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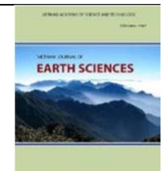

Empirical Attenuation relationship for Peak Ground Horizontal Acceleration for North-East Himalaya

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ABSTRACT

North-East India is located in one of the most seismic prone areas of the world. India has faced several devastating earthquakes in the past. The largest of these have originated in the Himalayan plate boundary region, which has remained a region of great scientific and engineering interest. In spite of this, very little seismological information is available about North- East India, which is the focus for present study. Only few attenuation relationships are available for this region, which are most valuable in a region where too much strong motion recordings are not available. However in recent time, with the inception of 300 strong motion instruments under Indian National Strong Motion Network deployed under Mission Mode project (Government of India), a good quality of strong motion data became available. Taking the advantage of data collected by this network and earlier analogue strong motion arrays, an endeavor has been made to develop an empirical attenuation relationship for peak horizontal ground accelerations for North-East Himalayan region in India. The data set consists of 216 peak ground horizontal accelerations from 24 earthquakes (4.0≤M≤6.8) recorded by strong-motion arrays and National Strong Motion Network project in India. The present analysis uses a two-step stratified regression model. The estimated attenuation relationship for the region is

$$\log(A) = -1.497 + 0.3882M - 1.19log(X + e^{0.2876M})$$

Where A is the peak ground acceleration (g), M is the magnitude, and X is the hypocentral distance from the source. The residual sum of squares is 0.1451. The obtained Empirical attenuation relationship will provide better insight for site specific studies as well as for hazard estimation for North-East Himalayan region. Attenuation relationships for expected peak ground acceleration (g) have been presented for magnitudes 5, 6, 7 and 8 for North-East Himalayan region.

Keywords: Empirical, attenuation, regression, mission-mode, North-East Himalaya.

1. Introduction

The collision of the Indian tectonic plate with the Eurasian Plate creates wonderful arc shaped Himalayan mountain ranges that extend from west-northwest to east-southeast These mountain ranges have length of about

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2,400 kilometres; width varies from 400 kilometres in the west to 150 kilometres in the east and attained heights up to 7,200 metres. Many major rivers originate from the glaciers of the Himalaya and provide homage to more than 600 million people. This region has a great potential for hydropower generation, and a number of small to large-scale hydropower projects are either in operation or are in under construction. But the region is also challenged by high seismic activity. Several tectonic features of local and regional scale have been mapped in the region around. Many moderate to large sized earthquakes, have occurred in this region. The whole Himalayan region is seismically very active. Like the other parts of Himalaya, the north-eastern Himalaya exhibits quiet high seismicity and lies within the seismic zone IV and zone V as per IS Code (IS 1893 (Part 1): 2002). Several earthquakes of smaller to moderate magnitudes have occurred in this region (Verma et al., 1976; Mukhopadhayay, 1984; Kayal, 1987; Kumar et al., 2012, 2013a, b). The two great earthquakes namely Shillong (1897) and Assam (1950) earthquakes having magnitudes 8.1 and 8.6, respectively occurred in this region. Shillong earthquake on June 12, 1897 (Mw, −8.1) was located near the northern edge of Shillong Plateau while Assam earthquake of August 15, 1950 was located in Mishmi hills. On September 18, 2011 the Sikkim earthquake of magnitude Mw 6.8 occurred in this region.

Earthquakes are one of the most unpredictable natural phenomena. As prediction of earthquakes is impossible now, only well engineered structures is the way to get safety. To reduce the loss of life and property, men have tried to estimate the level of ground shaking to which they may be subjected. Since the level of ground shaking is most commonly used in terms of ground motion parameters, methods for estimating ground motion parameters are required. The design of any engineered structures is based on the estimate of strong motion, either implicitly through the use of building codes or explicitly in the site-specific design of large or particularly critical structures (Sharma, 2005). Ground Motion Prediction Equations (GMPEs) are used for the estimation of the ground motion parameters which are needed for the design and evaluation of important structures including the nuclear power plants, hydel projects, etc. The seismic hazard may contribute greatly to the total risk of a nuclear power plant. Therefore, the selection of appropriate GMPEs may have a great influence on the design and safety of a structure. Development of a predictive mathematical model, called Attenuation Relationship is necessary to predict strong ground motion necessary to carry out a comprehensive assessment of seismic hazard and risk to reduce the economic and social effects. The data to develop empirical attenuation relationships consists of accelerogram recorded from previous earthquakes in three orthogonal directions, longitudinal, transversal and vertical. Such relationships have been developed in the past for various regions, and comprehensive reviews have been published for such relationships (Boore and Joyner, 1982; Campbell, 1985; Joyner and Boore, 1988; Abrahamson and Litehiser, 1989; Fukushima and Tanaka, 1990; Sharma, 1998; Douglas 2001 etc.). Attenuation relationships have been mainly developed for peak ground acceleration and response spectra. GMPEs describe the variation of the median and lognormal standard deviation of intensity measures (such as peak acceleration, spectral acceleration, or duration) with magnitude, site-source distance, site condition, and other parameters (Kramer, 1996). Different combinations of horizontal components are used in different attenuation relationship, such as, larger component (Ambraseys & Douglas, 2003), both components (Fukushima et al., 2003), geometric mean (Campbell & Bozorgnia, 2003), randomly chosen component (Atkinson & Boore, 2003), resolved component (Sun & Peng, 1993) etc.

Most of the relationships are developed using worldwide acceleration data acquired through the strong-motion arrays. A number of attenuation relationships have been developed using the dataset of Indian earthquake (e.g. Aman et al., 1995; Singh et al., 1996; Sharma, 1998; Jain et al., 2000; Iyengar and Ghosh, 2004; Nath et al., 2012; Raghukanth and Kavitha, 2014). Most of the dataset have been taken from the Himalayan region. In the present work, the strong motion data from strong-motion arrays and mission mode projects have been used to develop empirical attenuation relationship for peak ground acceleration for North-East Himalayan, as only few attenuation relationships are available for this region.

2. Seismotectonics and Seismicity

The entire Indian subcontinent can be divided into three main sub-regions on the basis of general geological and tectonic features (Khattri et al. 1984). The first sub-region is formed by the Kirthar and Sulaiman mountain ranges in the northwest, the Himalayan Mountains in the north, extending from west to east for a distance of 2500 km and the Arakan Yoma mountain ranges in the east, extending from north to south into the island arc system of the Andaman Nicobar, Sumatra and Java Islands. The average elevation in this region lies between 1000 and 4500 m.

The area covering the north-eastern part of India and northern Burma is one of the most interesting in the world from the viewpoint of tectonics. This area includes several prominent tectonic features such as the Arakan-Yoma, the Assam Valley, the Bengal basin, the Eastern Himalayas, the Irrawaddy basin, Naga Hills, Shillong Plateau, etc. The area lies approximately between latitude 20°N to 28°N and longitude 88° to 98°E (Figure 1).

In northeastern India, large scale thrust movements have taken place from northwest and southeast directions resulting in crustal shortening estimated to be of the order of 150 to 300 km (Evans, 1964). In northern Burma, the movements have been mostly in the east-west direction. These thrust movements have culminated in the formation of the northeast Himalaya in the north, Naga Hills to the southeast of Assam Valley, the folded belt of Tripura and Arakan-Yoma in northern Burma. Figure 1 shows the generalized tectonic map of India (Parvez et al., 2008).

Northeast India is seismically one of the six most active regions of the world, the other five being Mexico, Taiwan, California, Japan, and Turkey. It is placed in zone 5, the highest zone, of the seismic zonation map of India. It lies at the junction of the Himalayan arc to the north and Burmese arc to the east. The region has experienced 18 large earthquakes ($M \geq 7$) during the last hundred years including the great earthquakes of Shillong (1897, $M = 8.7$) and Assam-Tibet border (1950, $M = 8.7$). Besides, several hundred small and microearthquakes have also been recorded in the region. The high seismicity in the region is attributed to the collision tectonics between the Indian plate and the Eurasian plate in the north and subduction tectonics along the Indo-Myanmar range (IMR) in the east (Dewey and Bird 1970; Kayal, 1996, 1998). The high seismicity of the northeast Indian region has been attributed to a complex tectonic province displaying juxtaposition of the E-W trending the Himalaya and the N-S trending Arakan Yoma belt. The major tectonic background includes the eastern Himalayan structures, the Mishmi massif, the Indo-Myanmar arc, the Brahmaputra valley, and the Shillong plateau. The Himalayan structures mainly consist of the thrust planes namely the Main Central Thrust (MCT), Main Boundary thrust (MBT), Main Frontal Thrust (MFT), and their subsidiaries (Nandy 2001). The movement along the Po Chu fault, in the northeastern part of the region, is believed to have caused the 1950 Great Assam Earthquake of Mw 8.7 (Ben-Menahem 1974; Thingbaijam et al., 2008). The Shillong plateau has been implicated with a pop-up tectonics associating the 1897 Great Earthquake of Mw 8.1 (Bilham and England 2001). The southern end of the Kopili fault is believed to have generated the 1869 Cachar earthquake of MW 7.4. The Indo-Myanmar arc, sidelined by Patkoi-Naga-Manipur-Chin hills, has been associated with 1988 Manipur Earthquake of Mw 7.2. Overall, seismic activities in the region have been quite significant.

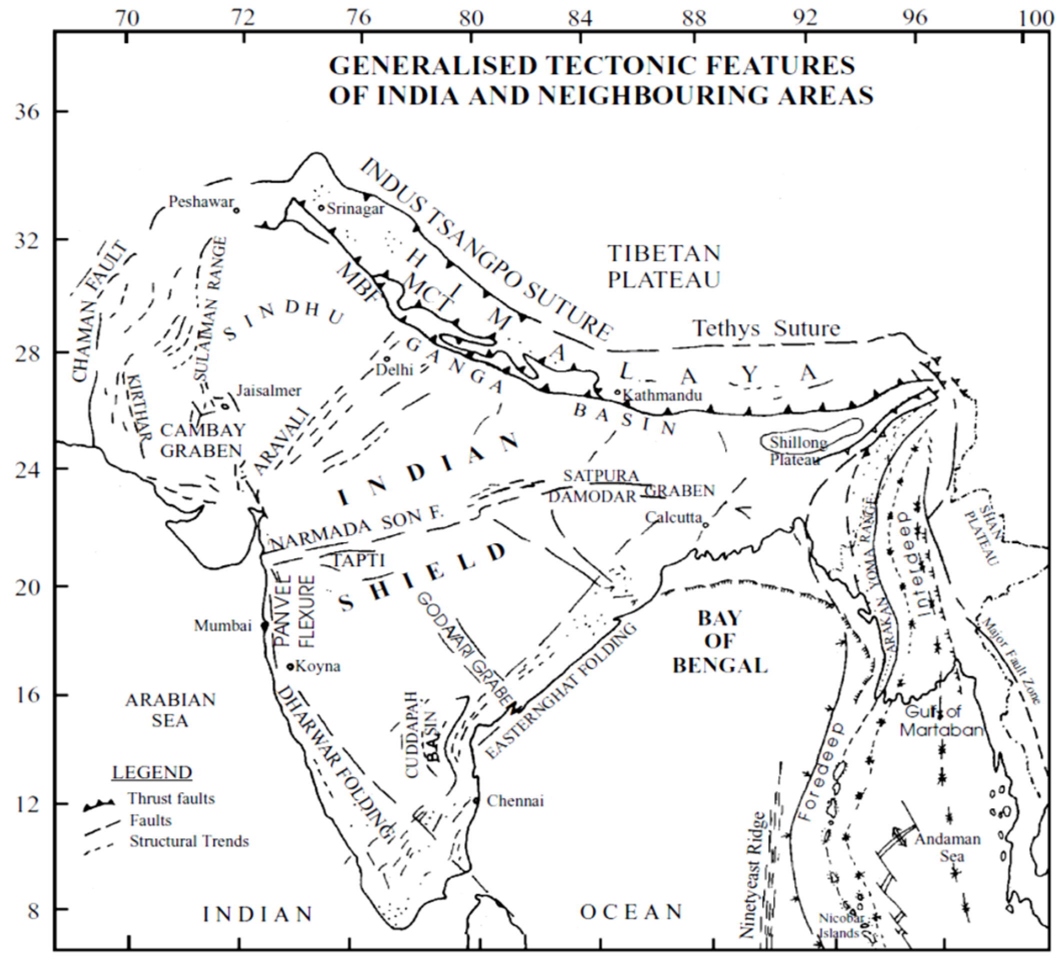

Figure 1. Generalized tectonic map of India and adjacent areas (Parvez et al., 2008)

3. Acceleration Data

Two types of data sets collected from the region of the Garhwal and Kumaon Himalaya have been used in the study. These data sets are briefly described in the following paragraphs:

The first data set 111 records from 7 earthquakes ($5.2 \leq M \leq 6.8$) as shown in figure 2 became available from the deployment of a strong motion array comprised of strong motion accelerographs (SMA-1 of Kinematrics) in the NE Himalaya for the purpose of measuring the strong ground motion due to moderate and large-sized earthquakes occurring in the region (Chandrasekaran, 1991). At each station, the threshold level (trigger level) to sense the ground motion was set about 0.01 g.

The analog recordings of these earthquakes were manually digitized using a semi-automatic digitizer and digital data was processed adopting standard processing procedures (Trifunac, 1976). The data was converted to a uniform sampling rate of 0.02 seconds and band-pass filtered (0.17-0.20 Hz; 25-27 Hz) using an Ormsby filter (Chandrasekaran and Das, 1992).

The second data set of 105 records from 17 earthquakes of magnitude range (4.0≤M≤6.8) was recorded by recently installed digital accelerographs (Figure 3) in the North-East Himalaya. These accelerograph installations form part of the National Strong Motion Network of 300 strong motion stations deployed under Mission Mode project to cover seismic zones V, IV and some thickly populated cities falling in seismic zone III (Kumar et al., 2012; Mittal et al., 2012). The digital accelerographs are of GSR-18 type (Geosig, model GSR-18) and data is acquired at a sampling rate of 200 Hz. About 260 digital accelerographs, networked using NIC-net allows monitoring the health of accelerographs as well as downloading of the strong motion data at IIT Roorkee campus.

The earthquakes considered for attenuation regression are shown in Table 1.

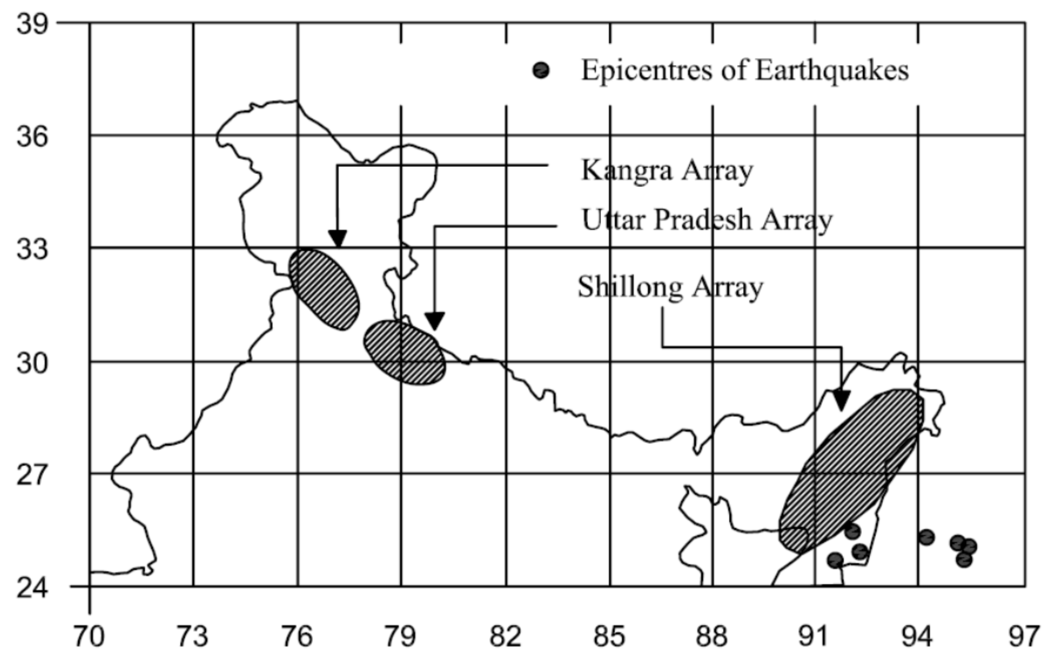

Figure 2. Map showing the strong motion arrays and locations of earthquakes (Sharma, 2005)

Attenuation Relationship

The development of attenuation relations for the peak ground acceleration have been well explained by the authors e.g. Boore and Joyner (1982), Campbell (1985), Tanaka and Fukushima (1987), Joyner and Boore (1988), Abrahamson and Litehiser (1989), Fukushima and Tanaka (1990) and Sharma (1998). In general form, the attenuation relation is considered as:

$$\log(a) = f_1(M) + f_2(r,E) + f_3(r,m,E) + f_4(F) + \varepsilon \quad (1)$$

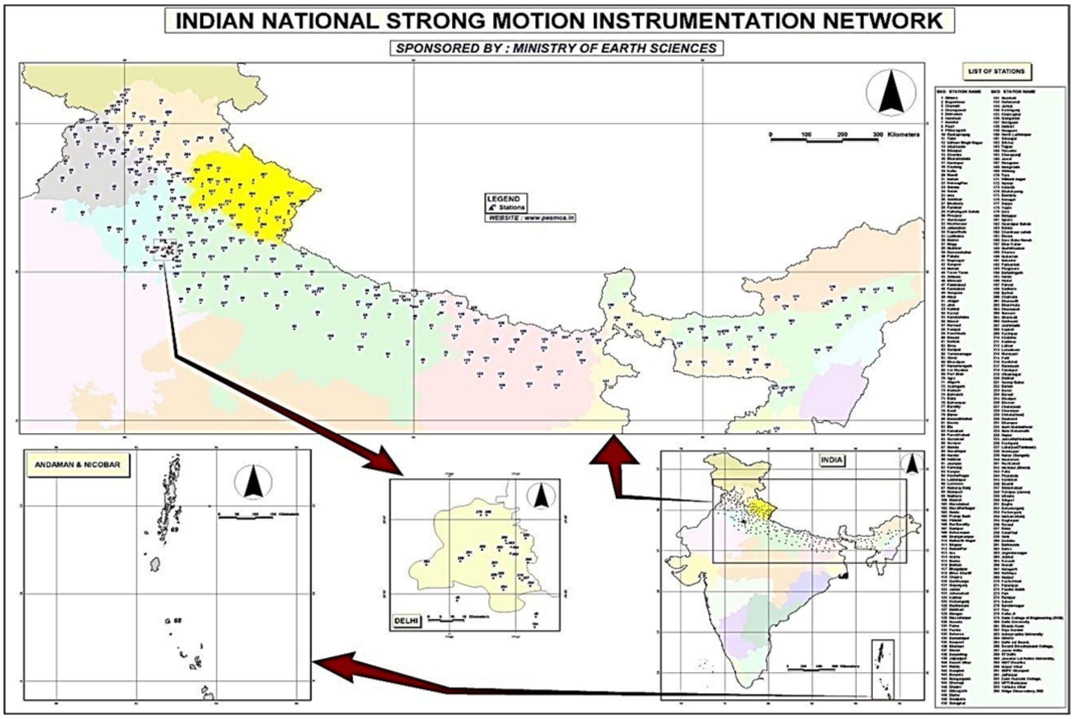

Figure 3. Indian nation strong motion instrumentation network (Kumar et al., 2012)

Table 1. The earthquakes considered for attenuation regression analysis

Earthquake	Date	Time	Latitude (˚N)	Longitude (˚E)	Depth (Km)	Magnitude	Records
1	19860910	13:20	25.43	92.08	43	5.2	12
2	19870518	07:24	25.27	94.20	50	5.7	14
3	19880206	20:21	24.65	91.52	15	5.8	18
4	19880806	06:07	25.15	95.13	91	6.8	33
5	19900110	00:21	24.75	95.24	119	6.1	14
6	19950506	07:29	25.01	95.34	122	6.4	9
7	19970805	08:23	24.89	92.25	35	5.6	11
8	20090215	07:35	26.00	90.20	39.3	4.4	5
9	20090224	17:46	25.90	94.30	10	4.8	5
10	20090425	04:04	30.60	79.30	10	4.0	2
11	20090819	10:45	26.60	92.50	20	4.9	2
12	20090830	19:27	25.40	94.80	85	5.3	5
13	20090903	19:51	24.30	94.60	100	5.9	9
14	20090921	08:53	27.30	91.50	8	6.2	14
15	20091029	17:00	27.30	91.40	10	4.2	5
16	20091029	19:56	26.60	90.00	5	5.2	5
17	20091108	21:43	24.40	94.80	22	5.6	12
18	20091229	09:01	24.50	94.80	80	5.5	6
19	20091231	09:57	27.30	91.40	7	5.5	5
20	20100226	04:42	28.50	86.70	28	5.4	7
21	20100911	07:02	25.90	90.20	20	5.0	3
22	20101212	01:40	25.00	93.30	15	4.8	2
23	20110204	13:53	28.40	94.60	30	6.4	7
24	20110918	12:40	27.70	88.20	10	6.8	13

where 'a' represents peak ground acceleration (PGA); fl (M) is a function of earthquake magnitude; f2 (r, E) is a function of earthquake-to-recording site distance and the tectonic environment; f3 (r, M, E) is a non-separable function of magnitude, distance, and tectonic environment; f4 (F) is a function of fault type; and ε is a random variable that represents uncertainty in log (a). Joyner and Boore (1981) used fl (M), f2 (r, E), and f4 (F) assuming that the distance and magnitude have the separable influence on peak ground motion. Campbell (1981) used f1 (M), f3 (r, M, E), and f4 (F) considering distance and magnitude have a non-separable effect on peak ground motion. While Abrahamson and Litehiser (1989) used a hybrid model of Campbell and Joyner and Boore. Campbell (1985) discussed the functional form fl (M), f2 (r, E), f3 (r, M, E), and f4 (F). In this study, the same type of functional form has been considered for regression analysis. The magnitude-distance distribution of peak ground horizontal accelerations is shown in Figure 4.

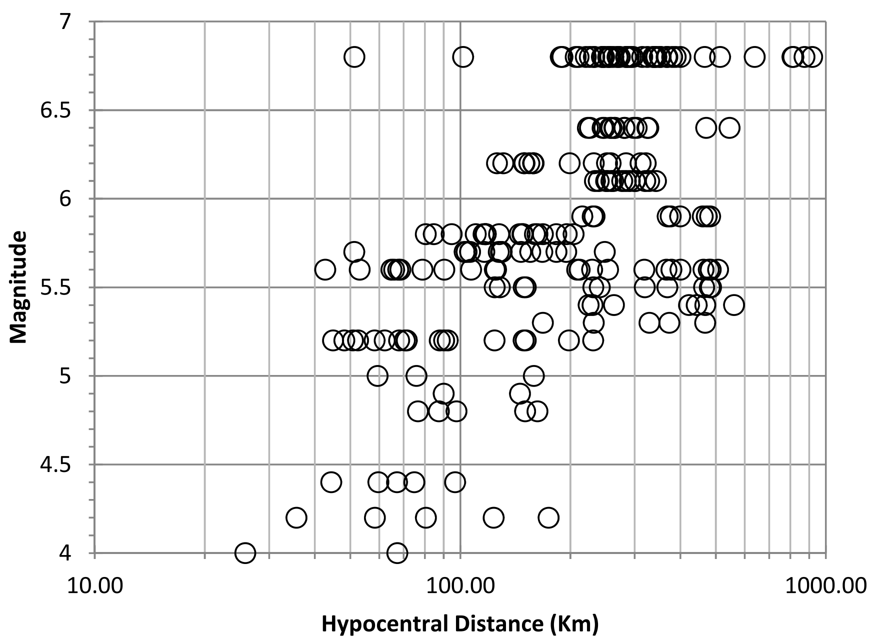

Figure 4. The magnitude-distance distribution of peak ground horizontal accelerations

First of all, a linear regression analysis had been carried out considering a simple relation as:

$$\text{Log}(A) = -b\log(X) + c \quad (2)$$

where A is the peak ground acceleration, X is the hypocentral distance, and b and c are the regression coefficients. The results for each earthquake have been shown in Table 2.

The estimated average value of the decay parameter 'b' is 1.20. The value by considering the whole that set 0.55±0.11, which is very small as compared to the average value from individual earthquakes. Fukushima and Tanaka (1990) well illustrated this phenomenon while considering the actual recordings as well as the synthetic data using numerical experiments. Two-step stratified regression analysis has been used by Fukushima and Tanaka (1990) to overcome this effect. Joyner and Boore (1988) adopted the same method to avoid the interaction of b-value estimates. In this study, the same method is applied here:

$$\log(A) = -blog(X) + \sum d_i l_i \quad (3)$$

Table 2. The values of regression coefficients for each earthquakes

Earthquake	'b' value	Coefficient 'c'
1	1.068±0.396	3.693±0.689
2	1.007±0.252	3.814±0.536
3	0.836±0.551	3.430±1.173
4	1.200±0.476	4.964±1.168
5	1.469±0.958	5.427±2.345
6	4.794±1.396	3.324±3.416
7	0.810±0.373	3.464±0.704
8	1.995±0.886	4.699±1.618
9	0.267±0.127	1.531±0.237
10	0.724±0.000	1.455±0.000
11	1.497±0.483	6.588±1.226
12	1.015±0.598	3.495±0.479
13	0.682±0.578	2.672±1.469
14	0.682±0.578	2.672±1.469
15	1.098±0.868	1.478±1.931
16	1.014±0.586	1.197±1.515
17	0.779±0.392	2.655±0.858
18	0.562±0.506	2.018±1.291
19	1.471±0.823	4.719±2.052
20	1.438±0.000	4.199±0.000
21	0.674±0.439	2.371±0.846
22	0.909±0.366	2.606±0.717
23	1.100±0.000	1.621±0.000
24	1.719±0.167	5.530±0.431

Where di is a coefficient for the ith earthquake and li is equal to 1 for the ith earthquake, and 0 otherwise. The 'b' value estimated in this way is 1.19±0.12, which is close to average 'b' values estimated from individual earthquakes.

After this, a multiple regression analysis was performed considering whole data between magnitudes and hypocentral distances as

$$\log(A) = aM - blog(X) + c \quad (4)$$

Where M is the magnitude (Table 1) and a, b, and c are the regression coefficients. The value of the decay parameter while considering the whole data set came out to be 1.179±0.098, which is less than the value estimated by equation 3, thus in regression analysis, the values 1.19±0.12 have been used.

In regression analysis the model as in equation (1), which represents the general form of the attenuation relationship used. The term f4(F) is not considered because only few fault plane solutions for these earthquakes are reported. Similarly, Sharma (1998) derived regression model for Himalayan region neglecting focal mechanism. Abrahamson and Litehiser (1989) derived an attenuation relation in the United States by segregating the data into interplate and intraplate, and they found a very small difference for the two source regions. The regression model thus selected for the attenuation relation, as from equation (1), is considered as follows:

$$\log(A) = c_1 + c_2 M - blog(X + e^{c_3}) \quad (5)$$

Where c_1, c_2, and c_3 are the regression coefficients. The value of 'b' is fixed to be 1.19.

The regression analysis gave the values of c_1=-1.497±0.3494, c_2=0.3882±0.1203 and c_3=0.8579±0.2341. The estimated attenuation relationship is as follows:

$$\log(A) = -1.497 + 0.3882M - 1.19(X + e^{0.2876M}) \quad (6)$$

The residual sum of squares for equation (6) is 0.1451, which is the sum of the squares of the difference of the observed and predicted peak horizontal accelerations. Earlier attenuation relationship developed for the Himalayan regions are:

$$log(A) = -1.072 + 0.3903M - 1.21\log(X + e^{0.5873M})$$
$(Sharma, 1998)$

$$\log(A) = 0.101M - 0.9258\log(X + e^{0.4562M})$$
$(Sharma, 2005)$

A comparison of these three relations derived for the Himalayan region is shown in Figure 5. The first relationship by Sharma (1998) was developed using the 66 recordings from 7 earthquakes, in which 5 earthquakes belongs to North-East Himalaya and 2 from North-West Himalaya. The second relationship was developed using 666 recordings from 82 earthquakes from worldwide. The present relationship is more close to Sharma (2005). In the present study, 216 recordings from 24 earthquakes occurred in North-East Himalayan region were used, which will provide better insight for site-specific studies as well as for hazard estimation. Attenuation relationship for magnitudes 5, 6, 7 and 8 for North - East Himalayan region are shown in Figure 6.

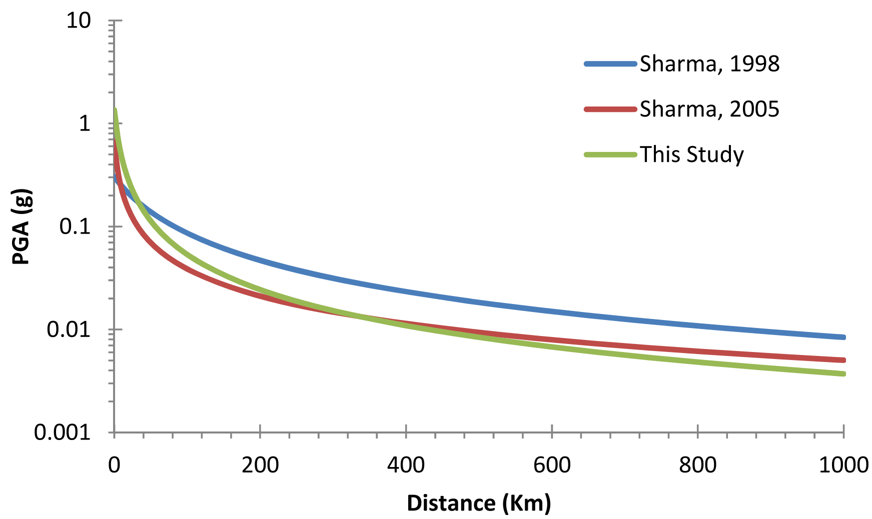

Figure 5. Comparison of Relationships derived for Himalayan region

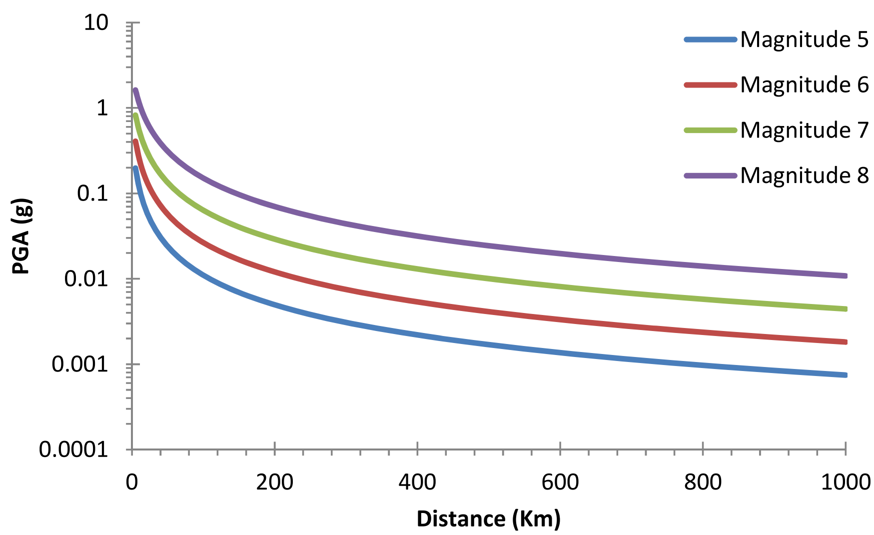

Figure 6. Attenuation relationship for magnitudes 5, 6, 7 and 8 for North-East Himalayan region

4. Conclusions

A data set of 216 peak ground horizontal accelerations from 24 earthquakes (4.0 ≤ M ≤ 6.8) recorded by strong-motion arrays and National Strong Motion Network project have been utilized to develop empirical attenuation relationship for peak ground horizontal acceleration for North-East Himalayan region. Using two-step stratified regression model an attenuation relationship as given in equation (6) has been developed for the North-East Himalayan region. Which will provide better insight for site-specific studies as well as for hazard estimation. Attenuation relationship for magnitudes 5, 6, 7 and 8 for North-East Himalayan region are presented.

Acknowledgments

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