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Earthquake ground motion predictive equations for Garhwal Himalaya, India

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ABSTRACT

Predictive equations based on the stochastic approach are developed for earthquake ground motions from Garhwal Himalayan earthquakes of $3.5 \le M_w \le 6.8$ at a distance of $10 \le R \le 250$ km. The predicted ground motion parameters are response spectral values at frequencies from 0.25 to 20 Hz, and peak ground acceleration (PGA). The ground motion prediction equations (GMPEs) are derived from an empirically based stochastic ground motion model. The GMPEs show a fair agreement with the empirically developed ground motion equations from Himalaya as well as the NGA equation. The proposed relations also reasonably predict the observed ground motion of two major Himalayan earthquakes from Garhwal Himalayan region. For high magnitudes, there is insufficient data to satisfactorily judge the relationship; however it reasonably predicts the 1991 Uttarkashi earthquake (M_w=6.8) and 1999 Chamoli earthquake (M_w=6.4) from Garhwal Himalaya region.

1. Introduction

The importance of estimating the seismic hazard in Garhwal Himalaya region can never be overlooked. Some of the major population centers such as Dehradun, Haridwar, Roorkee, Meerut, and Delhi National Capital Region (NCR) are in the close vicinity of the Garhwal Himalaya and frequently experience mild shaking due to occurrence of damaging earthquakes in the region.

The entire Himalayan belt starting from the Kashmir Himalaya to the Northeast Himalaya is approximately 2500 km long and frequency of occurrence of small-to-moderate earthquake along this belt is very high. Hence, it is important to understand the regional seismicity and attenuation characteristics of ground motion in the Himalayan region, which primarily depends on the quality and the availability of regional strong motion data.

In Himalaya, strong motion recording stations are sparsely distributed. A few strong motion records are available for the study regions. The lack of strong motion data can be remedied either by using strong motion records from other regions having similar geological and tectonic setup or by generating synthetic data for the region. Thus, an appropriate method based on the physics of the earthquake faulting, which includes the region-specific effects of the earthquake source, propagation model, and site conditions, can essentially be adopted for predicting the ground motion of the future earthquakes. There are several approaches for simulation of the ground motion among which the stochastic model for simulation of strong ground motions has found substantial application in earthquake engineering, which successfully presents comparisons of predicted and recorded data. It is a relatively simple and computationally efficient approach particularly useful for the regions having scarcity of strong motion records. The approach has been selected for this study as it can make large number of earthquake simulations incorporating wide range of parameters for source, site, and path effects.

Boore [1] developed a so-called band-limited white noise model for stochastic simulation of strong ground motion with seismological constraints. In the time domain procedure, a Gaussian white noise is windowed with a shaping function having a prescribed duration. The window is chosen such that the mean level of the spectrum of the windowed white noise is unity. The windowed time series is transformed back into frequency domain (using Fast Fourier Transform). Its **F**ourier **A**mplitude **S**pectrum (FAS) is scaled to the square root of the mean squared absolute spectrum and multiplied by the site specific shape of the theoretical FAS of the free-field acceleration of the horizontal ground

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motion at a site. Transformation back into the time domain results in the simulated (synthetic) time history of the horizontal component of the ground motion.

It has been seen that the stochastic ground motion model, in conjunction with Brune's point-source spectrum, successfully predicts high frequency ($f \geq 1$ Hz) ground motion amplitudes for earthquakes across the globe (e.g., California, Hanks and McGuire [2]; Eastern North America, Atkinson [3]; Toro et al. [4]; ENA, EPRI [5]; Northeast India, Raghukant et al. [6]; Peninsular India, Raghukant and Iyenger [7]). In recent years, several studies have been carried out to develop ground motion prediction equations for different parts of the world based on the stochastic method (Atkinson and Boore [8]). EPRI [5] is a comprehensive work to develop GMPEs for Central and Eastern United States (CEUS) based on stochastic ground motion simulation. Stochastic modeling is one of the important applications for characterizing earthquake ground motion in the regions, where none or a few empirically based GMPEs are available. Garhwal Himalaya is one of such region where a very few peer-reviewed GMPEs are available (e.g., Singh et al. [9]; Sharma [10]; Jain et al. [11]; Saini et al. [12]; Sharma and Bungum [13]); however, on close scrutiny by the GMPE criteria of Cotton et al. [14] (since others were not published in international peer-reviewed journals), only two by Singh et al. [9] and Sharma [10] could pass the criteria. This is the first study to develop GMPE for Garhwal Himalaya based on the stochastic approach and hence providing an alternative to lack of empirically based GMPE for the considered region.

In this paper, we have developed a new ground motion prediction equation (GMPE) for the rock site of the Garhwal Himalaya, India, using the catalog prepared by Harbindu et al. [15]. The method used to develop the GMPEs is briefly reviewed, with emphasis on the data defining each input parameter. The predictive equation is developed for estimation of peak ground acceleration (PGA) and response spectral values at different frequencies (0.25–20 Hz) for rock sites and compared to the available empirically based GMPEs for Himalaya as well as NGA equations (Boore and Atkinson [16]).

2. Seismotectonics of study area

The Himalaya tectonic zone, being a collision plate boundary, is manifested with a number of north dipping thrusts that are exposed at the surface. These thrusts originate at a decollement surface dipping 15° towards north at depths ranging from about 12 to 20 km (Seeber et al. [17]). Fault plane solutions of moderate sized earthquakes depict upthrusting from the north along shallow dipping planes (e.g. Ni and Barazangi [18]). The seismicity belt is mostly confined in between Main Central Thrust (MCT) in the north and Main Boundary Thrust (MBT) in the south, though closer to MCT (Fig. 1).

More recently, damaging earthquakes of magnitude 6.6 (Uttarkashi earthquake) and 6.8 (Chamoli earthquake) occurred in the Garhwal Kumaun Himalaya region on October 20, 1991 and March 29, 1999 respectively. These earthquakes caused widespread damage to poorly constructed buildings killing about 800 persons in Uttarkashi earthquake and 103 in Chamoli earthquake. The earthquake was felt at very far distances including Delhi (about 300 km epicenter) and maximum ground acceleration of 0.3g was recorded at Bhatwari (25 km from epicenter). The earthquake was followed by a large number of aftershocks and a maximum intensity of VIII+ was observed. The Chamoli

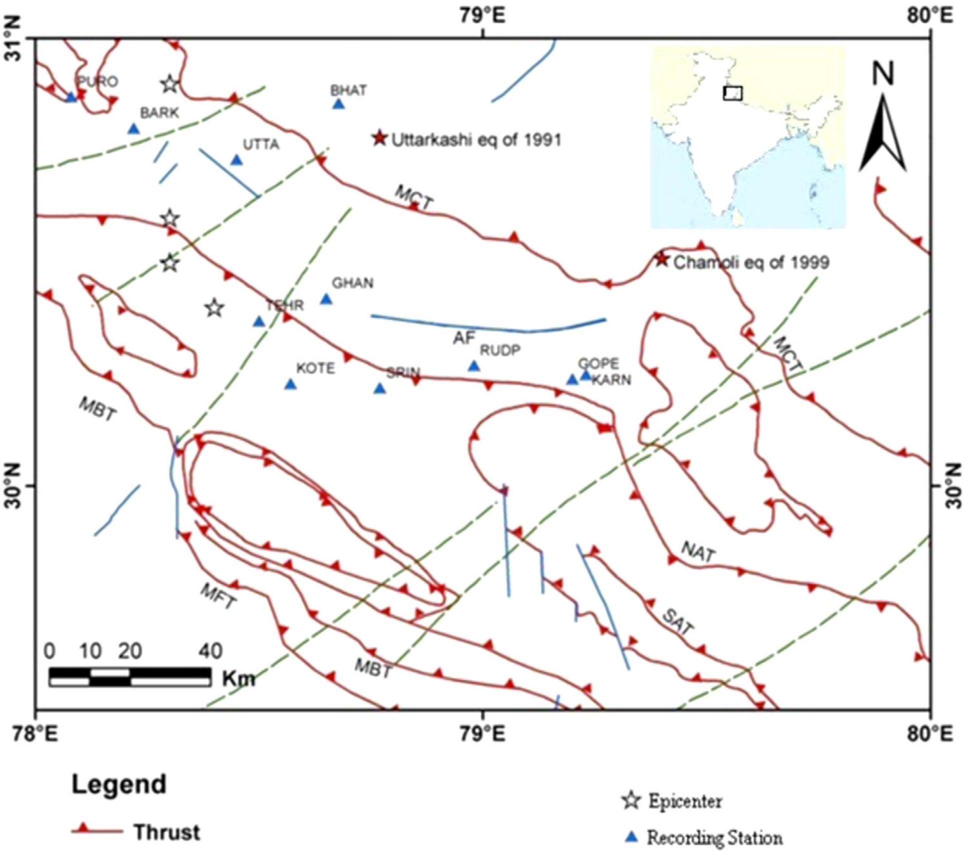

Fig. 1. Seismotectonic map of Garhwal Himalaya showing several prominent tectonic features present in the region. The triangles represent the strong motion recording stations in the region and stars show the epicenters of the earthquake considered in the present study (MBT: Main Boundary Thrust, MFT: Main Frontal Thrust, MCT: Main Central Thrust, NAT: North Almora Thrust, and SAR: South Almora Thrust).