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Seismic hazard analysis of India using areal sources

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ABSTRACT

In view of the major advancement made in understanding the seismicity and seismotectonics of the Indian region in recent times, an updated probabilistic seismic hazard map of India covering 6–38°N and 68–98°E is prepared. This paper presents the results of probabilistic seismic hazard analysis of India done using regional seismic source zones and four well recognized attenuation relations considering varied tectonic provinces in the region. The study area was divided into small grids of size 0.1° × 0.1°. Peak Horizontal Acceleration (PHA) and spectral accelerations for periods 0.1 s and 1 s have been estimated and contour maps showing the spatial variation of the same are presented in the paper. The present study shows that the seismic hazard is moderate in peninsular shield, but the hazard in most parts of North and Northeast India is high.

1. Introduction

Earthquakes are known to have occurred in the region of the Indian subcontinent from ancient times. Many great earthquakes have occurred in the northern subcontinent and in the Andaman & Nicobar regions. In the southern peninsula, damaging earthquakes have occurred but less frequently and with lower magnitudes than at the plate boundaries. The latest version of the seismic zoning map of India given in the earthquake resistant design code of India (BIS-1893 (Part 1), 2002) assigns four levels of seismicity for the entire country in terms of different zone factors. It was entirely based on earthquake history, seismotectonic setup and geophysical data, not based on a detailed hazard analysis. This points towards the need for evaluating the seismic hazard of India and development of a seismic zonation map of India based on the Peak Horizontal Acceleration (PHA) values.

The improper building construction techniques adopted in the rural areas and the high population density is the major causes of the heavy damage due to earthquakes in India. For a developing country like India, the steps towards seismic hazard evaluation are very essential to estimate an optimum value of possible earthquake ground motion during a specific time period. These predicted values will be an input to assess the seismic vulnerability of an area based on which new construction and the restoration works of existing structures can be carried out. Several attempts have been made in the past by various researchers to analyze the seismic hazard in various parts of the country (Bhatia et al., 1999 (India and adjoining areas); Seeber et al., 1999 (Maharashtra state); Jaiswal and Sinha, 2007 (Peninsular India); Vipin et al., 2009 (South India); Menon et al., 2010 (Tamil Nadu); Iyengar et al., 2010 (for Indian landmass) among many others). These past works focus on a specific region or use different methodologies to delineate seismic sources and to predict the ground motion.

The Indian subcontinent has a complex seismotectonic set up. The country is spread over a vast region and seismic activity in the region is non-uniform. This necessitates identifying regional seismic source zones with similar seismic activity based on space limits. In view of the major advancement made in understanding the seismicity and seismotectonics of this region, an updated probabilistic seismic hazard map of India covering 6–38°N and 68°–98°E will be presented in this paper using the latest data and its best scientific interpretation. Probabilistic Seismic hazard analyzes have been carried out using CRISIS software (Ordaz et al., 2007) to model areal sources and to estimate the seismic hazard with polygon–dipping areas. The outcome of the PSHA consists of seismic hazard contour maps of India for the horizontal component of ground motion for different structural periods (PHA, spectral acceleration at 0.1 and 1.0 s), on bedrock conditions with an estimated shear wave velocity of 1500 m/s.

2. Seismotectonic framework of the study region

The tectonic framework of Indian subcontinent covering an area of about 3.2 million sq. km is spatially varied and complex. Indian plate is moving northward at about 5 cm per year and it collides with the Eurasian Plate. Upon the Eurasian Plate lie the Tibet plateau & Central Asia. When continents converge, large amounts of

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shortening and thickening take place, like at the Himalayas and the Tibet. Due to this massive collision, the Himalayas were formed and large numbers of earthquakes are generated due to this process. This plate boundary extends from Himalayan regions to the Arakan Yoma and is a major cause of earthquakes in this region. A similar process, involving the Indian Plate and the Burmese micro-plate, results in earthquakes in the Andaman & Nicobar Islands. In addition to this there are earthquakes occurring within the Indian shield region, in the Indian peninsula and in adjoining parts of the Arabian Sea or the Bay of Bengal.

Majority of earthquakes occur along narrow zones that follow the edges of tectonic plates. These events are known as Inter-Plate or Plate Boundary earthquakes. These earthquakes are the direct result of the interaction between two or more tectonic plates. Sometimes earthquakes occur far away from plate boundaries. These arise due to localized systems of forces in the crust sometimes associated with ancient geological structures such as in the Rann of Kachchh in Gujarat. All earthquakes in peninsular India fall within this category. The plate boundary areas along the Himalayas and the Indo-Burmese arcs, along with the intervening area of northeast India, are characterized by very high level of seismicity (Gupta, 2006). The analysis of the seismic activity in India can be broadly characterized by three general seismotectonic considerations (Fig. 1): Tectonically active shallow crustal region, subduction zones and stable continental region (Nath and Thingbaijam, 2010). The subduction zone earthquakes can be further divided as regions with intraslab and interface earthquakes.

The tectonically active interplate regions include the Himalayas and southern Tibetan Plateau, northwest frontier province of Indian plate (Nath and Thingbaijam, 2010; Kayal, 2008). The Indian plate was considered as one of the fastest moving plates in the world. Before its collision with the Eurasian plate it has attained a very high velocity of around 20 cm/year (Kumar et al. 2007). The current movement of Indian plate is estimated to be around 5 cm/year. The collision and the subsequent formation of the Himalayas and the Tibetan Plateau are associated with very high seismicity.

The subduction zones include that of Hindukush–Pamir in the northwest frontier province, Indo-Myanmar arc, and Andaman–Sumatra seismic belt. The Indo-Burmese arc is an important tectonic feature, the seismicity of which is related to the subduction of the Indian plate underneath the Southeast Asian plate due to northeastward motion of India (Deshikachar, 1974). The northeastern corner of India, sandwiched between the Himalayan and Burmese arcs, is characterized by a complex seismotectonic setup and very high level of seismicity (Evans, 1964). The earthquakes in this area are of intraslab in nature (Gupta, 2010). This region falls at the junction of N–S trending Burmese arc and E–W trending Himalayan Arc. Due to this the entire region has suffered multiple phases of deformation processes and this has resulted in numerous geological structures (Sharma and Malik, 2006). The Andaman & Nicobar Islands, which are situated on the south eastern side of Indian land mass, consist of about 527 islands. The entire island chain is along the plate boundary between the Indian plate and the Burmese plate. These regions come under subduction zones with interface earthquakes. This region is also put in Zone V of the Indian Seismic zonation code (BIS-1893, 2002). Lots of damaging earthquakes and Tsunami has hit the Andaman–Nicobar Islands in the past.

Peninsular India is delineated as Stable Continental Region (SCR) with low to moderate seismic activity (Chandra, 1977). The seismicity of this region is of intraplate nature and appears to be associated with some local faults and weak zones (Rao and Murty, 1970). The ENE–WSW trending Son-Narmada-Tapti zone is a prominent tectonic province forming the northern margin of the peninsular shield of India. The major tectonic elements in the southern part of the peninsula can be listed as the massive Deccan Volcanic Province, the Southern Indian Granulite Terrain, the Dharwar Craton, the Cuddapah Basin, the Godavari and the Mahanadi Grabens, and the Eastern and Western Ghats on the east and west coasts, respectively (Gupta, 2006). The researchers like Purnachandra Rao (1999), Gangrade and Arora (2000), and Reddy (2003) have highlighted the need for seismic study of southern Peninsular India. The Bhuj earthquake (26 January 2001; Causality around 19,000) and Latur earthquake (30 September 1993; Causality around 7928) are the deadliest earthquakes in this region.

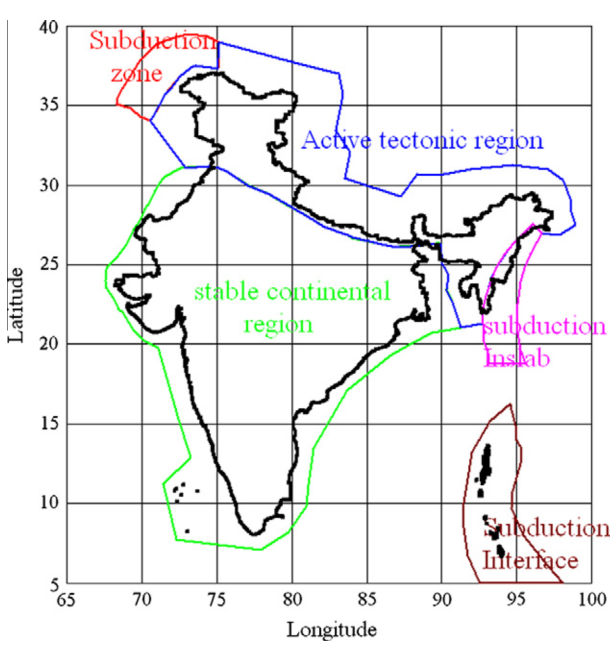

Fig. 1. Tectonic provinces in and around India (after Gupta (2006) and Nath and Thingbaijam (2010)).

3. Ground motion prediction equations

In India, there is scarcity of strong motion data and this in turn has resulted in the development of only very few region specific GMPEs. Some of the important GMPE available in India are Sharma (1998) for the Himalayan region, Iyengar and Ghosh (2004) for Delhi region; Raghu Kanth and Iyengar (2007) for Peninsular India; Nath et al. (2005) for Sikkim Himalaya; Nath et al. (2009) for Guwhati and Sharma et al. (2009) for Himalayan Region. Since only a few attenuation relations were available for the study area, in the present study we have used some of the well accepted GMPEs which were developed for other regions of the world which are having similar seismic attenuation characteristics. In a recent study, Nath and Thingbaijam (2010) reviewed the ground motion prediction in Indian scenario with reference to existing GMPEs developed for different tectonic environments and those employed by different regional hazard studies.

In the present analysis, different GMPEs were used to model the attenuation properties of the plate boundary region, shield region and subduction zones. The relation used for Shield region is Raghu Kanth and Iyengar (2007) which was developed for the Peninsular Indian Shield regions. Raghu Kanth and Iyengar (2007) observed that their model have predictions similar to those of the available models for other intraplate regions. The GMPE used for active tectonic regions is Sharma et al. (2009) developed for Himalayan regions of India.

Gupta (2010) analysed a limited number of strong-motion data recorded in the northeast Indian region, and concluded that the