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ORIGINAL PAPER

A study of characteristics of ground motion response spectra from earthquakes recorded in NE Himalayan region: an active plate boundary

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Abstract In the present work, acceleration response spectra are determined from earthquakes which have occurred in the NE region and the effect of local geology on its shape is studied. One hundred and ninety-five strong ground motion time histories from 45 earthquakes which have occurred in the NE region having a magnitude range of $3.5 \leq Mw \leq 6.9$ and a distance range of 20–600 kms are used. It is observed that the shape of the normalized acceleration response spectra is influenced by the local site conditions and regional geology. The influence of magnitude and distance on the spectra is also studied. The present study is carried out for three categories of rocks: Pre-Cambrian, Tertiary and Quaternary. It is inferred that the acceleration response spectra in the current Indian code designed for the entire country are applicable for NE region as it is within the spectral limits prescribed in Indian code. The ground motion is amplified at higher frequencies for stations located on hard rock, while for stations located on alluvium sites, it is amplified at lower frequencies. The sites located on hard rock show lowest values of spectral acceleration than the sites located on alluvium sites. The results obtained in the present study are compared with the similar results obtained in the stable continent region like Gujarat. It is found that the dominating period of response spectrum of similar rock types is found to be at higher side for NE region as compared to Gujarat region. This may be attributed towards the tectonic complexity of the NE region than the stable continent region like Gujarat.

Keywords Acceleration · Response spectra · Spectral acceleration · Alluvium

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1 Introduction

North-eastern (NE) region of India is located in the seismically active Himalayan belt, and the entire region falls in the zone V of the seismic zoning map of India. The tectonics of the region is very complex, and there is a need for seismic hazard assessment of this region as a whole. In this direction, lots of studies have been carried out in this part of India. Study of acceleration response spectra can provide useful information to engineering community. A response spectrum is the graphical representation of the response of structures of single degree of freedom constituting various frequencies to an earthquake motion. It is a site-specific seismic parameter which engineers require for designing various infrastructural facilities. The local site conditions affect the ground motion and modify its amplitude as well as the dominating period. In order to design a structure at a particular location, the actual time history records are required which will provide level of seismic forces for which the structure is to be designed. However, it is not possible to have such records at each and every location of interest. This problem can be overcome by simulating ground motions with site-specific ground motion parameters. Various seismological techniques are now available for simulating strong ground motions. To estimate ground motions at a site of interest, we have to model source, path and site effects appropriately. Further, the seismic analysis of structures cannot be carried out simply based on the peak value of the ground acceleration expected at a site, as the response of the structure also depends upon the frequency content of ground motions, its duration and dynamic properties of the structure. Response spectrum is one of the most popular tools which are widely used by engineers in the seismic analysis of structures. Housner (1959) derived smooth normalized acceleration and velocity response spectra from the two horizontal components of ground accelerations recorded for four large earthquakes in the western USA. The response spectra of strong motion records have significant peaks which may differ remarkably depending on the site conditions and can only be used to evaluate the seismic forces during specific earthquakes at certain sites (Newmark and Hall 1969). They proposed a new technique for estimating site-independent spectra based on the fact that the response spectrum over certain frequency ranges is related to an amplification factor of the peak values of ground acceleration, velocity and displacement. Hayashi et al. (1971) analysed a number of records of strong ground motion recorded on different soil conditions in Japan. The normalized shape characteristics of strong motion response spectra at 5 % damping have been studied by Seed et al. (1976). Mohraz (1976) estimated the average spectral acceleration for three types of geological conditions, i.e. rock, soft soil and more than 30-feet-deep alluvium in California region. Su et al. (2006) studied the nonlinear site effect on ground motion response spectra from the Chi–Chi and Northridge earthquakes. Response analysis studies have been carried out in India by Raghukanth and Iyengar (2007) for peninsular India. Chopra and Choudhury (2011) have carried out the response analysis for Gujarat area using recorded acceleration time histories for different site conditions.

The Indian subcontinent is unique in the sense that it comprises inter-plate and intra-plate regions and both regions are prone to large earthquakes. The inter-plate region comprises of the entire 2500-km Himalaya belt running from east to west. The entire Himalayan belt is considered as one of the most active seismic regions in the world, which has produced destructive earthquakes such as 1897 Shillong (Mw 8.1), 1905 Kangra (Mw 7.8), 1934 Bihar-Nepal (Mw 8.4), 1950 Assam (Mw 8.7), causing heavy loss of human lives and property (Kayal 2010). Recently, a major earthquake has occurred in central Nepal region with Mw 7.9 named as Nepal or Gorkha earthquake.

Under National Strong Motion Instrumentation Program, IIT, Roorkee, has installed a network of 300 strong motion instruments all along the Himalayan arc and adjoining region, funded by Ministry of Earth Sciences (MoES) (Kumar et al. 2012; Mittal et al. 2012). Under this project, 30 strong motion accelerographs are installed in the NE region. This network has recorded many earthquakes during its period of operation after 2008. Also, India Meteorological Department (IMD) has nearly 20 strong motion accelerographs in the NE region, which have recorded some moderate earthquakes occurred in NE area. The availability of strong motion data in the NE Indian region has provided us an opportunity to study the effect of various strong motion parameters on shape and amplitude of the response spectra. In the present work, the effect of local geology, magnitude and distance on average horizontal and vertical response spectra is studied using 195 acceleration time histories from 45 earthquakes which have occurred in NE Indian and its surrounding region. It is important to note that the NE region has high seismic productivity and is prone to large earthquakes which necessitate the evaluation of seismic hazard. This region has many oil and gas fields and refineries in operation, and many infrastructural projects are planned in the region for the societal benefits. In view of this, response analysis of this region using acceleration time histories is important for evaluating the seismic hazard of this region.

1.1 Geology and seismotectonics of NE India

NE Himalaya is probably one of the most seismically active areas in India and has produced few large/great earthquakes since historical time. As per seismic zoning map of India, entire NE Indian region falls in zone V, which is assigned to region with highest level of seismic activity (BIS 2002). During the last 115 years, since 1897, the region has experienced 20 major and two great earthquakes. A great earthquake has occurred on 12 June 1897 (Mw 8.1), which is well documented by Oldham (1899), and the other one on 15 August 1950 (Mw 8.7), which is also well studied by Tandon (1954). Though the Himalayan earthquakes are mostly of thrust type with one axis oriented towards the direction of movement of Indian plate, recent studies based on local network data have reported many earthquakes in the Sikkim, Bhutan and Arunachal Himalayas with strike–slip mechanisms (Kayal et al. 1993; Kayal 2008, 2010; De and Kayal 2003, 2004; Thingbaijam et al. 2008). Also the eastern syntax is zone, where the earthquakes are reported to have strike–slip mechanisms (Holt et al. 1991). Major faults which criss-cross the NE region are Main Boundary Thrust (MBT), Main Central Thrust (MCT), Mishmi Thrust (MT), Naga Thrust (NT), Kopili fault (KF), Dauki fault (DF), Sagaing fault (SF), Dhubri fault (DF) and many more small faults. Geologically, NE region can broadly be divided into three categories of rocks, namely Pre-Cambrian, Tertiary and Quaternary, as shown in Fig. 1. It is shown in Fig. 1 that most of the Quaternary formations are found in the Brahmaputra basin which consists of mainly the alluvium. Tertiaries cover the southern and south-eastern parts. Pre-Cambrian rocks are mostly found in Shillong Plateau. Most of the sites where strong motion accelerographs are kept are located on these three formations.

1.2 Data and analysis

The strong motion accelerograph (SMA) network installed by IIT, Roorkee, and funded by Ministry of Earth Sciences covers the entire Himalayan range from Jammu and Kashmir to Meghalaya. The SMAs consist of an internal AC-63 GeoSIG triaxial force-balanced

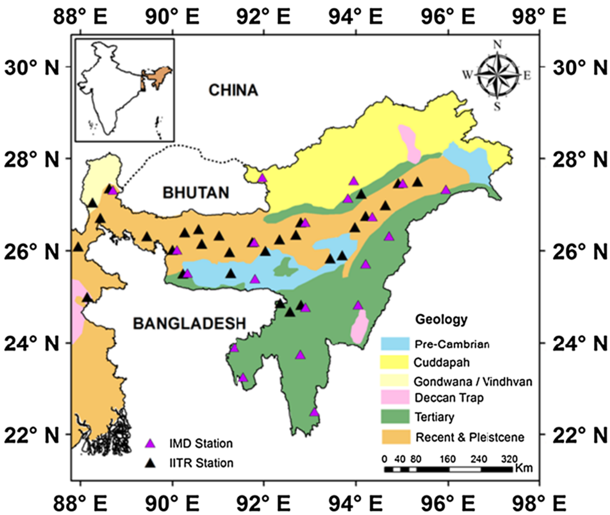


Fig. 1 SMA stations installed by IIT, Roorkee (now under Ministry of Earth Sciences), and India Meteorological Department (IMD) in NE India. Also the geology of NE region is shown with different colour schemes. IITR (Indian Institute of Technology, Roorkee) and IMD (India Meteorological Department). Source of geology map of India: http://www.mapsofindia.com/maps/india/geological.htm

accelerometers and GSR-18 GeoSIG 18-bit digitizers with external GPS. The recording for all instruments is in trigger mode at a sampling frequency of 200 sps. The recording is done on a compact flash card. These instruments are installed at various sites located on varied geological conditions (Mittal et al. 2006; Kumar et al. 2012; Mittal et al. 2012). Figure 1 depicts the locations of SMA stations and general geological background of NE India. Table 1 depicts the details of stations whose data have been used, their geology, number of earthquakes recorded and magnitude range of earthquakes. The stations are classified broadly into three groups, namely Pre-Cambrian, Tertiary and Quaternary, based on their underlying geology (Table 1; Fig. 1). The Pre-Cambrian is the earliest of the geologic ages, which are marked by different layers of heavily metamorphosed rocks more than 600 million years old. In the present study, we have considered the Pre-Cambrian as the hard rocks. Tertiary period rocks are the sedimentary rocks from the Cenozoic era, 1.5–66 million years old, while the Quaternary formations are the most recent one, comprising mainly of alluvium <1.5 million years old.

Forty-five earthquakes recorded by IMD and IITR networks have been used in the present study. The locations of these earthquakes are shown in Fig. 2. These earthquakes range from Mw 3.5–6.9, hypocentral distance 20–600 km. The distribution of these earthquakes in terms of PGA, magnitude and hypocentral distance is shown in Fig. 3a–c. Figure 3a presents peak ground acceleration (PGA), ranging from 20 to 60 gals with hypocentral distance. Magnitude with respect to hypocentral distance is shown in Fig. 3b. Figure 3c shows the distribution of PGA with respect to magnitude. The number of accelerograms and their magnitude range used in the present work for each station are shown in Table 1. A total of 195 strong motion records from 36 sites were analysed for determining the acceleration response spectra for each earthquake at each site. The acceleration response spectra of each record after corrected for base line at every site are determined using Duhamel integral approach for two horizontal and a vertical component. The geometric mean of the two horizontal acceleration response spectra is estimated to account for the horizontal response spectra. The spectra are normalized with the peak ground acceleration. The stations with the same geology are grouped together, and

Table 1 Geology and locations of the stations used in the present study

Station name (code)	Station_source	Lat	Lon	Geology	No. of earthquakes	Magnitude range
Darjeeling (DJL)	IITR	27.050	88.262	Gondwana/Vindhvan	1	4.9
Ziro (ZIRO)	IMD	27.526	93.95	Cuddapah	1	4.3
Malda (MAL)	IITR	25	88.146	Deccan Trap	1	4.5
Diphu (DIP)	IITR	25.839	93.435	Pre-Cambrian	8	4.8–6.2
Mangaldai (MNG)	IITR	26.003	92.029	Pre-Cambrian	4	4.0–4.2
Nongstoin (NON)	IITR	25.520	91.260	Pre-Cambrian	5	5.2–6.2
Hailakandi (HKD)	IITR	24.682	92.563	Tertiary	4	5.5–5.9
Karimganj (KAR)	IITR	24.870	92.354	Tertiary	5	4.8–6.8
Lakhimpur (LKH)	IITR	27.239	94.107	Tertiary	3	4.4–6.2
Silchar (SIL)	IITR	24.830	92.801	Tertiary	2	5.6–5.9
Tura (TUR)	IITR	25.511	90.220	Tertiary	11	4.4–5.9
Kohima (KOHI)	IMD	25.72	94.208	Tertiary	4	5.8–5.9
Mokokchung (MOKO)	IMD	26.321	94.716	Tertiary	4	5.8–5.9
Lekhapani (LKP)	IMD	27.333	95.946	Tertiary	2	4.4
Imphal (IMP)	IMD	24.831	94.047	Tertiary	2	5.8
Tura (TURA)	IMD	25.517	90.324	Tertiary	2	5.8
Boko (BOK)	IITR	25.976	91.230	Quaternary	6	4.0–6.2
Bongaigaon (BON)	IITR	26.473	90.561	Quaternary	13	4.4–6.2
Cooch Vihar (COB)	IITR	26.319	89.440	Quaternary	7	6.2–6.9
Dhubri (DHU)	IITR	26.02	89.995	Quaternary	2	4.4
Dibrugarh (DIBRU)	IITR	27.467	94.912	Quaternary	2	4.6
Gangtok (GTK)	IITR	27.352	88.627	Quaternary	17	4.4–6.9
Goalpara (GLP)	IITR	26.152	90.627	Quaternary	13	5.2–6.2
Golaghat (GOL)	IITR	26.516	93.972	Quaternary	4	4.8–5.9
Guwahati (GUA)	IITR	26.190	91.746	Quaternary	17	4.0–6.4
Jorhat (JHR)	IITR	26.759	94.206	Quaternary	4	5.4–6.4
Kokrajhar (KOK)	IITR	26.400	90.261	Quaternary	15	4.4–6.8
Morigaon (MOR)	IITR	26.248	92.339	Quaternary	4	4.0–4.2
Naugaon (NAU)	IITR	26.349	92.693	Quaternary	5	3.7–6.8
Sibsagar (SBS)	IITR	26.989	94.631	Quaternary	3	5.1–6.8
Siliguri (SLG)	IITR	26.712	88.428	Quaternary	3	4.9–6.8
Tejpur (TEJ)	IITR	26.619	92.797	Quaternary	3	3.7–6.2
Tinsukia (TIN)	IITR	27.503	95.332	Quaternary	3	4.5–5.9
Guwahati (GUWA)	IMD	26.193	91.79	Quaternary	3	3.5–5.8
Jorhat (JOR)	IMD	26.743	94.351	Quaternary	2	5.8
Tezpur (TEZ)	IMD	26.617	92.899	Quaternary	6	3.5–4.8

weighted average acceleration response spectra for particular geological formations in NE India are determined. To examine the local site effects on shape of the acceleration response spectra, we compared the spectra of different stations on same regional geology.

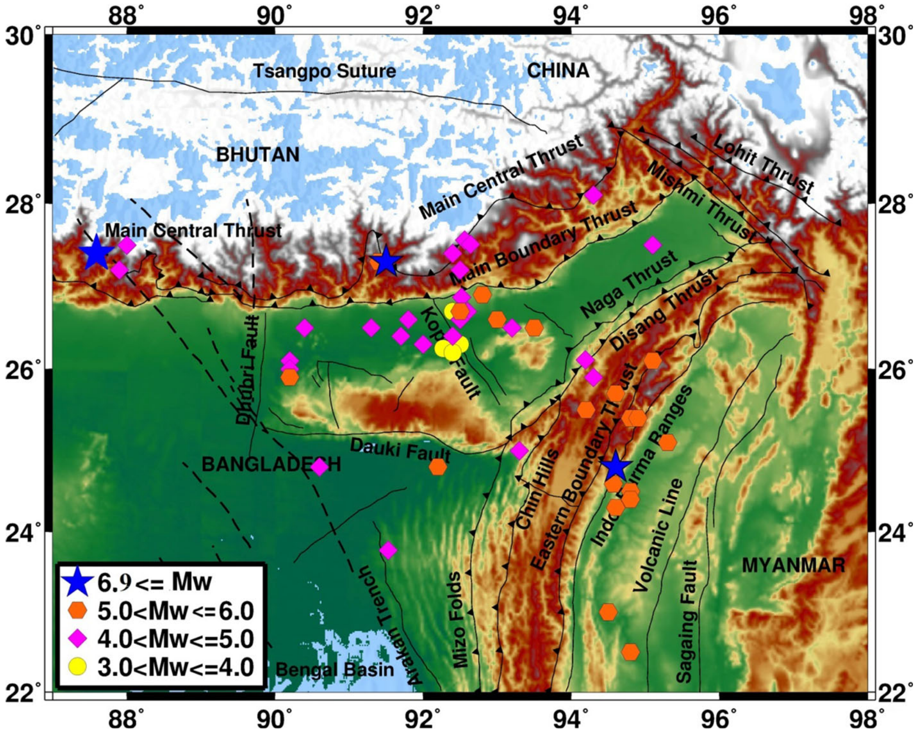


Fig. 2 Map showing the major tectonic features of NE Indian region and the earthquakes used in the present study

2 Results and discussion

Among the data set considered in the present study, the maximum sites in NE India fall in the Quaternary category as shown in Table 1. The average horizontal response spectra for all these sites show the maximum spectral amplification or normalized spectral acceleration (SA) of 3.1 at 0.26 s, as shown in Fig. 4a. Similarly, the average vertical response spectra for all these sites show the maximum spectral amplification of 2.76 at 0.2 s, as shown in Fig. 4b. For Tertiary formations, the average horizontal response spectra showed maximum spectral amplification equal to 2.9 at 0.21 s, as depicted in Fig. 5a, and for vertical component, this value is 2.8 at 0.09 s, as shown in Fig. 5b. Sites on Pre-Cambrian formations show maximum amplification of 2.9 at 0.11 s for horizontal component (Fig. 6a) and 2.6 at 0.07 s for vertical component (Fig. 6b). The average responses for three formations collectively are shown in Fig. 7a, b for horizontal and vertical components, respectively. The maximum average spectral amplification for Quaternary formations is observed at 0.26 s, while for Tertiary and Pre-Cambrian formations, it is 0.21 and 0.11 s, respectively. This shows that the geological formations modify the response spectra, and as we move from hard (PC) to soft (Q) formation, period increases. High frequencies are amplified in the hard rock sites represented by the Pre-Cambrian formations, and low frequencies are amplified in the alluvium constituting Quaternary formations. Alternatively, it can be said that ground motion at low frequencies on alluvium sites

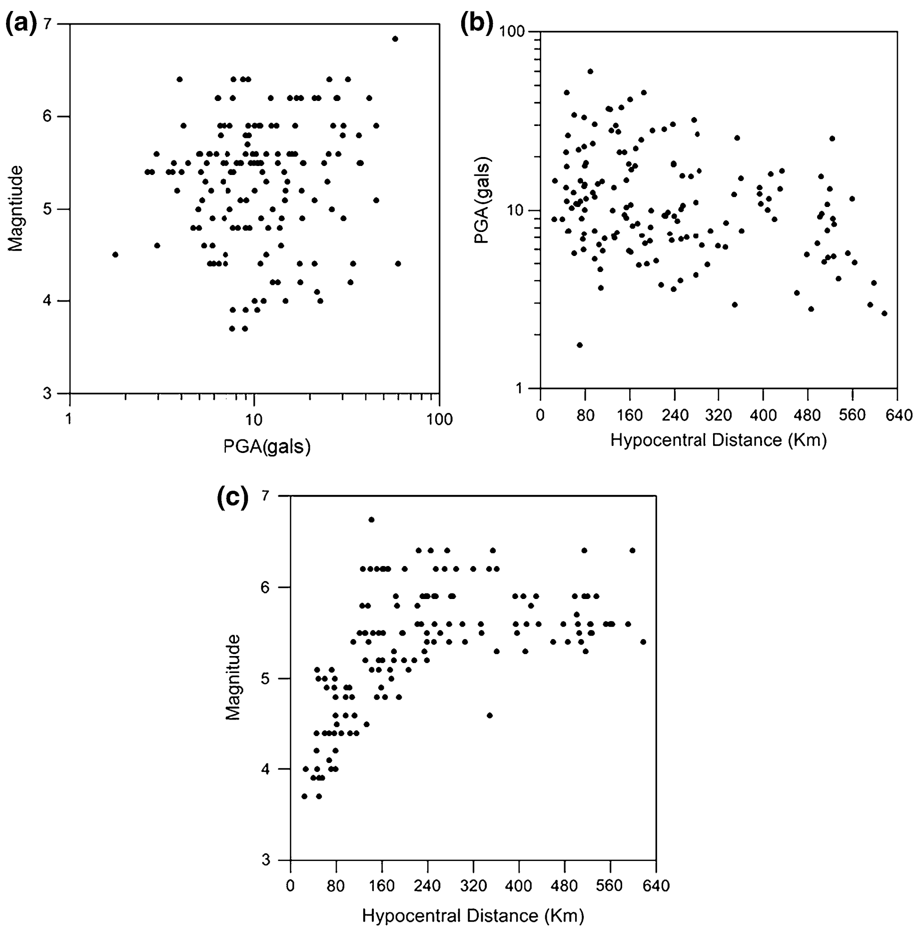
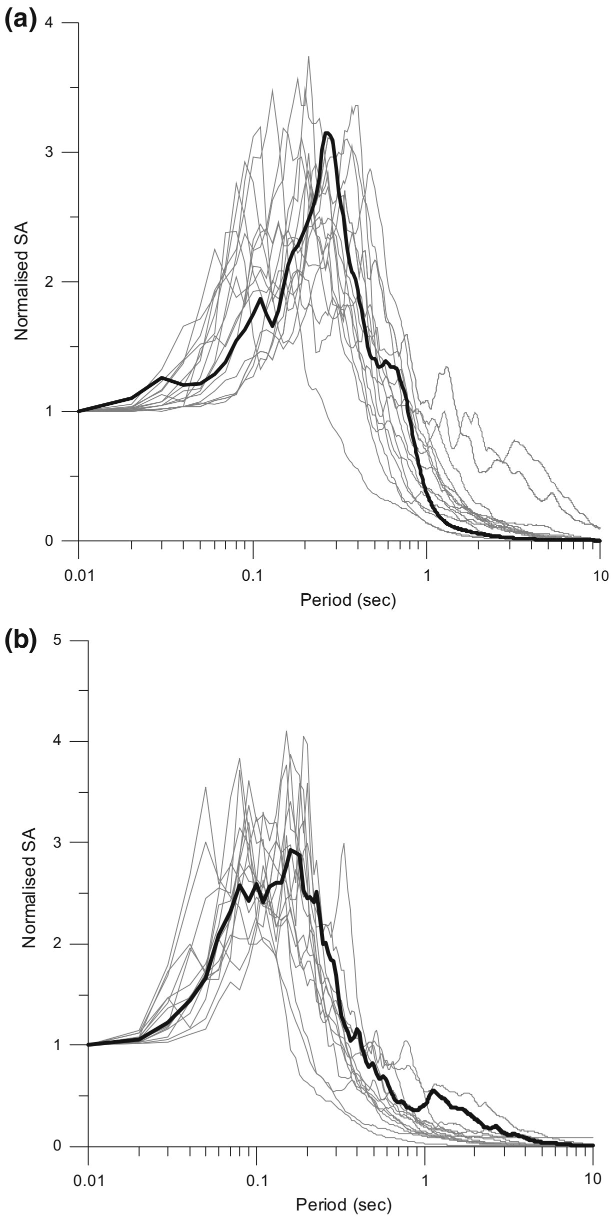


Fig. 3 A figure showing the relation of various strong ground motion parameters with each other used in present study. **a** Magnitude versus peak ground acceleration, **b** peak ground acceleration versus hypocentral distance distribution, **c** magnitude versus hypocentral distance distribution

is higher in comparison with hard rock sites. It is also observed that the level of spectral amplification among all the sites is same, around 2.8–2.9.

We have also compared these results with the spectrum provided in the Indian code (BIS 2002), as shown in Fig. 8. It is observed that the results obtained from present analysis fall within the spectrum specified in Indian code for hard and soft rocks. The spectra for the Indian code are designed by taking time histories from active tectonic regions. It is worth saying that the current Indian code applicable for the entire country is well founded for NE Indian region. Similar studies have been carried out by Raghukanth and Iyengar (2007) for peninsular India and Chopra and Choudhury (2011) for the Gujarat region which is considered as stable continent region (SCR). According to Raghukanth and Iyengar (2007), the response spectrum in Indian code (BIS 2002) underestimates seismic forces at high frequency for rock sites, while at soft soil sites it overestimates forces at low frequencies for peninsular Indian region. According to Chopra and Choudhury (2011), the response for Gujarat region is underestimated for hard rock sites in BIS (2002) code and

Fig. 4 Normalized acceleration response spectra at sites on Quaternary formations (alluvium) for geometric mean of horizontal components (**a**) and vertical components (**b**). *Light black colour lines* are the normalized spectra of individual stations, and *dark black* is for average response spectra



overestimated at soft soil sites. In the present study, we have tried to explore the similarities and differences in the spectra of similar rock formations in active and stable regions on the same tectonic plate (Fig. 8). Gujarat region exhibits the intra-plate seismicity, while NE Himalayan region falls under inter-plate seismicity regime. The data set for Gujarat region used by Chopra and Choudhury (2011) consists of earthquakes in magnitude range of 3.0–5.7 in distance range of 10–80 km. In the present analysis for NE region, the data are comprised of earthquakes in the magnitude range of 3.5–6.9 and the distance range in

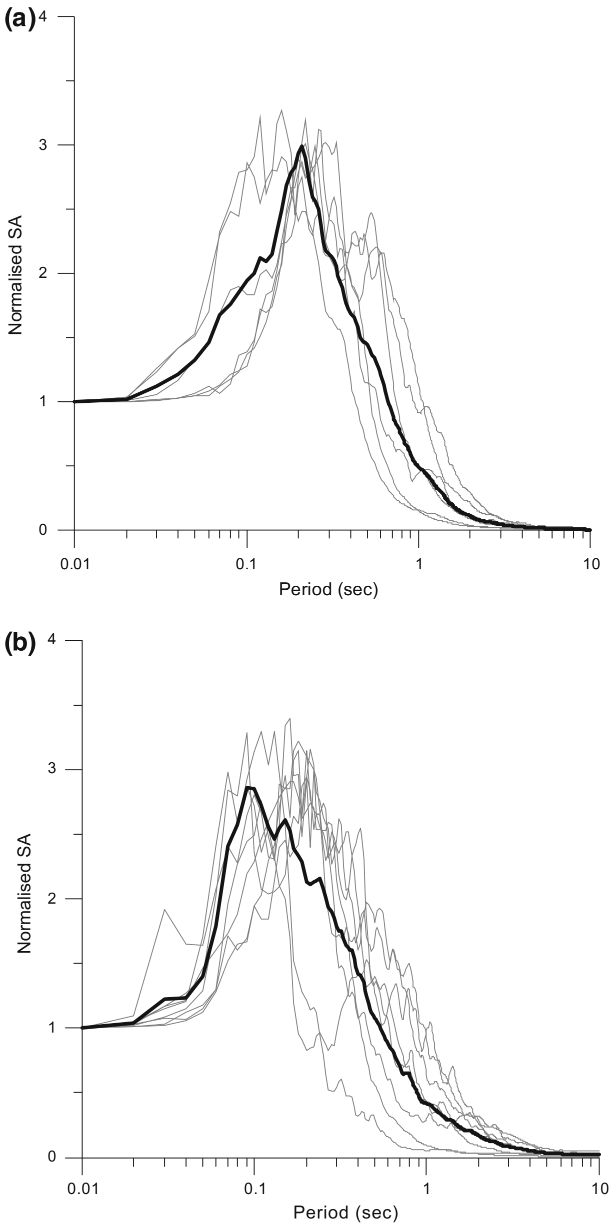


Fig. 5 Normalized acceleration response spectra at sites on Tertiary sites for geometric mean of horizontal components (**a**) and vertical components (**b**). *Light black colour lines* are the normalized spectra of individual stations, and *dark black* is for average response spectra

between 20 and 600 kms. The rocks in Gujarat are classified into Proterozoic, Mesozoic, Tertiary and Quaternary. In the present study, the comparison of spectra have been made of sites located on Proterozoic, Tertiary and Quaternary in Gujarat with Pre-Cambrian, Tertiary and Quaternary sites in NE region. It is observed that peak of response spectra of similar formations in both the regions is at different periods and it is on higher side for similar formations for the NE Indian region (Fig. 8), though the level of SA is same. Older rocks have peaks at higher frequencies, and younger at low frequencies for Gujarat as well

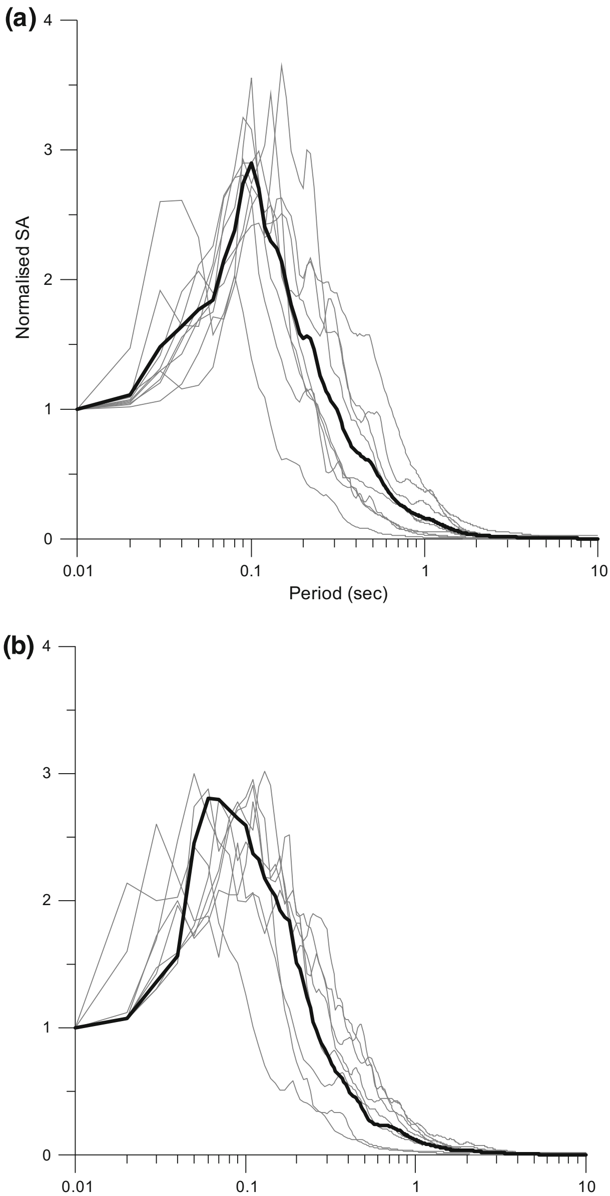


Fig. 6 Normalized acceleration response spectra at sites on hard rock (Pre-Cambrian) sites for geometric mean of horizontal components (**a**) and vertical components (**b**). *Light black colour lines* are the normalized spectra of individual stations, and *dark black* is for average response spectra

as NE region, but respective periods are different for similar site classes. We can also interpret this as, for the same structure with the same natural period, the level of seismic forces considered for engineering practices will be more in Gujarat region than for the NE region.

Different site conditions can induce amplifications at different periods in the response spectra (Seed et al. 1976; Mohraz 1976). Such types of studies based on spectral acceleration have been carried out previously by many researchers in world. Mohraz (1976) estimated the average spectral acceleration for three types of geological conditions for

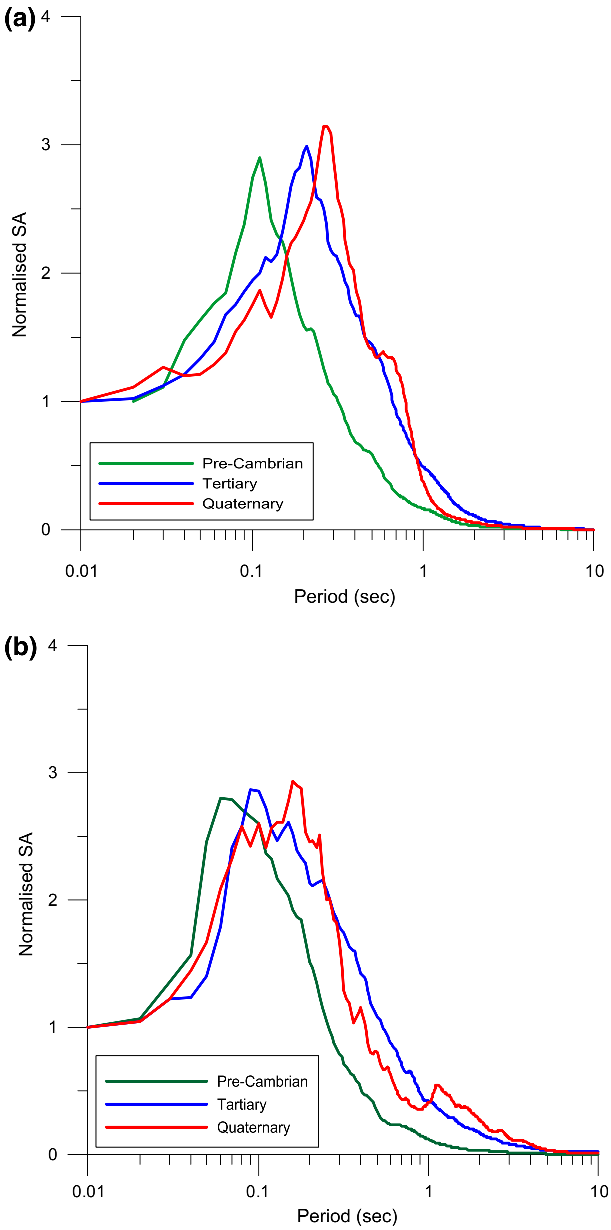


Fig. 7 Comparison of normalized acceleration response spectra for different geological strata such as Pre-Cambrian, Tertiary and Quaternary for horizontal (**a**) and vertical components (**b**)

California region. He observed that average SA is 2.1 for all the components at hard rock sites. For soft sites with less than 30-feet alluvium, SA is 2.6 for horizontal component and 2.2 for vertical component. Similarly, for sites with more than 30-feet alluvium SA were 2.3 for horizontal component and 2.1 for vertical component. Seed et al. (1976) used the normalized shape characteristics of strong motion response spectrum to study site conditions. Hayashi et al. (1971) estimated average horizontal SA for three different kinds of sites in Japan. He estimated maximum SA to be 3.3 for rock site, 2.5 for medium soil and

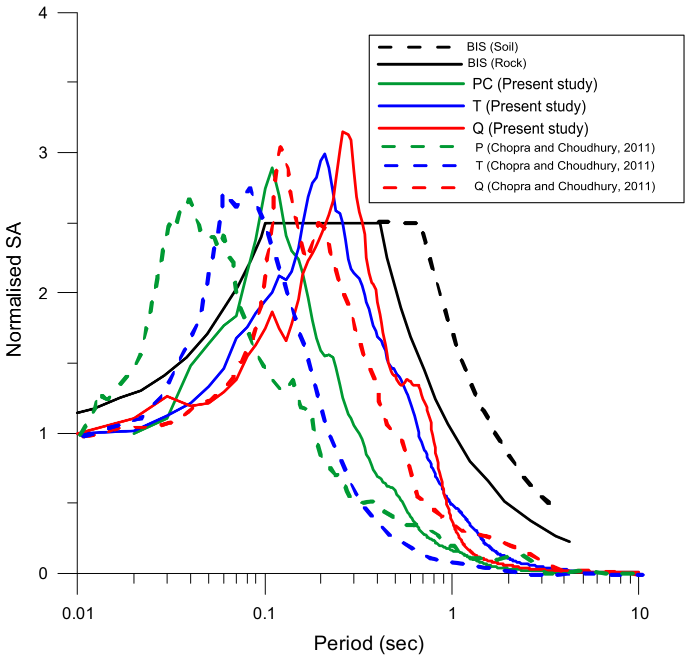


Fig. 8 Comparison of normalized acceleration response spectra for different geological strata such as Pre-Cambrian (*PC*), Tertiary (*T*) and Quaternary (*Q*) for horizontal component with BIS standard code for rock and soil. Comparison of normalized acceleration response spectra with the study of Gujarat region (Chopra and Choudhury 2011) for horizontal component. Here *solid green, blue* and *red lines* are showing results of present study for PC, T and Q, respectively. *Dotted green, blue and red* lines are for Proterozoic (P), T and Q, respectively, taken from Chopra and Choudhury (2011) for Gujarat region

2.6 for soft soil sites. In present study, spectral amplification for response spectra at PC, T and Q sites is ~2.8–2.9 for horizontal and vertical components, which matches with the global data. Some researchers have combined the use of surface geology and shear wave velocity for site classification (e.g. Borcherdt 1994a, b; Borcherdt and Glassmoyer 1992). The classification of site conditions and an estimation of the site amplification ratio obtained by using surface geology and geomorphologic units have been determined in Tokyo and Kanagawa, Japan (Yamazaki et al. 2000). The nonlinear site effect on ground motion response spectra from the Chi–Chi and Northridge earthquakes has been studied by Su et al. (2006). They found that nonlinearity affects ground motions from both earthquakes significantly. This was demonstrated by comparing the average ground motion response spectra from different site conditions within the same distance ranges. At large distances, the average soil site shows higher amplitudes in spectra at all frequencies than that of rock sites, but at short distances, in the presence of nonlinearity, the high-frequency part of the spectra shows smaller amplitudes on soil sites than that on rock sites. They have also examined ground motions of other recent large earthquakes in California, Japan and Turkey and found that the threshold of nonlinearity is quite consistent with the results from the Chi–Chi and Northridge earthquakes. On the other hand, for NE region the results are found to be linear as the spectral acceleration is less for the older formations while more for the recent formations.

The effect of magnitude on response spectra is studied by considering different stations that fall under different categories, i.e. PC, T and Q. At all these stations, response spectra are plotted from earthquakes of different magnitudes that occurred in the same source region. At Diphu, which is a hard rock (Pre-Cambrian) site, the horizontal normalized response spectra are compared from three earthquakes for magnitude ranges 5.3–5.9, as shown in Fig. 9a. The response spectra look similar for all the magnitudes considered except for the magnitude 5.9 for which at higher periods the shape of the response spectra slightly differs. In the same way, the response spectra for Tertiary site at Tura are compared for four different earthquakes in magnitude range 5.3–5.9, as shown in Fig. 9b. The spectra are almost similar for all the magnitudes considered at this site. Similarly, in Fig. 9c for Guwahati site situated on alluvium or Quaternary, the response spectra are compared for five different earthquakes in magnitude range of 5.5–6.4. Here also spectra

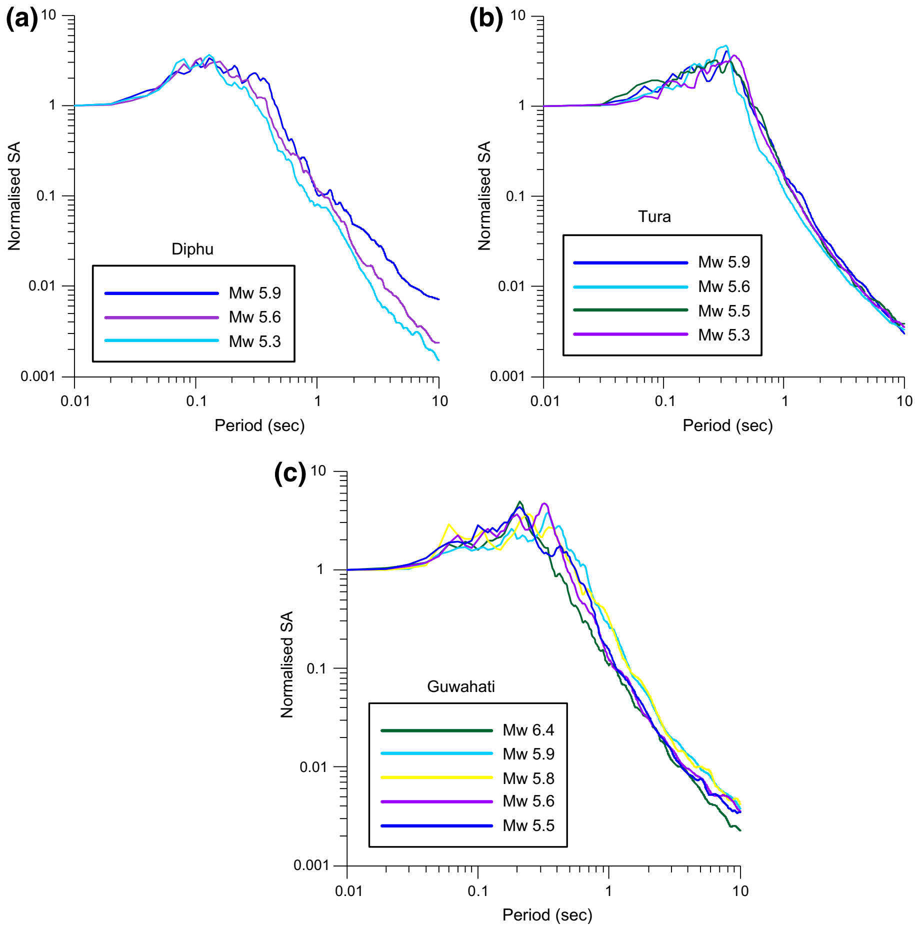
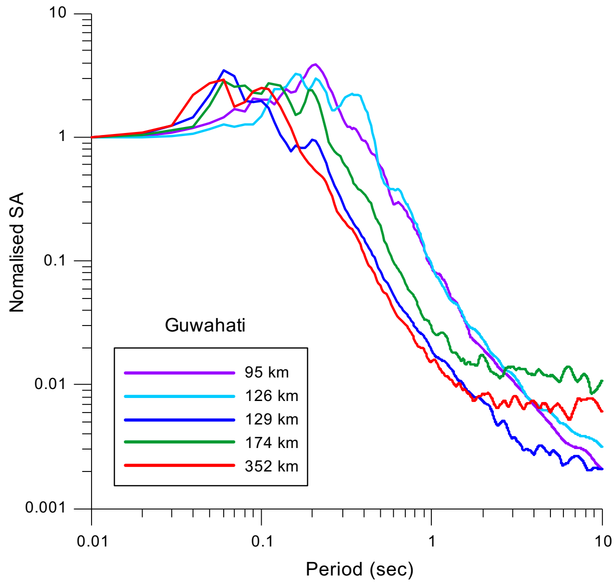


Fig. 9 **a** Normalized acceleration response spectra for earthquakes of different magnitudes occurring in the same source zone recorded at PC site Diphu for horizontal component, **b** normalized acceleration response spectra for earthquakes of different magnitudes occurring in the same source zone recorded at T site Tura for horizontal components and **c** normalized acceleration response spectra for earthquakes of different magnitudes occurring in the same source zone recorded at Q site Guwahati for horizontal component

Fig. 10 Normalized acceleration response spectra for earthquakes of same source with different distances (95–352 kms) occurring at alluvium site Guwahati for horizontal component



for different magnitude earthquakes follow each other and are similar. It can be interpreted as that the spectra follows the same trend for different magnitude ranges but as the magnitude increases more energy in low frequencies are observed. In order to study the effect of distance on shape and amplitude of the response spectra, the spectra from different earthquakes are observed for the same station. Guwahati located on Quaternary has recorded many earthquakes from different sources at varied distances as shown in Fig. 10. It is observed that the spectral amplification for earthquakes at shorter distances has peak at relatively higher periods than distant earthquakes. The peak SA shifts from higher period to lower period as distance increases. In Fig. 10, the earthquake recorded at Guwahati from distance of 352 kms shows the maximum spectral amplification of 2.9 at 0.07 s, while it is 3.8 at 0.22 s for an earthquake at an epicentral distance of 95 kms.

3 Conclusion

In the present study, we have used data of earthquakes in the magnitude range of 3.5–6.9. No recordings of any large or great earthquakes are available in the data set. The response spectra may have a different shape for any major/great earthquakes as they produce large ground motions in low frequency range. Nevertheless, the results of the present study are very much useful in evaluating the seismic hazard of the NE Indian region and also for construction industry's point of view due to the socio-economic importance of this region. The site-dependent response spectra estimated in the present study will be useful for the earthquake resistant designs of structures in varied geological conditions for NE region. Our study clearly depicts that local site conditions play a significant role in modifying the shape of the response spectrum. The predominant period increases as we move from older to younger rocks. Older rocks have peaks at higher frequencies and younger at low frequencies though the level of spectral amplification is same. The present analysis shows that the acceleration response spectrum in the current Indian code applicable for the entire country is suitable for estimating the seismic forces in NE India. After comparing our result with similar studies done in Gujarat which is an intra-plate region, it can concluded that for the same structure with same natural period, the level of seismic force considered for design will be more in Gujarat region than in NE region. The present analysis gives the response spectra by using small and moderate earthquakes. The major and great earthquakes are not there in the data set. We can simulate the major and great earthquakes in this region using small earthquakes and then find the response analysis using great or major earthquakes in future.

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