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Seismic vulnerability of Nainital and Mussoorie, two major Lesser Himalayan tourist destinations of India

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A B S T R A C T

Seismic vulnerability of the building stock in two major tourist destinations of Indian Himalaya, Nainital and Mussoorie, that receive a large floating population and fall in Zone IV of Earthquake Zoning Map of India where damage during an earthquake is expected to reach MSK intensity VIII, is evaluated using rapid visual screening (RVS) technique of FEMA and the likely seismogenic damage is depicted as a function of the damage grades of EMS-98. In all 6206 buildings falling under various categories of usage are surveyed in the two towns. Of the total 14 percent in Nainital and 18 percent in Mussoorie are observed to fall in Category 5 damage class. Particular care has been taken to assess damageability of lifeline structures that include hospitals, schools and hotels. In the event of an earthquake direct economic losses to the surveyed buildings alone in the two towns are estimated to be US$ 137.78 million.

1. Introduction

Continued subduction of the Indian Plate beneath the Eurasian Plate consumed intervening oceanic plate and resulted in collision of these two continental plates [1]. This was accompanied by deformation, upliftment, metamorphism and shearing of sediments deposited in hitherto intervening Tethyan ocean basin along with rock mass of these two plates involved in orogeny.

Since the plate collision around 55 Ma, the Indian Plate is continuously drifting north–northeastward at an average rate of 45–50 mm/year [1,2]. Global positioning system (GPS) measurements indicate that the Indian Plate is moving northeast at a rate of 55 mm/year of which 18–22 mm/year is accommodated within the Himalaya [3,4] while remaining is taken care of further north in Tibet and Asia [5,6]. This ongoing convergence is responsible for both neotectonic activities and seismicity in Himalaya, Tibet and the adjoining areas.

Himalaya has been seismically active and has witnessed four great earthquakes ($Mw \geq 8.0$) in the previous 120 years; 1897 Western Assam, 1905 Kangara, 1934 Bihar–Nepal and 1950 Eastern Assam (Arunachal), besides Kumaun and Garhwal earthquakes of 1720 and 1803 respectively [7]. Regions between rupture zones of these earthquakes are recognized as seismic gaps that have accumulated potential slip for generating Great Earthquake in near future [8]. Though shaken recently by Uttarkashi and Chamoli earthquakes of 1991 and 1999 respectively the state of Uttarakhand is recognized as falling in seismic gap of 1905 and 1934 Great earthquakes and identified as a potential site for a future catastrophic earthquake [8,9].

Arya indicated a possibility of around 80,000 persons being killed if the 1905 event repeats during daytime [10,11]. Validated by the toll of the 2005 Kashmir Earthquake [12] this highlights the issue of rising seismic vulnerability of the region due to rapid and unplanned growth of population and infrastructure. Devastating earthquakes of April and May 2015 in Nepal amply highlight seismic threat in the region as also vulnerability of the building stock therein.

Seismic risk is a function of the condition of built environment or vulnerability of building stock. Therefore, it is important to assess the vulnerability of built environment before undertaking any seismic risk reduction exercise. This is all the more important for the urban areas that have high concentration of both infrastructure and population. Besides making the masses aware of the threat, such an exercise is intended to pave way for an effective mitigation planning through appropriate structural and non-structural measures.

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2. Methodology

2.1. Rapid visual screening (RVS)

Detailed seismic vulnerability evaluation is a technically complex and expensive procedure and can only be performed on a limited number of buildings. It is therefore important to use simple procedures that help in rapid evaluation of vulnerability profile of different type of buildings. Application of more complex evaluation procedures can thus be limited to the identified most vulnerable buildings [13].

Rapid visual screening (RVS) is one such cost effective tool for identifying highly vulnerable structures that can subsequently be surveyed in detail for appropriate and structure specific mitigation action [14]. RVS was first proposed in the United States (US) in 1988 and was further modified in 2002 to incorporate latest technological advancements and lessons learnt from earthquake disasters in the 1990s. Though originally developed for typical constructions in the US, this procedure has been widely used in many other countries after suitable modifications.

RVS methodology is implemented without performing any structural calculations and the most important feature of this procedure is that it permits vulnerability assessment based on walk-around of the building by a trained evaluator. The procedure utilizes a scoring system that requires the evaluator to identify (i) primary structural lateral load-resisting system and (ii) building attributes that modify seismic performance expected for this lateral load-resisting system. The inspection, data collection and decision-making process typically takes place at the building site and takes around an hour for one building. The evaluation procedure and system is compatible with GIS-based city database and also permits the use of collected building information for a variety of other planning and mitigation purposes.

Sinha and Goyal [13] have modified the data collection form of FEMA-154/ATC-21 [14] to make it relevant for Indian conditions in different seismic zones. The one prescribed for Seismic Zone IV of Seismic Zoning Map of India [15] has been modified to suit local conditions and the same (Table 1) has been used for assessing seismic vulnerability of the buildings in the present study.

Taking note of seasonal variation in occupancy, provision was made for recording the peak and lean occupancy of the buildings. In order to take the relief of the area into account, provision of broad estimation of the slope into three categories ($<15°$, $15°–30°$ and $>30°$), was also included. Some parameters like building identification number, ward number, owner's name, roof type, accessibility were also added for a broader information spectrum and to make analysis easier to perform. Provision was also made for including the subjective remarks of the field surveyor. IKONOS and WorldView imageries were utilized for mapping the structures and ARC INFO GIS software (version 9.3) for preparation of database, analysis and correlation.

2.2. Seismogenic structural damage assessment

Methodology of Sinha and Goyal [13] for correlating RVS scores of surveyed structures in different seismic zones with probable seismic damage grades of European Macroseismic Scale (EMS-98, [16]) is used in the present study for assessing the seismogenic losses. Authors suggest only three hazard zones for RVS studies in India; low (Zone II), moderate (Zone III) and high (Zones IV and V) as more precise categorization between Zone IV and V is not envisaged to enable better assessment of structural vulnerability using RVS procedure due to the influence of a large number of other factors on building performance in intense ground shaking conditions.

EMS-98 has five damage grades (Grade 1–Grade 5) of which Grade 4 and Grade 5 are important for risk assessment as these have the potential of threatening the lives of the occupants and causing damage to the contents therein [16]. Grade 4 or very heavy damage grade denotes heavy structural damage and very heavy non-structural damage and is characterised by serious failure of walls (gaps in walls) and partial structural failure of roofs and floors. Grade 5 or destruction denotes very heavy structural damage and is characterised by total or near total collapse of the structure.

In the present study high probability of Grade 5 damage and very high probability of Grade 4 damage class of Sinha and Goyal [13] is identified as Category 5 damage class while high probability of Grade 4 damage and very high probability of Grade 3 damage class is identified as Category 4 damage class.

2.3. Seismogenic losses in economic terms

In the present study the buildings falling in Category 5 damage class are taken as requiring reconstruction and entire contents of these buildings are deemed as being lost. The buildings falling in Category 4 damage class are however taken as being capable of restoration. The cost of restoration of these buildings is considered as being 20 percent of their replacement value [17].

Losses likely to be induced to the built environment due to earthquake are assessed as being the cost of reconstruction of the houses falling in Category 5 damage class and the contents therein together with the cost of repair of the houses falling in Category 4 damage class.

Total constructed area of the houses likely to be damaged is considered while estimating the cost of reconstruction according to the general construction rates. The value of the contents in the houses is assessed as being a function of both; the reconstruction cost and building use. For residential buildings the content value is taken as 50 percent of the replacement cost while for school, commercial, mixed (commercial and residential), hotel, hospital, religious and office buildings the economic worth of the contents likely to be lost is taken to be 25, 200, 100, 25, 400, 10 and 50 percent of the cost of replacement of the structures respectively [17].

3. The study area

The present study focuses on two famous tourist destinations of the Indian Himalaya, Nainital and Mussoorie that are located in the state of Uttarakhand (Fig. 1). Both the towns fall in Zone IV of the Seismic Zoning Map of India [15] and are situated in Lesser Himalaya in close proximity of Main Boundary Thrust (MBT) that is a north–northeast dipping major regional tectonic discontinuity of Himalaya bringing Proterozoic–early Cambrian low-grade metasedimentary rocks of Lesser Himalaya in juxtaposition with Miocene–Pleistocene molassic sediments of Siwalik Group.

Like geological and geomorphic setup, demographic figures of both these towns are comparable. Population of Nainital is 41,377 of which 21,648 are males and 19,729 are females while with 16,623 males and 13,495 females population of Mussoorie is 30,118. Child population in the range of 0–6 years in Nainital and Mussoorie are 3946 and 2673 that are 9.5 and 8.9 percent of the total population respectively. Literacy rate of Nainital and Mussoorie are 92.93 percent and 89.69 percent respectively that are higher than state average of 78.82 percent [18]. The population of the towns is however highly variable and during the peak tourist season (from April / May to September / October) a huge influx of floating population results in manifold increase in total population.

Habitation in both the towns started during the British rule;

first habitation in Mussoorie (Fig. 2) and Nainital (Fig. 3) came up around 1836 and 1841 respectively. Built environment of both the towns is observed to be quite old and large influx of tourists warrants seismic vulnerability assessment and adoption of suitable mitigation measures for reducing human miseries in the event of an earthquake in the region.

Previous earthquake experiences suggest that collapse of lifeline structures can increase human sufferings by manifold and therefore a note of their seismic performance needs to be taken on priority basis so as to devote special attention for improving their seismic performance.

Hospital is an important lifeline structure that is required to function even more vigorously in post-disaster phase. Disruption of hospital functions due to the impact of disaster is bound to jeopardize the pace of post-disaster relief efforts as well as the life of the victims in the area. In Bhuj Earthquake of 2001 collapse of the 281 – bed Civil Hospital killed 172 people and left large number of injured and sick persons without medical care. In Bhachau one doctor and three staff members were killed while one health worker was killed in Anjar [19]. Medical infrastructure suffered major losses in this earthquake (Table 2). Special attention is given to this aspect in the present study while carrying out vulnerability assessments.

Apart from hospitals, school buildings are important structures and collapse of these can add to the trauma of the affected community. Vulnerability of children is considered to be high and they

Table 1
The data collection Form utilized for field survey (modified after Sinha and Goyal, 2004 [13]).

Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

FEMA-154/ATC-21 Based Data Collection Form **(Seismic Zones IV & V)**

Address: ....
.... Ward no. ....
ID...
No. Stories .... Year Built......................................
Surveyor.. Date...............................
Owner Name..
Building Name...
Use ....

Current Visual Condition: Excellent ☐ Good ☐ Damaged ☐ Distressed ☐

\

PHOTOGRAPH
(or specify photograph numbers)

Comments:

Plan and Elevation Scale

ROOF TYPE	EASY ACCESS
Lintel Sloping Tin	Yes No

Occupancy (Peak) (Low)

Max. Number of Persons: 0-10, 11-100, 101-1000, 1000+

Assembly, Govt., Office, Commercial, Historic, Residental, Emer. Service, Industrial, School

Max. Number of Persons: 0-10, 11-100, 101, 101-1000, 1000+

SOIL TYPE (IS 1893-2002): Type I Hard Soil, Type II Medium Soil, Type I Soft Soil

FALLING HAZARDS: Chimneys, Parapets, Cladding, Other

BASIC SCORE, MODIFIERS, AND FINAL SCORE,S

Building Type	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF)	C2 (SW)	C3 (INF)	URM (BAND)	URM 2	URM 3
Basic Score	3.8	2.8	3.2	2.5	2.8	2.6	2.8	1.8	1.4
Mid Rise (4 to 7 stories)	N/A	+0.2	N/A	+0.4	+0.4	+0.2	+0.4	-0.2	-0.4
High Rise (>7 stories)	N/A	+0.6	N/A	+0.6	+0.8	+0.3	N/A	N/A	N/A
Vertical Irregularity	-2.0	-1.0	N/A	-1.5	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Code Detailing	N/A	+0.4	N/A	+0.2	+1.4	+0.2	N/A	N/A	N/A
Soil Type II	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type III	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6
Poor condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
FINAL SCORE, S									

Result Interpretation (Likely building performance)		Further Evaluation Recommended
S<0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage	
0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage	Yes
0.7 < S < 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage	No
2.0 < S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 2 damage	
S > 3.0	Probability of Grade 1 damage	

*=Estimated, subjective, or unreliable date
DNK= Do Not Know
FRAME= Steel Frame
INF= Burnt Brick Masonry Infill Wall
MRF= Moment-Resisting Frame
FD= Flexible Diaphragm
SW= Shear Wall
LM= Light Metal
BAND= Seismic Band
URM3= Unreinforced masonry (lime mortar)
URM2= Unreinforced burnt brick or stone masonry (cem mortar)
RD= Rigid diaphragm

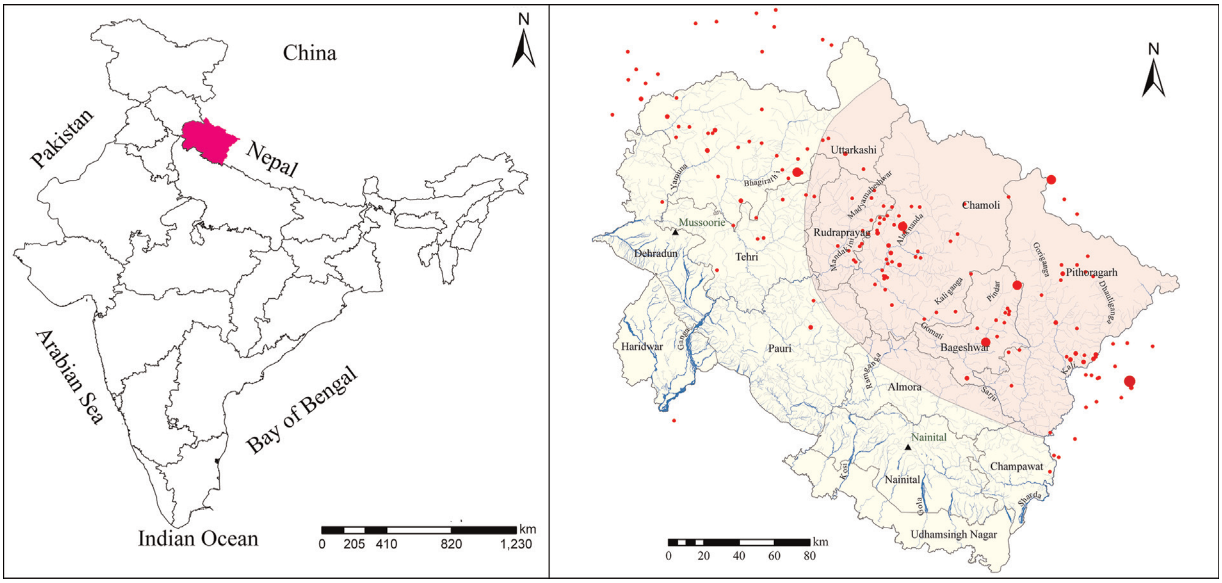

Fig. 1. Location map of the area. In the left location of the State of Uttarakhand is shown while the figure on the right shows the Earthquake Zoning Map of Uttarakhand (Zone V depicted in orange) with epicenters of past earthquakes and position of Mussoorie and Nainital.

Fig. 2. Panaromic view of Mussoorie.

Fig. 3. Panaromic view of Nainital.

often constitute major proportion of the disaster victims. Large number of students were killed in both Muzaffarabad and Sichuan earthquakes. 74,500 human lives were lost in 7.6 magnitude Muzaffarabad Earthquake of October 8, 2005. 7669 schools in Pakistan occupied Kashmir and North West Frontier Province were destroyed in this incidence, killing 18,100 students which constituted 24 percent of the total dead. 7.9 magnitude Sichuan Earthquake of May 12, 2008 killed 90,000 people of which 5535 were students amounting to 6 percent of the total.

Both Nainital and Mussoorie have a large number of renowned residential schools and children from across the nation and abroad come here for schooling. Particular emphasis has therefore been accorded to the vulnerability assessment of school buildings in the two towns so as to plan and introduce appropriate mitigation measures.

Apart from these, damage to tourism infrastructure can lead to widespread panic as the persons affected would be from across the country and abroad. Similar situation was experienced in Uttarakhand on the aftermath of 2013 Kedarnath tragedy in which the death toll was more than 4000 [20].

The towns under the present study are major tourist destinations and people from all over the country and abroad visit these places in large numbers. Besides being major source of income of large proportion of the population of these towns tourism is also an important source of state revenue. Earthquake induced destruction of hotel buildings and consequent death of tourists can thus derail the economy of the state with lasting adverse implications. This highlights the need of undertaking vulnerability assessment of tourism infrastructure, particularly hotels, so as to ensure enforcement of appropriate mitigation measures through licensing mechanism.

The study has thus been designed to take note of seismic vulnerability of school, hospital and hotel buildings besides other infrastructure in the two towns, Nainital and Mussoorie that are covered by the present study.

4. Seismic damageability of structures in the two towns

A wide variety of construction types and building materials are used in urban areas of India. These include local materials such as mud and straw, semi-engineered materials such as burnt brick and stone masonry and engineered materials such as concrete and steel. The seismic vulnerability of the different building types depends on the choice of building materials. The building vulnerability is generally highest with the use of local materials without engineering inputs and lowest with the use of engineered material with engineering inputs. The building stock of Mussoorie and Nainital towns are classified into nine categories, out of which three building types are under unreinforced brick / stone masonry, and others are wood, steel (two building types) and concrete (three building types). These building types are described as (i) URM 1 (unconfined rubble masonry) type that are unreinforced burnt brick or stone masonry constructions reinforced with RCC or seismic bands running horizontally or vertically or in both directions in a few cases, (ii) URM 2 type that are unreinforced burnt brick or stone masonry constructions with cement mortar without specific seismic safety provisions, (iii) URM 3 type that are unreinforced burnt brick or stone masonry constructions with cement or lime mortar and do not have specific seismic safety provisions as also normal loading safety measures, (iv) wood buildings mostly constructed with seasoned wood and have floor and roof framing of wood joists or rafters on wood studs, (v) S1 types that have a steel frame with floor and roof framing consisting of cast-in-place concrete slabs or metal deck with concrete fill supported on steel beams, open web joists, or steel trusses, (vi) S2 type that are pre-engineered and prefabricated with transverse rigid steel frames with roof and walls consisting of lightweight metal, fiberglass or cementitious panels, (vii) C1 type that have a moment resistant frame assembly of cast-in-place concrete beams and columns, (viii) C2 type that are essentially C1 type but have shear walls to resist the lateral loads of the building, (ix) C3 types is an older type of building construction that consists of a frame assembly of cast-in-place concrete beams and columns and infill walls that are constructed of solid clay brick, concrete block, or hollow clay tile masonry. Most construction (94 percent) in both the towns are however observed to be unconfined rubble masonry (URM), mostly stone and brick masonry with slate / CGI roofing.

Table 2
Damage to healthcare facilities in 2001 Bhuj Earthquake (After Rai et al., 2002 [19]).

Sl. no.	Facilities	Destroyed	Damaged
1.	Medical colleges and speciality hospitals	–	15
2.	District hospitals	5	26
3.	Community health center (CHC)	21	46
4.	Primary health center (PHC)	48	118
5.	Ayurvedic/Homeopathic dispensaries	110	8
6.	Sub-centers	227	357
7.	Go-downs (warehouses)	6	4
8.	Integrated Child Development Scheme (ICDS) *Anganwadis* (kindergartens)	800	2180
9.	Chief District Project Officer Office	11	4

Of the 6206 buildings surveyed under the present study the oldest is reportedly constructed in 1836 in Mussoorie where another 282 are reportedly constructed in pre-1900 period. The building stock in Nainital is also equally old and 487 of the surveyed buildings are reportedly constructed in pre-1900 period (Fig. 4).

Most surveyed buildings in both the towns are observed to be low rise; 950 in Nainital and 1135 in Mussoorie being single storeyed and 1634 in Nainital and 1957 in Mussoorie being double or triple storeyed. As many as 13 buildings in Nainital and 30 in Mussoorie are however observed to be more than five storeyed (Fig. 5).

Analysis of the data collected from the field shows that 14 percent of the surveyed buildings in Nainital and 18 percent in Mussoorie fall in Category 5 damage class in case of seismic intensity reaching VIII on MSK scale. In Nainital most buildings falling in this damage class are located in Ward numbers 11 and 3 that are located at the northern and southern extremity of the lake (Fig. 6). Together these two Wards account for 53 percent of the Category 5 damage class buildings in Nainital. Ward numbers 1 and 6 that are located at the northern extremity of the town also have significant number of buildings falling in this damage class.

In Mussoorie most buildings falling in Category 5 damage class are located in Ward numbers 7, 5, 3, 6, 4 and 8 (Fig. 7). Together these account for 67 percent of the buildings falling in this building class. These fall in the heart of the city and extend east–west parallel to the ridge.

Most buildings falling in Category 5 damage class are observed to be constructed in pre-1951 phase; 42 percent in Nainital and 20 percent in Mussoorie being constructed in pre-1900 period and 32 percent in Nainital and 44 percent in Mussoorie being constructed between 1901 and 1950 (Fig. 8).

It is important to note that most structures falling in the Category 5 damage class are low rise; 14 percent in Nainital and 30 percent in Mussoorie being single storeyed and 54 percent in Nainital and 60 percent in Mussoorie being two or three storeyed

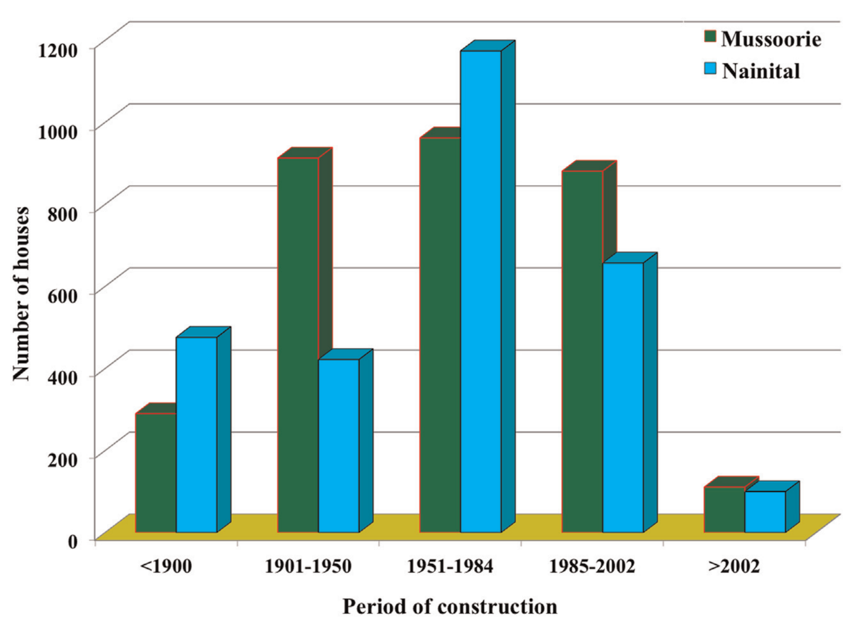

Fig. 4. Diagram depicting age of the surveyed buildings in Mussoorie and Nainital.

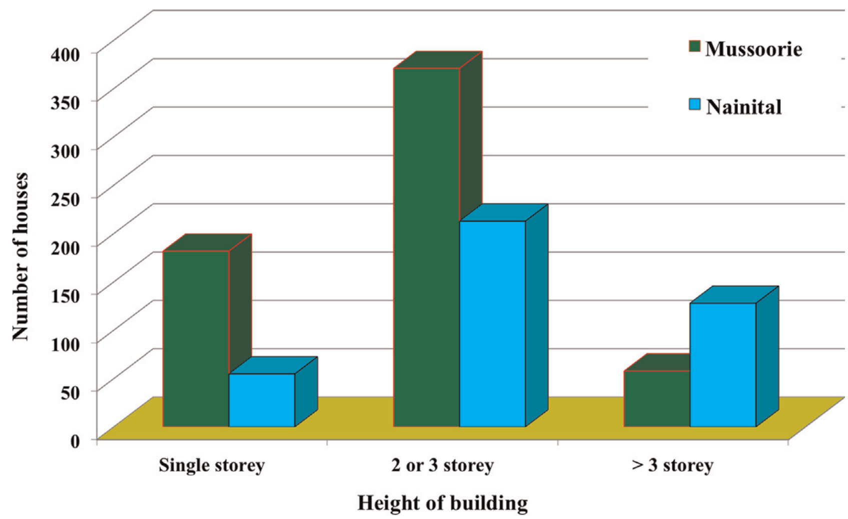

Fig. 5. Diagram depicting the height of the surveyed buildings in Mussoorie and Nainital.

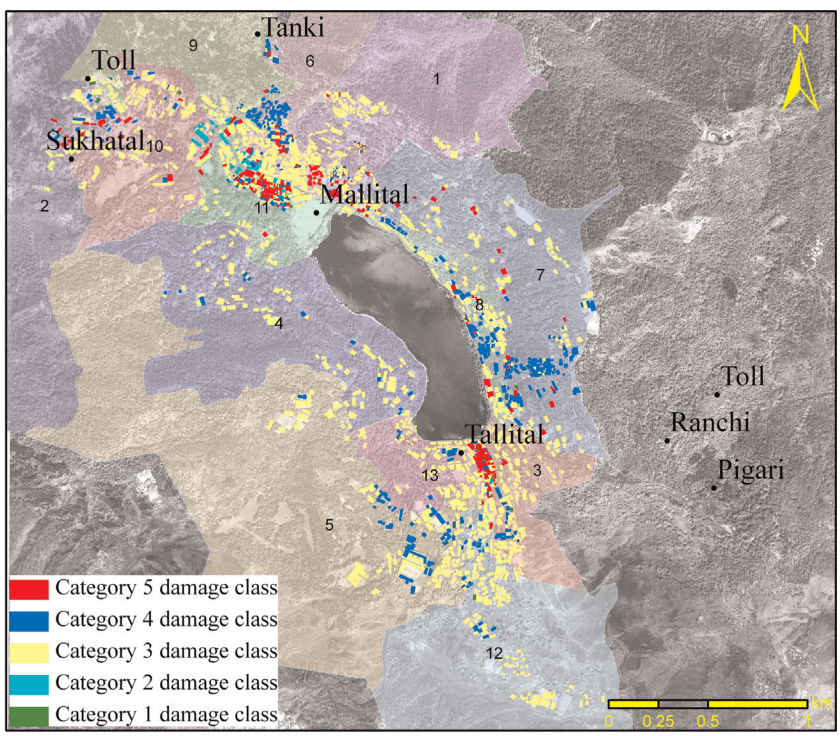

Fig. 6. Diagram depicting distribution of buildings with different seismic damageability class in Nainital. In the background is WorldView imagery on which Ward boundaries are shown in different colors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Fig. 9). This however need not lead one to conclude that particular care is taken while constructing multi-storeyed buildings because only 6 percent of the surveyed single storeyed buildings in Nainital and 16 percent in Mussoorie fall in this damage class whereas 13 percent of two or three storeyed in Nainital and 19 percent in Mussoorie together with 48 percent of more than three storeyed buildings in Nainital and 27 percent in Mussoorie fall in Category 5 damage class.

Total built up area of the structures falling in Category 5 damage class in Nainital and Mussoorie is calculated to be 117,613 m^2 and 296,974 m^2 respectively. At the standard rate of US$ 180 per m^2, the replacement cost of these buildings is estimated to be US$ 21.17 and US$ 53.46 million respectively. It is further estimated that contents worth US$ 14.62 and US$ 34.01 million respectively would be lost in Category 5 damage class structures in the two towns.

Total built up area of the structures falling in Category 4 damage class in Nainital and Mussoorie is calculated to be 185,753 m^2 and 217,440 m^2 respectively. The cost of repair of these buildings is estimated to be US$ 6.69 and US$ 7.83 million respectively.

Total direct economic loss of US$ 137.78 million is thus estimated to incur to the surveyed structures in the two Himalayan towns; Nainital and Mussoorie, in the event of earthquake intensity reaching VIII on MSK Scale.

This however is a gross underestimate as the study does not cover the entire building stock of the towns. Moreover the study does not account for the cost of demolition of the damaged structures. At the same time the cost of restoration of structures falling in other damage grade classes has also not been considered.

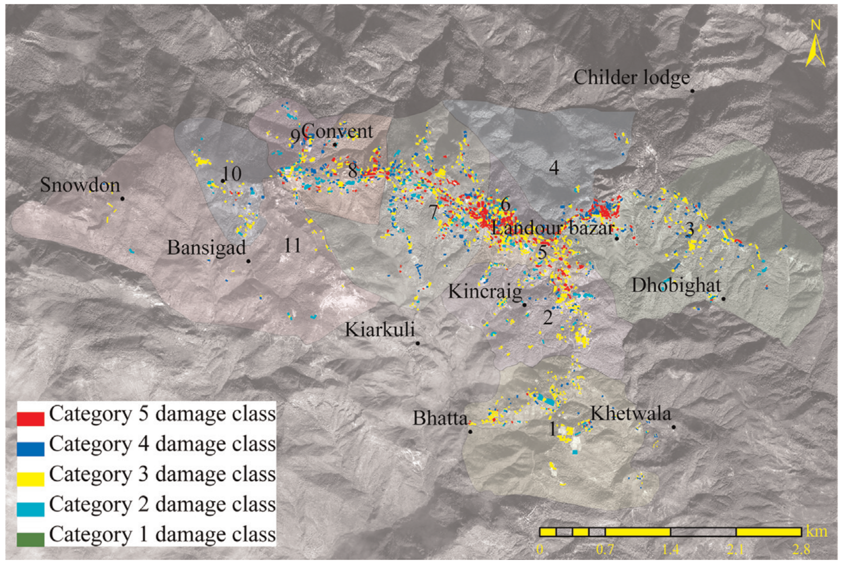

Fig. 7. Diagram depicting distribution of buildings with different seismic damageability class in Mussoorie. In the background is IKONOS imagery on which Ward boundaries are shown in different colors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5. Vulnerability of lifeline buildings and tourism infrastructure

Damage to lifeline structures is known to add to the trauma and sufferings of the disaster-affected population besides having an adverse impact upon the post-disaster relief and rescue initiatives. Of the various lifeline structures seismic vulnerability of hospital and school buildings is accorded special attention. Tourism is the main economic activity in both the towns taken up under this study and damage to this sector can have long term impact on the economy of the state as has been witnessed on the aftermath of 2013 Kedarnath disaster. Seismic vulnerability of the hotels has also therefore been included in this study.

A total of 8 hospital buildings in Nainital and 13 in Mussoorie together with 103 school buildings in Nainital and 302 in Mussoorie are covered under the present study. These include government hospitals and schools as also those managed by individuals and trusts. 46 hotel buildings in Nainital and 320 in Mussoorie are also covered under the study.

Except for one hospital building in Nainital all others are observed to be up to three storey high. A total of 48 percent of the surveyed hospital buildings are single storeyed. It is important to note that majority of these buildings are quite old with 50 percent in Nainital and 77 percent in Mussoorie reportedly constructed in pre-1951 period. One in Nainital and two in Mussoorie are even reportedly constructed in pre-1900 period.

Except for eight school buildings of Mussoorie all other school buildings covered by the present study are observed to be up to three storey high and 28 percent in Nainital and 27 percent in Mussoorie are single storeyed. Large proportion of the school buildings in both the towns are old; 23 percent in Nainital and 26 percent in Mussoorie being constructed in pre-1900 phase. Age of both hospital and school buildings is sure to reflect adversely on their seismic performance and is a cause of serious concern.

Hotel industry was relatively late to pick up in both the towns and most hotels are observed to be relatively new; 37 percent in Nainital and 48 percent in Mussoorie being constructed in post-1984 period. Large number of hotels in both the towns are however more than three storeyed; 26 percent in Nainital and 14 percent in Mussoorie. Only 7 percent of the surveyed hotels in Nainital and 7 percent in Mussoorie are observed to be single storeyed. 11 percent of the surveyed hotels in Nainital and 19 percent in Mussoorie fall in Category 5 damage class.

It is important to note that one surveyed hospital building in

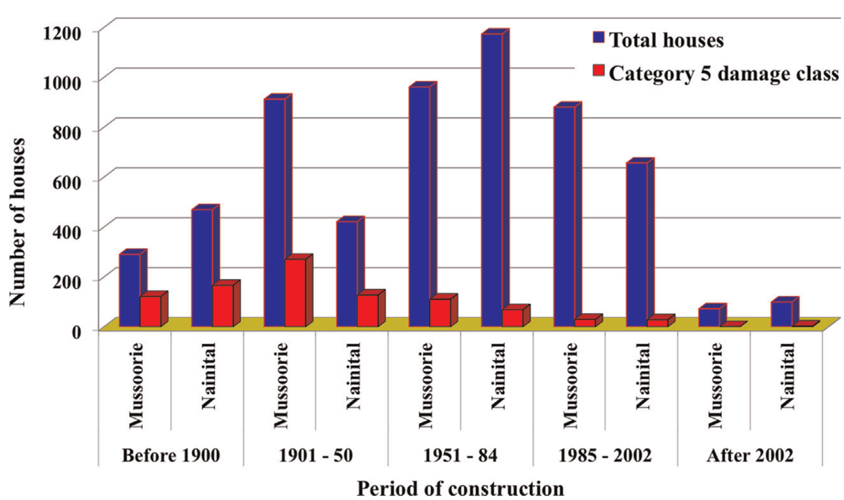

Fig. 8. Diagram depicting age of the buildings falling in Category 5 damage class in Mussoorie and Nainital.

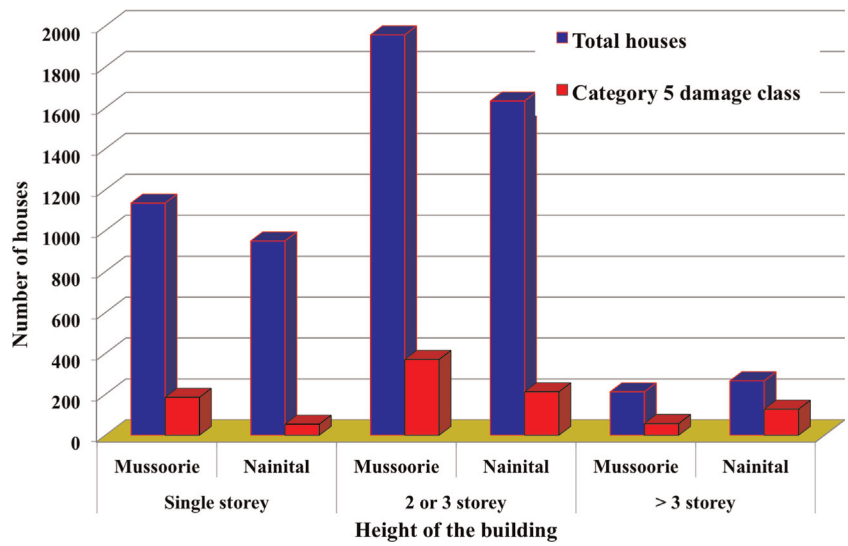

Fig. 9. Diagram depicting height of the buildings falling in Category 5 damage class in Mussoorie and Nainital.

Nainital and 7 in Mussoorie fall in Category 5 damage class while another one in Nainital and four in Mussoorie fall in Category 4 damage class. All the hospitals falling in Category 5 and 4 damage classes are constructed before 1907 and most (04) are single storeyed. Of the surveyed school buildings, 04 in Nainital and 13 in Mussoorie fall in Category 5 damage class. Of these none is more than three storey high and 03 in Nainital and 07 in Mussoorie are reportedly constructed in pre-1900 period.

Total built up area of the hospitals falling in Category 5 damage class is estimated to be 459 m^2 in Nainital and 4908 m^2 in Mussoorie. The cost of replacement of these structures at standard rate of US $ 180 per m^2 thus comes out to be US$ 0.97 million while the contents worth US$ 3.86 million are expected to be lost in a seismic event. Thus total economic losses to the hospital buildings falling in Category 5 damage class is expected to be US$ 4.83 million. This however cannot account for the cost of misery and inconvenience that would be faced by the affected population due to the damage to this critical facility.

Likewise built up area of the school buildings falling in Category 5 damage class, is estimated to be 4148 m^2 in Nainital and 13,556 m^2 in Mussoorie. The cost of replacement of these structures thus comes out to be US$ 3.19 million while the contents worth US$ 0.80 million are expected to be lost in a seismic event. Thus total economic losses to the school buildings falling in Category 5 damage class is expected to be US$ 3.99 million.

6662 m^2 of built up area of hotel buildings in Nainital and 56,049 m^2 in Mussoorie falls in Category 5 damage class. Reconstruction of hotel buildings is thus estimated to cost US$ 11.29 million and contents worth US$ 2.82 are estimated to be lost in the event. Thus, the total economic losses to the hotel buildings falling in high probability of Category 5 damage class is expected to be US $ 14.11 million.

6. Discussion and conclusion

Earthquake is a harsh reality for all tectonically active regions. Constraints in earthquake prediction amplify the importance of effective planning, preparedness and mitigation for saving lives and property and reducing the misery of the affected population. Assessment of seismic vulnerability is however a necessary precondition for realistic planning and effective mitigation. RVS, together with GIS and remote sensing tools, have been utilized in the present study for assessing seismic vulnerability of the built environment of Nainital and Mussoorie that fall in Zone IV of Seismic Zoning Map of India.

Of the surveyed 6206 buildings 14 percent in Nainital and 18 percent in Mussoorie show high probability of Category 5 damage in the event of a seismic activity reaching intensity VIII on MSK Scale. Most of these buildings are reportedly constructed in pre-1951 phase.

Hospitals constitute the most critical facility required on the aftermath of any disaster event and therefore it is important to assess the seismic performance of the buildings housing these facilities. Disruption of hospital functions has the potential of magnifying the trauma and misery of the affected population by manifold. Together with hospitals, safety of school buildings is critical. Besides enhancing trauma of the affected community including children, the collapse of school buildings would disrupt relief work as in the post-disaster phase these are often used as shelters, makeshift dispensaries and stores of relief supplies. Tourism is the main economic activity in both the towns taken up under the present study and therefore it is important to assess the safety of the hotel buildings. Seismic vulnerability assessment of these buildings is thus accorded special attention.

8 hospitals in Nainital and 13 in Mussoorie are covered by the present study and of these most are reported to be housed in very old low rise buildings with sloping tin roofs. The study indicates that eight of the surveyed hospital buildings are likely to incur serious structural losses (Category 5 damage class) while essential services in the other five falling in Category 4 damage class are likely to be disrupted due to heavy non-structural damage.

The likely earthquake induced economic loss to the hospital buildings is not significant as compared to the likely total earthquake induced economic loss to the surveyed buildings of the towns but it is important to note that 13 out of 21 surveyed hospitals of these towns would probably not be in a position to deliver the intended emergency healthcare facilities due to varying degree of structural and non-structural damages. Such a situation would enhance pressure upon the resources of the remaining hospitals that are ill equipped to cope with such an eventuality. This is likely to result in total collapse of healthcare facilities in the townships in the aftermath of an earthquake.

In any case the seismic event is not going to be localized and disruption of transportation network due to earthquake-induced landslides can further complicate the situation. The additional healthcare reinforcement cannot thus be expected to arrive soon from the nearby towns. This would result in complete chaos and foil the gains of all search and rescue attempts. The study thus reveals the harsh fact that most healthcare infrastructure in both Nainital and Mussoorie is highly vulnerable to seismic threat and this could result in exponential rise in human casualties.

The study thus recommends detailed seismic vulnerability assessment of all lifeline structures including the healthcare facilities on priority basis. Based upon this a detailed mitigation plan needs to be evolved for timely rehabilitation of lifeline structures. This strategy has to have a happy blend of demolition, reconstruction and retrofitting and the required factor of safety (1.5) as enumerated by the Indian Standards (IS) Code should be ensured for all important buildings while implementing this strategy.

The hospitals and other public facilities operated by private individuals and trusts should be made to comply with the required safety standards and appropriate legislative measures should necessarily be invoked for ensuring the same. The Act of the Parliament of India (Disaster Management Act, 2005; [21]) provides various powers in this regard to State and District Disaster Management Authorities under its various sections. The powers delegated by the same should be utilized to ensure the safety of lifeline structures.

Together with hospitals, it is highly important to ensure safety of other buildings as well; particularly schools, hotels and other commercial establishments. As revealed by the study most buildings in Mussoorie including school buildings date back to the period when concepts of seismic safety were not well developed and these are therefore not expected to comply with present day seismic safety standards. Despite this it would neither be practical nor feasible to demolish and reconstruct majority of the buildings by enacting a law.

It is thus important to undertake aggressive and massive awareness drive for risk communication and for bringing forth acceptability of appropriate seismic safety measures amongst the masses. People routinely invest upon maintenance of their buildings and in case the gravity of the situation is communicated along with simple and appropriate technological options for risk reduction, many would dovetail maintenance with retrofitting.

Tax benefits and soft loans for the complying house owners would further motivate people to participate in the risk reduction drive. Risk transfer options with differential premium would also lead to people's participation in risk reduction measures. Moreover, for all public utilities including school, hospital, hotel, cinema, multiplex, restaurant and mall seismic safety has to be laid down as a necessary precondition. Linking this to licensing permission for operating these establishments in both new and already constructed structures holds the keys to reducing earthquake risk and consequent human miseries and trauma.

In a democratic set up political compulsions often lead to delays in the implementation of policies influencing masses and therefore it is highly important to bring forth political consensus on this important issue and all the political parties should be made aware of the importance of the planned initiatives so that these remain part of the priority agenda of all the players. It is, at the same time important to communicate the importance of the issue to the masses so that public opinion is built in favor of appropriate techno-legal options for risk reduction. This is sure to break political inertia and initiate positive action for seismic risk reduction.

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References

[1] J.F. Dewey, S. Cande, W.C. Pitman, Tectonic evolution of the India/Eurasia collision zone, Eclogae Geol. Helv. 82 (1989) 717–734.
[2] J. Besse, V. Courtillot, Palaeogeographic maps of the continents bordering the Indian Ocean since the early Jurassic, J. Geophys. Res. B 93 (1988) 1791–1808.
[3] R. Bilham, L. Larson, F. Jeffrey, GPS measurements of present day convergence across the Nepal Himalaya, Nature 386 (1997) 61–64.
[4] P. Banerjee, R. Burgmann, Convergence across the northwest Himalaya from GPS measurements, Geophys. Res. Lett. 29 (2002) 1–4.
[5] J. Avouac, P. Tapponnier, Kinematic model of active deformation in central Asia, Geophys. Res. Lett. 20 (1993) 895–898.
[6] G. Peltzer, F. Saucier, Present day kinematics of Asia derived from geological fault rates, J. Geophys. Res. 101 (1996) 27943–27956.
[7] V.C. Thakur, Reassessment of earthquake hazard in the Himalaya and implications from 2004 Sumatra–Andaman earthquake, Curr. Sci. 90 (2006) 1070–1072.
[8] R. Bilham, V.K. Gaur, P. Molnar, Himalayan seismic hazard, Science 293 (2001) 1442–1444.
[9] C.P. Rajendran, B. John, K. Rajendran, Medival pulse of great earthquakes in the central Himalaya: viewing past activities on the frontal thrust, J. Geophys. Res.: Solid Earth 120 (2015) 1–19.
[10] A.S. Arya, Damage scenario of a hypothetical 8.0 magnitude earthquake in Kangra region of Himachal Pradesh, Bull. Indian Soc. Earthq. Technol. 27 (1990) 121–132.
[11] A.S. Arya, Possible effects of a major earthquake in Kangara region of Himachal Pradesh, Curr. Sci. 62 (1992) 251–256.
[12] L.A. Owen, U. Kamp, G.A. Khattak, E.L. Harp, D.K. Keefer, M.A. Bauer, Landslides triggered by the 8 October 2005 Kashmir earthquake, Geomorphology 94 (2008) 1–9.
[13] R. Sinha, A. Goyal, A National Policy for Seismic Vulnerability Assessment of Buildings and Procedure for Rapid Visual Screening of Buildings for Potential Seismic Vulnerability, Report of the Department of Civil Engineering, Indian Institute of Technology, Bombay, 2004, 12 pp ⟨http://www.civil.iitb.ac.in/~rsinha/Vulnerability_Assessment.pdf⟩.
[14] FEMA 154, Rapid Visual Screening of Buildings for Potential Seismic Hazards, Edition 2 Redwood City, 2002.
[15] Indian Standard (IS): 1893, Part 1, Creteria for earthquake Resistant Design of Structures, Bureau of Indian Standards, New Delhi, 2002.
[16] S. Goivinazzi, S. Lagomarsino, A macroseismic method for vulnerability assessment of buildings, in: Proceedings of the 13th World Conference of Earthquake Engineering, 1–6 August, 2004, Vancouver B.C., Canada, Paper no. 896 ⟨http://www.researchgate.net/publication/255620187_A_MACRO SEISMIC_METHOD_FOR_THE_VULNERABILITY_ASSESSMENT_OF_BUILDINGS⟩.
[17] D.J. Dowrick, Earthquake Risk Reduction, John Wiley & Sons Ltd., London (2003), p. 506.
[18] Census of India, Office of the Registrar General and Census Commissioner, Ministry of Home Affairs, Government of India, 2011 ⟨http://censusindia.gov.in/Tables_Published/Tables_published.html⟩.
[19] D.C. Rai, A.M. Prasad, S.K. Jain, Hospitals and Schools, in: S.K. Jain, W.R. Lettis, C.V.R. Murty, J.P. Bardet (Eds.), Earthquake Engineering Research Institute, Oakland, CA, 2002, pp. 319–339 , Earthquake Spectra, supplement A to volume 18.
[20] Piyoosh Rautela, Lessons learnt from the deluge of Kedarnath, Uttarakhand, India, Asian J. Env. Disaster Manag. 5 (2013) 167–175.
[21] Disaster Management Act, Ministry of Law and Justice, Government of India, 2005 ⟨http://atingl.nic.in/Downloads/THE%20DISASTER%20MANAGEMENT%20ACT%202005.pdf⟩.