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Site Characteristics of Indo-Gangetic Plain Area Using Strong Motion Data of Nepal Earthquake (Mw 7.9) of 25th April 2015

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Abstract

The site characteristics have now been considered as one of the important parameters controlling the variations in the ground motions as well as affecting the damage during the earthquakes. The information about site characteristics is also useful for the simulation of earthquake strong ground motions. The Indo-Gangetic Plain (IGP) is densely populated and exposed to the earthquake prone Himalayan region. The seismic hazard in the region due to large earthquakes in Himalaya region is high.

The characteristic 13 sites of Indo-Gangetic Plain have been investigated in the present study. The waveforms of 2015 Gorkha (Nepal) earthquake and its four aftershocks recorded at these sites have been used for this purpose. The widely used Horizontal to Vertical Spectral Ratio (HVSR) method has been used. The average amplification level of 1.2 – 4.0 has been estimated for the broadband frequency range of 0.1-10 Hz. The spatial distribution of the predominant frequencies has been presented and found to be in the range of 0.15 to 4.52 Hz and the average amplification level of 2-4 is observed corresponding to predominant frequencies at different sites. The level of predominant frequency is related to the alluvium present in the study area. The estimated values are important for evaluation of seismic hazard of the region based on simulated strong ground motions.

Keywords: Indo-Gangetic Plain (IGP), Seismic Hazard, Gorkha earthquake, Site Amplification

1. Introduction

The Indo-Gangetic Plain (IGP) is one of most populated areas of Indian subcontinent. IGP lies between Himalayas and Indian Peninsula, one of the largest alluvial basins of the world. The IGP developed mainly by the alluvium of the Indus, Yamuna, Ganga, Ramganga, Ghagra, Rapti, Gandak, Bhagirathi, Silai, Damodar, Ajay and Kosi rivers. IGP is also called as Himalayan fore-deep basin. The fluvial deposits and landforms of the IGP have been influenced by the stresses directed towards north related to Indian plate. Himalayan range along with the IGP have experienced devastating earthquakes such as 1897 Shillong (Mw 8.7), 1905 Kangra Valley (Mw 8.6), 1934 Bihar (Mw 8.4), 1950 Assam (Mw 8.7) and 1988 Bihar-Nepal (Mw 6.6) (Kayal, 2008). Hence the fore-deep region of Central Himalaya is affected by the Himalayan seismicity.

Increase in population and the growth rate of the big cities and development of metropolises all over the IGP area has tremendously increased. Most of the cities in IGP region including New Delhi are located on the soft sediments. Hence, local site condition is desirable because it may give rise to the amplification of seismic waves during earthquakes. Thus, for an efficient mitigation of seismic risk, site-specific studies are of utmost importance. The site amplification functions are important for determining the site specific seismic hazard assessment, microzonation studies, and the simulation of strong ground motions of a region.

The characteristics like amplitudes, frequency contents and duration of earthquake ground motions are influenced significantly by the local site conditions. The site conditions further affect the degree and extent of damage during an earthquake. Due to this reason, the ground vibrations due to any earthquake at one site may be stronger than those of another site at similar distance. The topographic and local geological conditions termed as site conditions are the reasons for such variations of earthquake ground motions. The earthquakes such as 1985 Mexico and 2001 Bhuj have clearly demonstrated that the site conditions can have a significant influence on the amplitudes and response spectral characteristics of the earthquake ground motions as well as on damage pattern (Furumura and Kenntt, 1998; Sairam et al, 2018; Rastogi et al, 2011).

There are two techniques which have been used for the evaluation of the site effects: theoretical and empirical. The theoretical approach is based on classical geophysical and geotechnical techniques such as seismic refraction, seismic reflection, boreholes, penetrometers, etc. which provide reliable estimates of the parameters like thickness of sedimentary layers, S and P wave velocities and density of various layers. The empirical approaches are based on direct measurement of earthquake records. While evaluating the site effects, our main objective is to remove the effect of source and path effects from observed seismogram. There are numerous methods to evaluate the site effects like Standard Spectral Ratio (SSR) technique (Lermo et al., 1988; Mittal et al., 2012), Generalized Inversion Scheme (GIS) (Boatwright et al., 1991; Mandal et al., 2008), Coda Wave technique (Chin and Aki, 1991; Frankel, 1994; Sharma et al., 2008), Horizontal to Vertical Spectral Ratio (HVSR or H/V ratio) technique (Suzuki et al., 1995; Chavez-Garcia el al., 1996; Chopra et al., 2012) etc. Each method presents its own advantages and limitations.

A number of studies (Khattri et al., 1984; Ravi and Bhatia, 1999; Iyengar and Ghosh, 2004; Nath and Thingbaijam, 2012; Parvez et al., 2002) have been made on site amplification and seismic hazard of Indo-Gangetic plane region. A major earthquake (Mw 7.9) occurred in the central Nepal region on 25th April 2015 at 11:41 hrs (IST) at a depth of 15 km, which was located 281 km north of Patna, Bihar and about 120 km NNE of Bagha, Uttar Pradesh (UP) of India (Sharma et al., 2017). A series of aftershocks has been associated with the main shock. In this study we have used the data of Nepal Earthquake and its strong aftershocks recorded at 13 stations in the IGP region to estimate the site amplification of the IGP region. The shear wave velocity 200-375 m/sec is recorded at these sites which indicate alluvium soil in the entire study area (Kumar et al., 2012). This study will be very much useful to assess the seismic hazard in the study region.

2. Geological Settings

The Indo-Gangetic Plains are one of the three major features of Indian subcontinent with Himalaya along the north and Indian Peninsula occurring to the south. It is largest alluvial basin in the world and supporting a population of >500 million, almost a third of the population of the subcontinent and it is a fore-deep basin of Himalaya orogeny (Sinha and Friend, 1994). It stretches from the Arabian Sea in the west, the most populous parts of Pakistan, most of northern and eastern India, Gujarat, Punjab, Uttar Pradesh, and virtually all of Bangladesh, with a huge river delta at each end.

It came into existence due to the collision of the Indian and Eurasian plates during Middle Miocene (Prakash and Kumar., 1991). Later, the Siwalik fore-deep had come into existence. IGP expanded and deepened as sedimentation proceeded progressively northward until the Late Quaternary, 1.5–1.7 million years ago. This was the time when it broke up into two unequal parts along the fault known as the Himalayan Frontal Thrust. The northern part became the Siwalik Ranges, and the southern part became the subsiding basin (Valdiya 1998, 2001). This depression was filled up rapidly with sediments derived predominantly from the Himalaya and partly from the hills of the northern Peninsular India, by Indus-Ganga river system and attains a thickness of several kilometres, eventually transforming the basin into vast plains known as the Indo-Gangetic Plains. It is 150–500 km wide and covers about 300,000 km^2 area in northern India (Valdiya, 2015). The average elevation of Indo-Gangetic Plains is 150 m (Aggarwal, 1977). This vast alluvial plain is composed of different sediment fills and accordingly classified into older Alluvium (Bhangar) and Newer Alluvium (Khadar) by Pascoe (1973). The nature and properties of the alluvium vary in texture from sandy to clayey, calcareous to non-calcareous and acidic to alkaline. This plain varies in width from 200 km in the east to 400 km in the west (Kumar et al., 2012).

The Ganga Plains bounded by the outer Himalayan thrust sheets in the north and over significant areas to the south by Bundelkhand Craton and its constituents. The main geologic units that occur in the region of the Indus Plains include the Himalayan thrust sheets, the Indus Suture Zone and Kohistan Arc. In its lower segment, Indus flows parallel to the NE-SW trending West Pakistan fold belt (Sinha, 2014). Himalayan Frontal Thrust (HFT), also referred to Himalayan Frontal Fault (HFF) and Main Frontal Thrust (MFT), demarcates a sharp physiographic and tectonic boundary between the Himalayan foothills and IGP. It represents a discontinuous zone of active reverse faulting between the Sub-Himalaya and the IGP. Himalaya has been originated by collision between Indian and Eurasian Plates and N-S convergence is going along the Himalayan arc since Eocene (Molnar et al., 1973). There are a number of faults and other tectonic features existing in the region. The north-south compression generated throughout the plate ensures that it is continuously under stress and provides the basic source of accumulating strain in the fractured zones. The accumulated stress creates slip along these lineaments and eventually can cause earthquakes.

3. Data Used

In the present study, the strong motion data of Nepal earthquake occurred on 25th April 2015 and its strong aftershocks recorded by a network consisting of 13 stations in the Indo-Gangetic Plain region, have been used. The epicentral locations of earthquakes and stations used have been shown in Figure 1. Details of the stations and their locations are presented in Table 1 and the hypocentral parameters of earthquakes used in this study are listed in Table 2. The 13 stations used are amongst the 300 strong motion stations network operated by The Department of Earthquake Engineering, Indian Institute of Technology Roorkee (IITR) under the umbrella of Ministry of Earth Sciences in the entire Himalayan belt. This network produced strong motion data and covered parts of Himachal Pradesh, Punjab, Haryana, Uttaranchal and Shillong regions. Strong motion accelerographs consist of internal AC-63 GeoSIG triaxial force-balanced accelerometer and GSR-18 GeoSIG 18-bit digitizer with external GPS.

4. Methodology

The site amplification characteristics were estimated using the ratios of horizontal to vertical component spectra at various sites used in the present study. The H/V method was originally proposed by Nakamura (1989) and further extended by Lermo and Chavez-Garcia (1993). According to this method, amplification can be inferred by taking the horizontal-to-vertical component Fourier spectral ratio (H/V) of the site. The hypothesis of this technique is that for a soft layer overlying a half space, the soft layer will amplify the horizontal component of ground motion, while amplification effects on the vertical component are small enough to be neglected.

The H/V ratio technique assumes a half space with a horizontal sedimentary layer on top. The vertical component of the transfer function, hv(f), is given as the ratio between the vertical component of motion on the surface, Vs(f), and that on the base of the sediments, VB(f), in frequency domain (Castro et al., 1997):

$$hv(f) = Vs(f)/ VB(f)=Sv(f)P(f)Zv(f)/Sv(f)P(f) \quad (1)$$

where, Sv(f) denotes the source effect, P(f) denotes the path effect from source to the base sediments, and Zv(f) denotes the amplification caused by the site sediments. The horizontal component of the transfer function hu(f) can be represented in similar manner as:

$$hu(f)=Hs(f)/HB(f)=Su(f)Zu(f)P(f)/Su(f)P(f) \quad (2)$$

Where, Hs(f) and HB(f) are the horizontal component of the motion at the surface and at the bedrock. Using equations (1) and (2), the ratio becomes:

$$hu(f)/ hv(f) = Zu(f)/ Zv(f) = Hs(f)\ V_B(f)/ H_B(f)\ Vs(f) \quad (3)$$

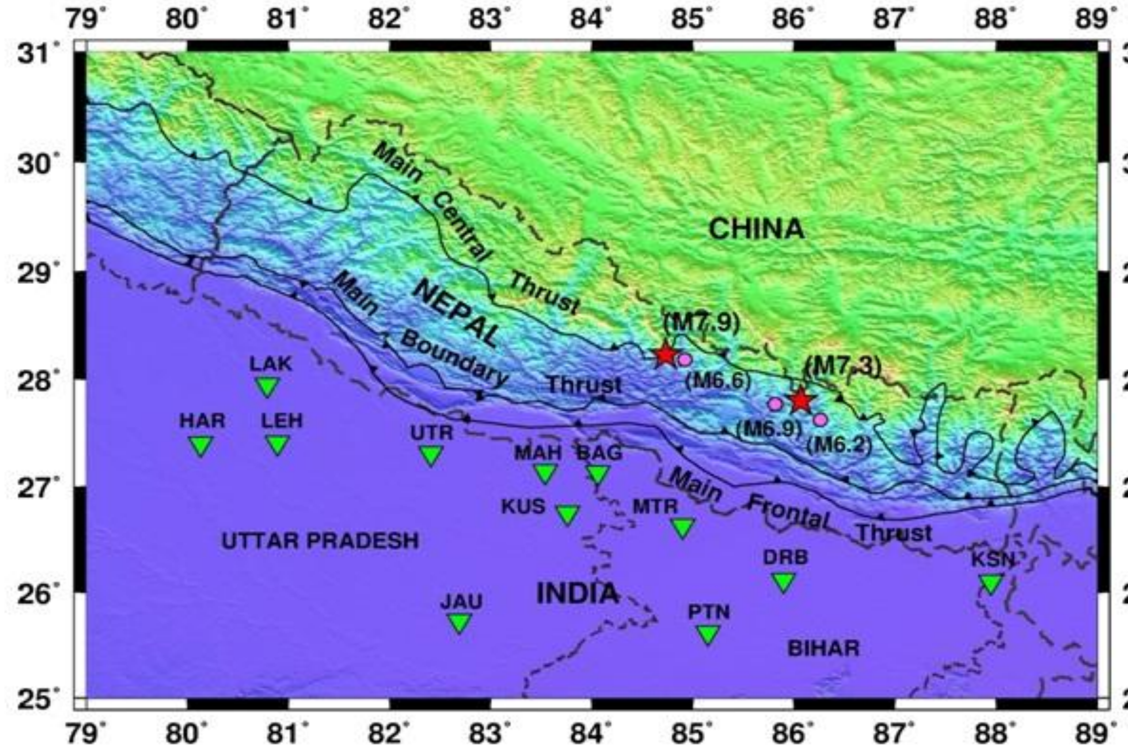

Figure 1: Map showing the Indo-Gangetic Plain region and seismological network deployed in the region. Two red stars show major earthquakes in the region and circles represent the aftershocks. The details of the earthquakes are given in Table 2.

Now, Zv(f)=1 as it is assumed that the vertical component of the ground motion is free from any influence of the sediments at the site. The spectral amplitude of both the components ($H_B(f)$ and $V_B(f)$) at the bed rock i.e. at the base of the sediments is assumed to be same and therefore,

$$H_B(f) = V_B(f) \quad (4)$$

From equation (3) the horizontal transfer function becomes:

$$Zu(f) = Hs(f) / Vs(f) \quad (5)$$

The equation (5) is thus used to estimate the transfer function at the given site using the single station method of the earthquakes recordings.

Table 1: Names of stations, codes and site classification used in the present study

S.No.	Station Code	Station Name	Station Latitude	Station Longitude	Site Geology
1	LAK	Lakimpur Kheri	27.95	80.79	Alluvium
2	MAH	Maharaj Ganj	27.14	83.54	Alluvium
3	TUL	Tulsipur	27.53	82.40	Alluvium
4	UTR	Utraula	27.31	82.41	Alluvium
5	KUS	KushiNagar	26.75	83.76	Alluvium
6	LEH	Laharpur	27.41	80.89	Alluvium
7	JAU	Jaunpur	25.73	82.69	Alluvium
8	DRB	Darbhanga	26.12	85.90	Alluvium
9	HAR	Hardoi	27.40	80.13	Alluvium
10	PTN	Patna	25.62	85.15	Alluvium
11	BAG	Bagha	27.13	84.06	Alluvium
12	MTR	Motihari	26.63	84.90	Alluvium
13	KSN	Kishanganj	26.10	87.95	Alluvium

Table 2: Epicentral locations of earthquakes and the SMA recording stations in UP and Bihar.

Date	Time (IST)	Mag. (Mw)	Lat	Long	Depth (km)	Stations which Recorded
25/04/2015	11:41	7.9	28.61	84.36	15	LAK, LEH, MAH, UTR, JAU, HAR, PTN, BAG, MTR, KSN, ASK, BHA, BER, KAM, KAP, KNA, PIT
25/04/2015	06:45	6.6	28.62	84.48	10	LEH, MAH, UTR, PTN, BAG, MTR, KSN
26/04/2015	07:09	6.9	27.36	85.54	10	KUS, LEH, MAH, TUL, UTR, JAU, BAG, MTR, KSN
12/05/2015	07:05	7.3	27.71	86.08	10	MTR, KSN
12/05/2015	07:36	6.2	27.62	86.11	10	KSN

Various steps involved for estimating the site amplification by using H/V ratio method are as:

- Nepal earthquake data of 25th April, 2015 and its strong aftershocks are converted in Ascii format.
- Fourier Spectra of three components is calculated.
- Converting two horizontal components into single horizontal component and divide the same by vertical component. The H/V site amplification values are estimated using the following formula given by:

$$H/V=\sqrt{((F^2_{NS}+F^2_{EW})/2)/(F^2_{UD})} \quad (6)$$

- We find the values of Predominant frequency at which the site amplification is maximum.

Here ($F_{NS}+F_{EW}$) represents the horizontal component (North-South and East-West) and (F_{UD}) represents the vertical component amplitudes. We obtain the ratio of the horizontal to vertical spectra (H/V) and estimate the predominant frequency bands of significant amplification.

5. Results and Discussion

PGA varies in case of the Nepal earthquake sequence from 3 to 79 cm/sec^2 in the study region (Table 3). It is interesting to note that the stations which lay in the SE direction from the main shock, experienced more PGA values than the stations lying in the SW direction of the main shock. The explanation towards the distribution of PGA in this area is explained in detail by Sharma et al. (2017). To understand the site characteristics and the predominant period of the ground motion, Nepal earthquake sequence has been analysed by computing site amplification using the methodology written in the previous section. The H/V ratios are plotted with respect to frequency for each station as shown in Figure 2 (a to n). The estimated H/V ratios for all 13 sites and their average and mean spectra are shown in Figure 2n. In this figure the thick red line is the average site amplification for the region and thick blue lines are the estimated standard deviation. The amplification levels corresponding to predominant frequencies are given in Table 3.

Overall the amplification levels in the region are in the range 1-10 for the broad frequency band of 0.15 to 4.5 Hz. The obtained results are also consistent with those of other reported studies in the region. The amplification functions obtained by using Standard Spectral Ratio (SSR) technique for the region are in range of 2.0-4.0 for the sites located in the same region as that of present study (Srinagesh et al., 2011). Hardoi (HAR) is a common site among the two studies and it shows significant correlation between both the values. Manisha et al. (2016) have also estimated the site amplification function for the National Capital Region (NCR) which lies near to Indo Gangetic Plain and obtained amplification level in the range 1.0-3.0 for broad frequency band of 3.0-10.0 Hz using the HVSR technique. Mukhopadhyay et al. (2002) used the microtremor measurements to estimate the H/V ratios in Delhi and obtained spectral amplification levels vary from 1.2 to 6.2 corresponding to different resonance frequencies of the range 0.1–10 Hz at different sites in the region. Iyengar and Ghosh (2004) have estimated amplification levels of 2–3 at the natural frequencies in the range 0.5–6.0 Hz at the 17 drill hole sites in Delhi region which lies in IGP.

Table 3 shows that the station BAG represents the higher value of predominant frequency (4.52 Hz) and LAK represents less value of the predominant frequency (0.15 Hz). It shows the range of the predominant frequency of the alluvium deposits. The site amplification factor is very high in the region which becomes hazardous in case of earthquakes from Central Himalaya. The study area is mainly composed of low rise to medium rise buildings and improperly designed houses with high resonance frequencies as well as tall buildings with low resonance frequencies. Multiple frequencies in this particular area can create a resonance effect both for low as well as medium rise buildings. The estimated values of predominant frequency and site amplification using real earthquake waveform data are important for evaluation of seismic hazard of the region.

6. Conclusion

The region of IGP is exposed to hazard from Himalayan earthquakes and therefore have high seismic hazard. The site amplification functions have been estimated for the 13 sites of IGP region using the waveforms of 2015 Gorkha (Nepal) earthquake and its 4 aftershocks recorded at these stations. The average value of the site amplifications for the frequency band 0.1-10.0 Hz is found to be in the range 1.2-4.0 for the sites with significant soil cover. The predominant frequencies are found to be in the range of 0.15 – 4.52 Hz and corresponding site amplification varies from 2.0 to 4.0. The site amplification functions estimated in the present study are useful for the simulation of site specific ground motions in the IGP region and its surroundings.

Table 3: Site amplification and dominating frequency using H/V method for Nepal Earthquake sequence at stations used in the present study.

Sr No.	Date	Station Name	SA	Dominating Frequency (Hz)
1	25-04-2015	BAG	8.40	4.52
2		DRB	9.08	2.53
3		HAR	4.43	1.53
4		JAU	4.79	1.77
5		KSN	6.69	0.44
6		LAK	4.20	0.15
7		LEH	5.02	0.18
8		MAH	5.59	0.40
9		MTR	5.36	0.98
10		PTN	5.01	1.68
11		UTR	8.09	2.59
12	25-04-2015	KSN	7.92	2.57
13		LEH	6.47	1.57
14		MAH	7.58	4.23
15		MTR	8.10	1.41
16		PTN	9.33	1.87
17		UTR	7.08	0.47
19	26-04-2015	JAU	9.18	3.17
20		KSN	5.86	3.39
21		KUS	9.90	2.27
22		LEH	5.52	1.83
2		MAH	9.75	2.16
24		MTR	8.05	1.91
25		TUL	10.01	2.05
26		UTR	8.66	2.57
27		BAG	9.89	0.85
28	12-05-2015	KSN	9	0.95
29		MTR	7.08	1.06

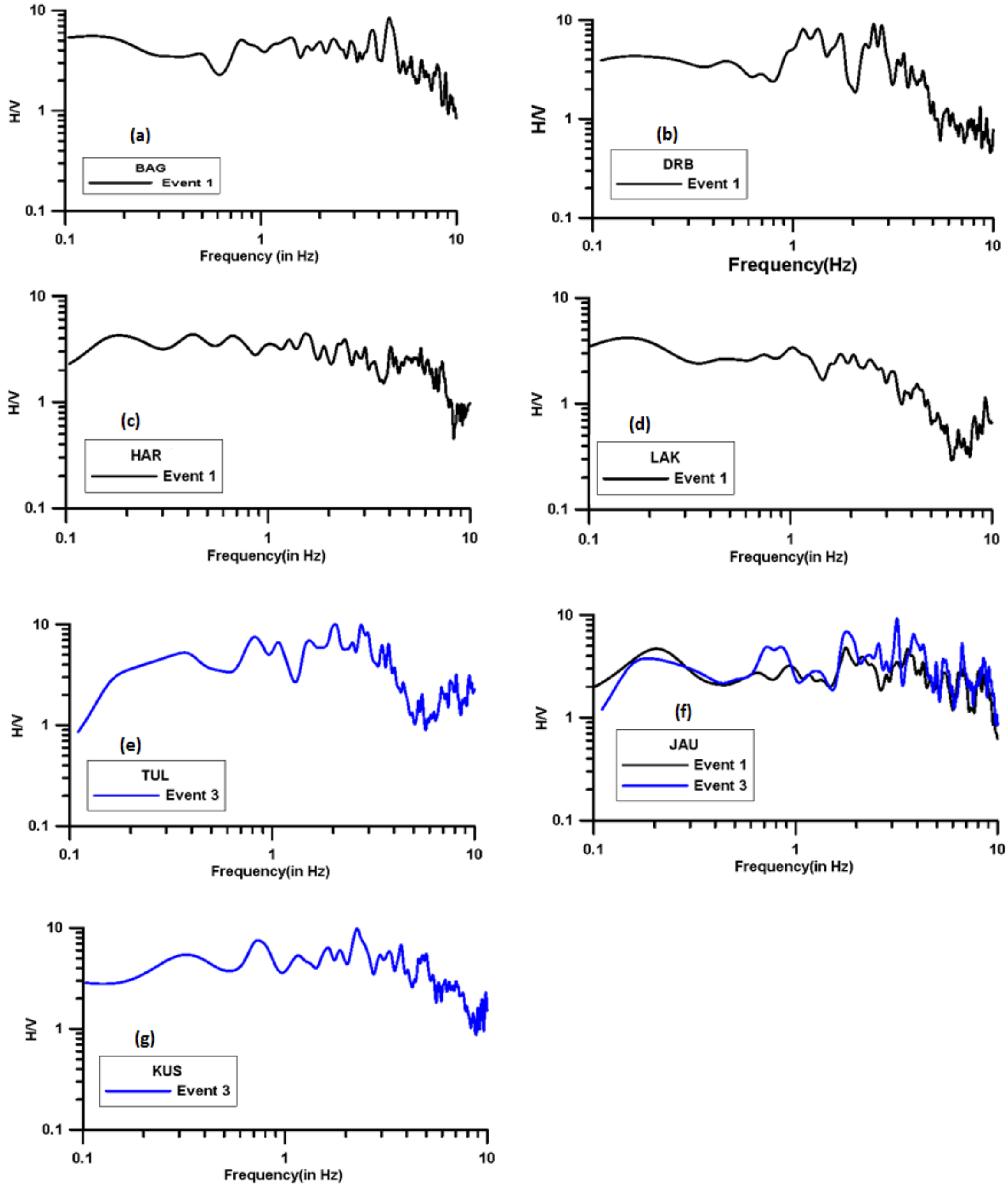

Figure 2: Plots for H/V ratio with respect to frequency (stationwise).

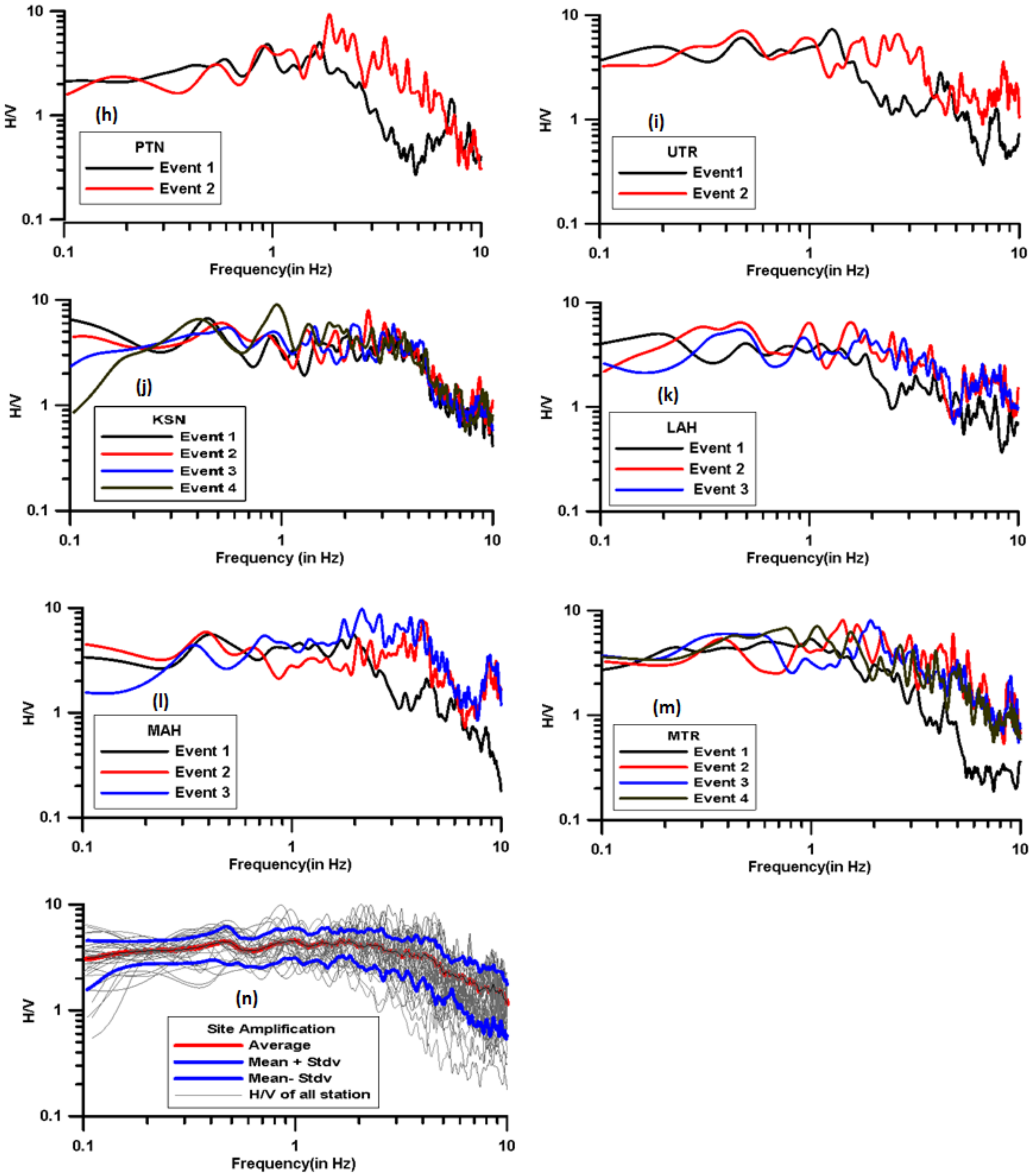

Figure 2 (continued): Plots for H/V ratio with respect to frequency (stationwise). Plot n is for the average site amplification.

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