Seismic vulnerability of the health infrastructure in the Himalayan township of Mussoorie, Uttarakhand, India

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Abstract

Purpose – The purpose of this paper is to attempt to assess the seismic vulnerability of the built environment in the Himalayan township of Mussoorie in the state of Uttarakhand (India), paying specific attention to hospitals. Also an attempt is made to assess the magnitude of minimum economic losses, so as to design and undertake measures for reducing human misery in the event of a major disaster.

Design/methodology/approach – Seismic vulnerability of the building stock is evaluated using FEMA technique rapid visual screening and the likely earthquake induced damage is depicted as a function of the damage grades of the European Macroseismic Scale (EMS-98). In total, 3,344 buildings, including 14 hospitals, are surveyed. In the field the structures are mapped using IKONOS satellite imagery while the collected data are analysed under geographic information system environment.

Findings – It was found that 18 percent of surveyed structures fall in high probability of Grade 5 damage and very high probability of Grade 4 damage class. This is estimated to result in economic loss of US$52.47 million. Almost, 80 percent of the hospitals of Mussoorie are thus likely to be non-functional in the post-earthquake phase due to varying degrees of structural and non-structural damage.

Research limitations/implications – The study does not account for the cost of demolition or ground clearance cost for reconstruction, or losses likely to be incurred by public infrastructure. Thus, it is implied that retrofitting and replacement of vulnerable healthcare infrastructure should be facilitated on a priority basis along with development of suitable plans for mitigating losses in an earthquake event.

Practical implications – The study brings forth the importance of corrective actions (retrofitting/replacement) and detailed vulnerability assessment of all lifeline structures on priority basis.

Social implications – The results are intended to reduce seismic vulnerability and human toll in the event of any earthquake in the area.

Originality/value – The work is based upon the original data generated by the authors through rigorous fieldwork in the area and the results are totally based on these.

Keywords India, Seismology, Earthquakes, Hospitals, Hazard prevention in buildings, Seismic vulnerability, Seismicity, Damageability, Building performance, Vulnerability analysis

Paper type Research paper

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Introduction

Continued subduction of the Indian Plate beneath the Eurasian Plate consumed the intervening oceanic plate and led to the collision of the alien landmasses. This caused deformation, upliftment, metamorphism and shearing of the sediments deposited in the hitherto intervening ocean basin (Tethys) along with the rock mass of the 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 (Besse and Courtillot, 1988; Dewey *et al.*, 1989). Global positioning system measurements conclusively 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 (Bilham *et al.*, 1997) and the remaining is taken care of further north in Tibet and Asia (Avouac and Tapponier, 1993; Peltzer and Saucier, 1996). This ongoing convergence is responsible for both neotectonism and seismicity in Himalaya, Tibet and the adjoining areas.

The Himalaya has been seismically active and has witnessed four great earthquakes (Mw $\geq$ 8.0) in the previous 113 years; 1897 Western Assam, 1905 Kangara, 1934 Bihar – Nepal and 1950 Eastern Assam (Arunachal) earthquakes. Arya (1990) indicates possibility of around 80,000 persons being killed if the 1905 event repeats during daytime. Validated by the toll of the 2005 Kashmir earthquake this assertion highlights the issue of rising seismic vulnerability in the region due to rapid growth of population and infrastructure.

Entire Indian Himalaya falls in Zones IV and V of Earthquake Zoning Map of India (Indian Standard (IS) 1893, Part 1, 2002) and in the recent past (1991 and 1999) the state of Uttarakhand has witnessed two moderate magnitude earthquakes with their epicenters at Uttarkashi and Chamoli, respectively. The state however falls in the seismic gap of 1935 and 1905 great earthquakes and has not witnessed a major earthquake for more than previous 200 years. This enhances seismic risk in the region.

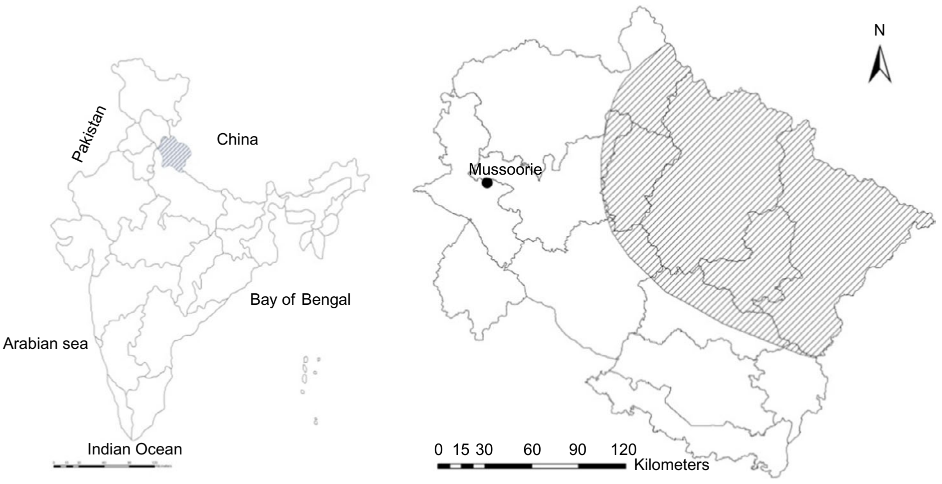
Seismic risk is a direct function of the state of built environment or vulnerability of the building stock. Assessment of the vulnerability of the built environment is therefore important for undertaking any seismic risk reduction exercise. This is all the more important for the urban areas that have concentration of both infrastructure and population. Such an exercise is intended to pave way for effective mitigative planning through appropriate structural and non-structural measures.

The study area

The present study focuses on the Himalayan township of Mussoorie located in close proximity of the capital city (Dehradun) of Uttarakhand state in India (Figure 1). Mussoorie is a famous Himalayan tourist destination situated in Lesser Himalaya in close proximity of Main Boundary Thrust that is a north – northeast dipping tectonic discontinuity bringing Lesser Himalayan rocks in juxtaposition with the rocks of Siwaliks. The area falls in Zone IV of the Earthquake Zoning Map of India (IS, 1893, Part 1, 2002).

Mussoorie has a population of 26,069 (Census of India, 2001). The population of the town is however highly variable and during the peak tourist season (from April/May to September/October) the same witnesses manifold increase.

Built environment of Mussoorie is particularly old and large influx of tourists to the township warrants seismic vulnerability assessment and adoption of suitable mitigative measures for reducing human miseries and toll in the event of an earthquake in the area. Previous earthquake experiences suggest that the collapse of lifeline structures can enhance human sufferings by manifold and therefore their seismic performance needs to be taken note of on priority basis. In the 2001 Bhuj earthquake collapse of the 281 – bed Civil Hospital killed 172 people and left large number of injured and sick persons without any medical treatment. In Bhachau, one doctor and three staff members were killed



Note: 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 hatched) with district boundaries and the position of Mussoorie

Figure 1.
Location map of the area

while one health worker was killed in Anjar (Rai*et al.*, 2002). This earthquake caused widespread loss of medical infrastructure. The present study therefore focuses upon the safety of hospital buildings in Mussoorie.

Methodology

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 simpler procedures that help in rapid evaluation of the vulnerability profile of different type of buildings. More complex evaluation procedures can thus be limited to the most critical buildings (Sinha and Goyal, 2004).

Rapid visual screening (RVS) is one such cost effective tool for identifying highly vulnerable structures that can subsequently be surveyed in detail for appropriate mitigative action. RVS was first proposed in the USA in 1988 and was further modified in 2002 to incorporate latest technological advancements and lessons from earthquake disasters in the 1990s. Though originally developed for typical constructions in the USA this procedure has been widely used in many other countries after suitable modifications. 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 evaluation procedure and system is compatible with geographic information system (GIS)-based city database and also permits use of the collected building information for a variety of other planning and mitigation purposes.

The RVS method is designed to be implemented without performing any structural calculations and utilises a scoring system that requires the evaluator to identify the primary structural lateral load-resisting system together with the building attributes that modify the seismic performance expected for this lateral load-resisting system. The inspection, data collection and decision-making process typically takes place at the building site.

Data collection

Modified version of the FEMA-154/ATC-21 based data collection form was used for collecting information in the field. 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 that include 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 imagery was utilised for mapping the structures while the database was prepared using ARC INFO GIS software (version 9.3) that was also used for analysis and correlation.

Expected earthquake induced damage to structures

When exposed to a particular intensity of ground shaking, different building types experience different levels of damage depending on their inherent characteristics. Damageability is thus defined as the level of damage that is likely to be incurred in a seismic event. Sinha and Goyal (2004) have developed a methodology of correlating RVS scores of the surveyed structures in different seismic zones with probable seismic losses using European Macroseismic Scale (EMS-98) damage grades. The authors suggest only three hazard zones for RVS studies. These correspond to low (Zone II), moderate (Zone III) and high seismic risk (Zones IV and V) as more precise categorisation between Zones 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 the building performance in intense ground shaking conditions. This methodology has been used in the present study to assess the likely earthquake induced damages.

EMS-98 recommends five damage grades. Of these Grades 4 and 5 are important for vulnerability and risk assessment as these have the potential of threatening the lives of the occupants as also causing damage to the contents therein. 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.

Earthquake induced losses in economic terms

In the event of an earthquake buildings falling in high probability of Grade 5 damage and very high probability of Grade 4 damage class are likely to collapse and would thus have to be reconstructed. For the purpose of the present study, the cost of reconstruction of these structures together with likely value of the contents therein has been taken as being the economic loss likely to be incurred to the surveyed buildings. Both the covered area of the buildings and number of floors therein have been accounted for while determining the reconstruction cost. Contents of a building vary with its usage and therefore the economic worth of the contents likely to be lost is estimated as a function of the replacement cost of the structures (Table I).

Priortisation for mitigation

Despite having undertaken seismic safety audit of the structures economic constraints often limit commissioning of all the safety related provisions. This calls for prioritisation of the building stock. It is common practice to address seismic safety related issues of lifeline structures on priority basis. Hospital is an important lifeline structure that is required to function even more vigorously in the 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 also the life of the victims in the area. Special attention has therefore been accorded to hospital buildings in Mussoorie.

Seismic damageability in Mussoorie

Of the 3,344 buildings surveyed in Mussoorie the oldest is reported to be constructed in 1836 while other 282 are reportedly constructed in pre-1900 period (Figure 2). Most surveyed buildings are observed to be low rise; 1,135 being single storeyed and 1,957 being double or triple storeyed (Figure 2). As many as 30 buildings are however observed to be more than five storeyed. Most construction (94 percent) is observed to be unconfined rubble masonry, mostly stone and brick masonry with slate/CGI roofing. Most buildings of the town can thus be classified as being non-engineered.

Analysis of the data collected in the field shows that 18 percent of the surveyed buildings fall in high probability of Grade 5 damage and very high probability of Grade 4 damage in case of damage reaching intensity VIII on MSK scale. Most buildings falling in this damage class are constructed in pre-1950 phase; 21 percent

Table I. Value of building contents as percent of the reconstruction cost

Building usage	Content value (percent of the reconstruction cost)
Residential	50
School	25
Commercial (shops)	200
Mixed (shops and residential)	100
Hotel	25
Hospital	400
Religious	10
Office	50

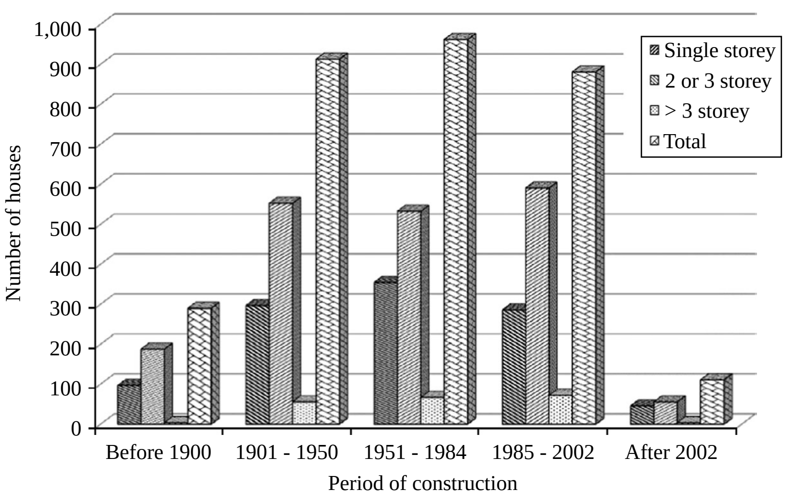


Figure 2. Diagram showing building construction trend in Mussoorie

in pre-1900 and 52 percent between 1901 and 1950 (Figure 3). It is important to note that most structures falling in high damage grade are low rise; 30 percent being single storeyed and 61 percent being two or three storeyed. This need not lead one to conclude that particular care is taken while constructing multi-storeyed buildings as only 16 percent of the surveyed single storeyed buildings fall in high probability of Grade 5 damage and very high probability of Grade 4 damage class while 19 percent of two or three storeyed and 27 percent of more than three storeyed buildings fall in this damage class.

Total built up area of the structures falling in high probability of Grade 5 damage and very high probability of Grade 4 damage class in Mussoorie is calculated to be 296,974 m^2. At the standard rate of US$108 per m^2 the replacement cost of these buildings is estimated to be US$32.07 million. This however is a gross underestimate as this does not include the cost of demolition of the structures and the cost of restoration of structures falling in other damage grade classes. It is further estimated that contents worth US$20.40 million would be lost in these structures. Total direct economic loss of US$52.47 million is thus estimated to incur to the surveyed structures in the Himalayan township of Mussoorie in the event of earthquake induced damage reaching intensity VIII on MSK scale.

State of the health infrastructure in Mussoorie

In total, 14 hospital buildings of Mussoorie are covered by the present study. These include government hospitals as also Private hospitals run by individual trusts. Of these six hospitals each are single and double storeyed while two are three storeyed and all have sloping tin roofs. It is important to note that majority of these buildings (11) are quite old and are reportedly constructed in pre-1950 period. Two of the buildings are even reported to be constructed in pre-1900 phase. Age of these structures is sure to reflect adversely on their seismic vulnerability and is a cause of serious concern.

It is worrying to note that half of the surveyed hospitals of Mussoorie fall in high probability of Grade 5 damage and very high probability of Grade 4 damage class while another five fall in high probability of Grade 4 damage and very high probability

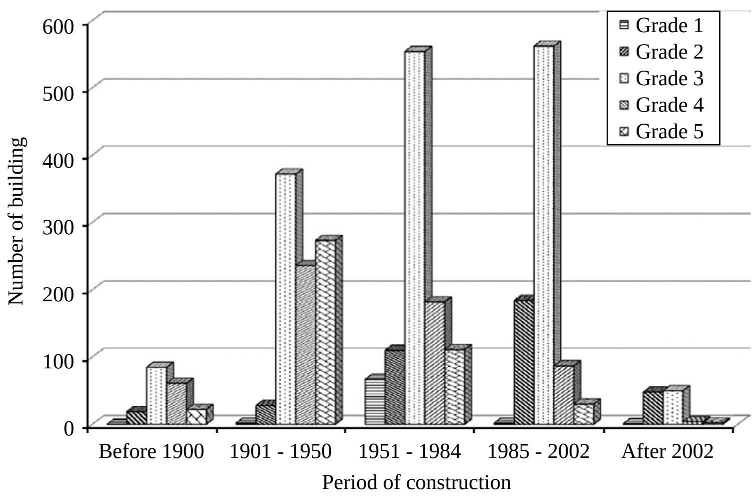


Figure 3. Diagram depicting distribution of the buildings falling under different damage grade classes with respect to their period of construction

of Grade 3 damage class. All the hospitals falling in high probability of Grade 5 damage and very high probability of Grade 4 damage class are constructed before 1907 and most (04) are single storeyed.

Total built up area of the hospitals falling in high probability of Grade 5 damage and very high probability of Grade 4 damage class is estimated to be 4,911 m^2. The cost of replacement of these structures at standard rate of US$108 per m^2 thus comes out to be US$0.53 million while the contents worth US$2.12 million are expected to be lost in the event. Thus, total economic losses to the hospital buildings falling in high probability of Grade 5 damage and very high probability of Grade 4 damage class is expected to be US$2.65 million.

Discussion and conclusion

Earthquake is a harsh reality for any tectonically active region. Constraints in earthquake prediction amplify the importance of effective planning, preparedness and mitigation for saving lives and property. Assessment of seismic vulnerability is however a necessary precondition for realistic planning and effective mitigation. RVS, together with GIS and remote sensing tools, has been utilised in the present study for assessing seismic vulnerability of the built environment of Mussoorie that falls in Zone IV of Earthquake Zoning Map of India.

Of the surveyed 3,344 buildings 18 percent show high probability of Grade 5 damage and very high probability of Grade 4 damage in the event of a seismic activity reaching intensity VIII on MSK scale. Most of these buildings are reportedly constructed in pre-1950 phase with only 6 percent being constructed in post-1984 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 and therefore vulnerability assessment of these buildings is accorded special attention.

In total, 14 hospitals of 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 half of the surveyed hospital buildings are likely to incur serious structural losses (high probability of Grade 5 damage and very high probability of Grade 4 damage) while the essential services in the other five falling in high probability of Grade 4 damage and very high probability of Grade 3 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 township but it is important to note that 12 out of 14 surveyed hospitals of the township would probably not be in a position to deliver the intended emergency healthcare facilities due to varying degrees of structural and non-structural damage. Such a situation would enhance pressure upon the resources of the remaining hospitals that are ill equipped to cope with such a scenario. This is likely to result in total collapse of healthcare facilities in the township on the aftermath of an earthquake.

In any case the seismic event is not expected to be localized and therefore additional healthcare reinforcement cannot be expected to arrive soon from the nearby towns. Disruption of transportation network due to earthquake induced landslides can further complicate the situation. This would result in complete chaos and foil the gains of all search and rescue attempts. The toll of the disaster could thus be magnified by manifold.

The study thus reveals the harsh fact that most health care infrastructure in the township of 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 study a detailed mitigation plan needs to be evolved for timely rehabilitation of lifeline structures. This strategy has to have happy blend of demolition – reconstruction and retrofitting and the required factor of safety (1.5) as enumerated by the (ISs) code for important buildings should necessarily be ensured 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 of the IS code and appropriate legislative measures should necessarily be invoked for ensuring the same. The Act of the Parliament of India (Disaster Management Act, 2005) also 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 utilised to ensure the safety of lifeline structures.

Together with lifeline structures it is highly important to ensure safety of other buildings as well. As revealed by the study most buildings in Mussoorie date back to time when concepts of seismic safety were not well developed and these are not expected to comply with present day seismic safety standards. It would neither be practical nor feasible to demolish and reconstruct majority of the buildings by enacting a law. It is therefore important to undertake aggressive and massive awareness drive for risk communication and for popularising 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 be a part of the mitigation drive. Risk transfer options with differential premium would also lead to people's participation in risk reduction measures.

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 political parties. It is at the same time important to communicate the importance of the issue to the masses so that public opinion is built in favour 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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