lack of maintenance was responsible for distressed condition of 31.44% masonry and 16.78% RCC buildings. Geographically dispersed nature of infrastructure and lack of engineering expertise with the departments often makes it challenging to keep track of the state of individual buildings, and undertake appropriate corrective measures.

It is therefore recommended that the responsibility of maintenance and repair of all lifeline buildings be entrusted to a single department, and instead of present practice of allocating building maintenance budget to different departments, all maintenance related financial resources be provided to this department. This would ensure regular assessment of building vulnerability and implementation of required corrective measures besides ensuring economy, accountability, and transparency in building maintenance and would thus reduce the vulnerability of emergency response infrastructure.

Acknowledgements

Funding support from the World Bank assisted Uttarakhand Disaster Recovery Project (UDRP) is acknowledged while all the engineers involved in data collection are thanked. Thanks are also owed to colleagues at Disaster Mitigation and Management Centre, Uttarakhand State Disaster Management Authority and UDRP together with Secretary and Additional Secretary, Disaster Management Shri S.A. Murugesan and Shri Savin Bansal for support, cooperation, and encouragement. We would also like to thank the anonymous reviewers for painstakingly reviewing the manuscript and suggesting improvement.

References

1. Agrawal S, Chourasia A. Methodology for seismic vulnerability assessment of building stock in mega cities. Microzonation. 2007:182.
2. Arikan M, Sucuohlu H, Macit G. Economic assessment of the seismic retrofitting of low cost apartment buildings. Journal of Earthquake Engineering. 2005; 9(4): 577-584.
3. Arya AS. Guidelines for damage assessment and post-earthquake action. Building Materials and Technology Promotion Council (BMTPC),; 1997.
4. ATC-21. Rapid visual screening of buildings for potential seismic hazards: A handbook. 1988.
5. ATC-21-1. Rapid visual screening of buildings for potential seismic hazards: Supporting documentation. 1988.
6. Bhakuni C, editor Seismic vulnerability assessment of school buildings. Proceedings of the SECED Young Engineers Conference 21-22 March 2005, University of Bath, Bath; 2005.
7. Bilham R, Gaur VK, Molnar P. Himalayan seismic hazard. Science. 2001;293(5534): 1442-4.
8. Calvi GM, Pinho R, Magenes G, et al. Development of seismic vulnerability assessment methodologies over the past 30 years. ISET Journal of Earthquake Technology. 2006; 43(3): 75-104.
9. Disaster Management Act. Ministry of Law and Justice, Government of India; 2005.
10. Dowrick DJ. Earthquake risk reduction: John Wiley & Sons; 2003.
11. Ferreira M, Proença J, editors. Seismic vulnerability assessment of the educational system of bucharest. The 14th World Conference on Earthquake Engineering, Beijing, China; 2008.
12. Grünthal G. European macroseismic scale 1998. European Seismological Commission (ESC), 1998.Standard I. Criteria for earthquake resistant design of structures. Bureau of Indian Standards, Part. 1893; 1.
13. Standard I. Code of Practice for Design and Construction of Foundations in Soils: General Requirements. Bureau of Indian Standards, New Delhi. 1986..
14. Joshi GC, Ghildiyal S, Rautela Piyoosh. Seismic vulnerability of lifeline buildings in Himalayan province of Uttarakhand in India. International Journal of Disaster Risk Reduction 2019; 37.
15. MHA. Revised list of items & norms of assistance from State Disaster Response Fund (SDRF)/ National Disaster Response Fund (NDRF), Ministry of Home Affairs, Government of India; 2015. https://www.ndmindia. nic. in/images/ pdf/SDRF-NDRFNorms-dated8april2015.pdf
16. Mora MG, Valcarcel JA, Cardona OD, et al. Prioritizing interventions to reduce seismic vulnerability in school facilities in Colombia. Earthquake Spectra. 2015; 31(4), 2535-2552.
17. Nasrazdani H, Mahsuli M, Talebiyan H, Kashani H. Probabilistic modeling framework for prediction of seismic retrofit cost of buildings. Journal of Construction Engineering and Management. 2017; 143(8).
18. Rajendran CP, Rajendran K. The status of central seismic gap: A perspective based on the spatial and temporal aspects of the large Himalayan

earthquakes. Tectonophysics. 2005; 395(1-2): 19-39.
19. Rautela Piyoosh. Lessons learnt from the deluge of Kedarnath, Uttarakhand, India. Asian Journal of Environment and Disaster Management. 2013; 5 (2): 167 - 75.
20. Rautela P. Lessons learnt from June 16/17, 2013 disaster of Uttarakhand, India. Science and Technology in Disaster Risk Reduction in Asia: Elsevier; 2018. p. 273-300.
21. Rautela P, Joshi GC, Bhaisora B. Seismic vulnerability and risk in the Himalayan township of Mussoorie, Uttarakhand, India. Current science. 2010:521-6.
22. Rautela P, Joshi GC, Bhaisora B. Seismic vulnerability of the health infrastructure in the Himalayan township of Mussoorie, Uttarakhand, India. International Journal of Disaster Resilience in the Built Environment. 2011.
23. Rautela Piyoosh, Joshi GC, Bhaisora B, et al. Seismic vulnerability of the built environment; The Lesser Himalayan townships of Nainital and Mussoorie in Uttarakhand, India with particular emphasis upon the lifeline buildings. In: Current trends in Environmental Resource Management; Eds. Naithani S, Joshi G, Mohanty SS), Gaura Books India Pvt. Ltd., New Delhi. 2014: 177 – 187.
24. Rautela P, Joshi GC, Bhaisora B, Dhyani C, Ghildiyal S, Rawat A. Seismic vulnerability of Nainital and Mussoorie, two major Lesser Himalayan tourist destinations of India. International journal of disaster risk reduction. 2015; 13:400-8.
25. Rautela P, Joshi G, Bhaisora B, Khanduri S, Gildiyal S, Dhyani C, et al. Earthquake Risk Assessment around Naintal in Uttarakhand Himalaya, India. Journal of Geography and Natural Disasters. 2019;9(1):1-6.