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Ground motion prediction equation considering combined dataset of recorded and simulated ground motions

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ABSTRACT

Himalayan region is one of the most active seismic regions in the world and many researchers have highlighted the possibility of great seismic event in the near future due to seismic gap. Seismic hazard analysis and microzonation of highly populated places in the region are mandatory in a regional scale. Region specific Ground Motion Predictive Equation (GMPE) is an important input in the seismic hazard analysis for macro- and micro-zonation studies. Few GMPEs developed in India are based on the recorded data and are applicable for a particular range of magnitudes and distances. This paper focuses on the development of a new GMPE for the Himalayan region considering both the recorded and simulated earthquakes of moment magnitude 5.3–8.7. The Finite Fault simulation model has been used for the ground motion simulation considering region specific seismotectonic parameters from the past earthquakes and source models. Simulated acceleration time histories and response spectra are compared with available records. In the absence of a large number of recorded data, simulations have been performed at unavailable locations by adopting Apparent Stations concept. Earthquakes recorded up to 2007 have been used for the development of new GMPE and earthquakes records after 2007 are used to validate new GMPE. Proposed GMPE matched very well with recorded data and also with other highly ranked GMPEs developed elsewhere and applicable for the region. Comparison of response spectra also have shown good agreement with recorded earthquake data. Quantitative analysis of residuals for the proposed GMPE and region specific GMPEs to predict Nepal–India 2011 earthquake of Mw of 5.7 records values shows that the proposed GMPE predicts Peak ground acceleration and spectral acceleration for entire distance and period range with lower percent residual when compared to exiting region specific GMPEs.

1. Introduction

Ground shaking during an earthquake is responsible for structural damages and ground failures within the epicentral region as well as at far distances. Seismic hazard analysis of any region focus to arrive precise ground shaking parameters such as PGA (Peak Ground Acceleration) or Peak ground velocity (PGV). The region specific Ground Motion Prediction Equation (GMPE) is playing important role in the seismic hazard analysis for macro- and micro-level hazard mapping. Developed countries are in the process of arriving the Next Generation of ground motion Attenuation (NGA) for the better prediction of ground shaking due to any future earthquake events [20,39]. However, studies towards developing regional representative GMPEs are limited in India. Also limited regional GMPEs are available to estimate the representative seismic hazard both at bedrock at the surface by accounting the local site effects in India and other parts of the world [10,54,9]. The seismic zonation map given in Indian standard in its current form does not provide a quantitative seismic hazard values at micro-level. Many recent studies have highlighted that macro-level zonation factor (or PGA) given in Indian standard code [34] is either higher or lower than that of the micro-level PGA obtained after seismic hazard studies at regional scale [8,46,54]. Thus, the zonal values given in IS code are required to be updated after rigorous micro-level findings. Such micro-level ground motion estimation studies should be based on the past seismicity and region specific GMPE. Several seismic hazard maps are being produced in India using available GMPEs with limited validity of the degree of suitability of representative GMPEs for the region [9].

Many researchers ([40,77]) have highlighted the chances of large seismic event in Himalayan region considering the seismic activity and gap. Based on the recorded earthquake data from different parts of Himalayan region, numerous researchers have attempted for GMPEs for the region. Such GMPEs have been

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extensively used in the seismic hazard studies in and around Himalayan region. Review of existing region specific GMPEs reveals that each GMPE has its own limitations and merits. Regional GMPEs were developed considering limited range of magnitude and distance, limited near source region data, limited higher magnitude earthquakes ground motions and use of other region ground motion data. In spite of such serious limitations, these GMPEs are being used extensively for hazard mapping in Himalayan Region. Present work highlights in detail the shortcoming in the existing GMPEs and further a new GMPE is proposed using region specific ground motions. The region under study evidences plate boundary and intraplate earthquakes with majority of events following the strike-slip fault mechanism.

Initially a large ground motion data collected from the recorded ground motions from a number of earthquakes in Himalayan region. This dataset does not cover an entire distance and magnitude range. In order to make a consistent database, additional ground motions have been generated synthetically using regional seismotectonic parameters. Each earthquake synthetic ground motions have been verified by comparing with available recorded data acceleration time history and response spectra. Once, sufficient validation between the recorded and synthetic ground motion has been found, more number of ground motions have been generated which are distributed uniformly around the epicentre covering a wide range of distances. Further to account large magnitude in GMPE, synthetic ground motions for major and great earthquakes have been generated which have been verified by comparing with PGA values from the isoseismal maps. Real and synthetic ground motions at rock level are used to arrive the PGA and spectral acceleration at different period, which are used to develop a new GMPE for Himalayan region. The new GMPE proposed has been validated by comparing with the PGA of the recent earthquake, which was not the part of database. The proposed GMPE is derived using more realistic and large regional dataset when compared to earlier published GMPEs. The predicated PGA and spectral acceleration values by proposed GMPE match well with recent recorded earthquakes and is valid for wide range of magnitudes and distances.

2. Existing regional GMPE models

In order to develop the best suitable GMPEs for any region, capturing of tectonic setting is a prerequisite. In order to understand this, a large number of recorded ground motions which are distributed over a wide range of magnitude, distance, source and site parameters should be known. Various researchers have analysed the attenuation characteristics of the Himalayan region based on the available data. Region specific GMPEs developed by Singh et al. [69], Sharma [65], Iyenger and Ghosh [35], Nath et al. [52,51], Sharma and Bungum [63], Das et al. [23], Baruah et al. [11], Sharma et al. [64] and Gupta [28] are based on the recorded as well as simulated earthquake data in the Himalayan region. In addition to these equations, NDMA (National Disaster Management Authority, 2010) [78], Government of India, developed indigenous GMPEs for the probabilistic seismic hazard mapping of India considering only the simulated data. A summary of the existing GMPEs for the Himalayan region in terms of magnitude range, distance range, frequency ranges and the database used for the development is presented in Table 1.

Singh et al. [69] had developed attenuation relation for Himalayan region based on the recorded earthquake data. General form of the attenuation equation given by Kanai [42] was used for the analysis. Singh et al. [69] had estimated the coefficients in the attenuation relation for felt earthquakes based on isoseismal maps. The authors then correlated the coefficients from PGA attenuation relation with the Modified Mercalli Intensity scale (MMI) attenuation relation and compiled the final coefficients of GMPE for Himalayan region. This final form of GMPE given by Singh et al. [69] is applicable to the magnitude range of 5.5–6.8 and up to hypocentral distance of 100 km. Similarly, Sharma [65] had developed the attenuation relation for Himalayan region based on 66 peak ground acceleration records from 5 earthquakes with a magnitude range from 5.5–6.8, reported from 1986 to 1991. Most of these earthquake data cover an epicentre distances of up to 150 km. Earthquake data set used by Singh et al. [69] and Sharma [65] were similar and no standard error terms were incorporated in both the GMPEs. In the absence of the standard error term, these GMPEs have limited application in the Probabilistic Seismic Hazard Analysis (PSHA). Hence, these two GMPEs are not considered in this study.

Iyenger and Ghosh [35] have highlighted the limitations of GMPE by Sharma [65] for PSHA. Iyenger and Ghosh [35] proposed a new GMPE by combining the earthquake data used by Sharma [65] and earthquakes data recorded around Delhi region. The input data consist of events recorded within 300 km radial distance around Delhi for an earthquake magnitude range of 4.0–7.0. Iyenger and Ghosh [35] have shown that the annual rate of earthquake occurrence in Delhi is much lesser compared to the Himalayan region.

Nath et al. [52] had developed GMPE based on 80 earthquakes recorded in the Shillong Strong Motion Array (SSMA) during the period of 1998–2003. These earthquakes were in local magnitudes

Table 1
Summary of GMPEs developed for the Himalayan region.

SL. no.	Study	Range of magnitude (Mw)	Distance range (km)	Distance function used	Spectral coefficients available for periods	Remarks
1.	Singh et al. [69]	5.5–6.8	≤100	R_{HYPO}	zero	Felt earthquake isoseismal maps of 5 events are used
2.	Sharma [65]	5.5–6.8	≤150	R_{HYPO}	zero	66 recorded data from 5 earthquakes
3.	[35]	4.0–7.0	≤300	R_{HYPO}	zero	Earthquakes data recorded around Delhi region
4.	Nath et al. [52]	3–8.5	≤100	R_{HYPO}	0.06–0.4	80 recorded events in Shillong Strong Motion Array (3.0–5.6) and 25 simulated events (5.6–8.5)
5.	Das et al. [23]	5.5–7.2	≤300	R_{EPIC}	0.04–1.0	261 recorded data from 6 moderate earthquakes at 87 stations
6.	Sharma and Bungum [63]	4.6–7.6	≤200	R_{HYPO}	0.04–2.5	Combined dataset of 175 ground motions of 14 earthquake from India (4.6–6.6) and 9 earthquakes from Europe (6.2–7.6).
7.	Baruah et al. [11]	2.5–5.0	≤145	R_{HYPO}	zero	82 recorded earthquakes at 8 broadband stations
8.	Nath et al. [51]	4.8–8.1	≤100	R_{RUP}	0.05–4.0	Simulated ground motions considering model parameters used in Mw of 4.8 simulation
9.	Sharma et al. [64]	5.2–6.9	≤ 100	R_{JB}	0.04–2.5	Combined dataset consisting of 6 recorded earthquakes from India and 10 recorded earthquakes from Zegros region
10.	Gupta [28]	6.3–7.2	> 150	R_{RUP}	0.02–3.0	56 recorded data from 3 events
11	NDMA [54]	4–8.5	≤500	R_{HYPO}	0.0–4.0	1600 Simulated ground motions