International Journal of Disaster Risk Reduction 13 (2015) 400–408

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

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

Piyoosh Rautela*, Girish Chandra Joshi, Bhupendra Bhaisora, Chanderkala Dhyani, Suman Ghildiyal, Ashish Rawat

Disaster Mitigation and Management Centre, Department of Disaster Management, Government of Uttarakhand, Uttarakhand Secretariat, Rajpur Road, Dehradun 248001, Uttarakhand, India

ARTICLE INFO

Article history:
Received 12 July 2015
Received in revised form
26 August 2015
Accepted 26 August 2015
Available online 28 August 2015

Keywords:
Himalaya
Uttarakhand
Earthquake
Seismic vulnerability
Damageability
Building performance
Vulnerability analysis

ABSTRACT

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.

* Corresponding author.
E-mail address: rautelapiyoosh@gmail.com (P. Rautela).

http://dx.doi.org/10.1016/j.ijdrr.2015.08.008
2212-4209/

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;