Estimation of site response function using Nakamura technique: A case study from Kumaun Himalaya.

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Estimation of site response function using Nakamura technique: A case study from Kumaun Himalaya

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Abstract

The aim of this study is accomplished by utilizing the H/V spectral ratio method (Nakamura technique) to investigate the site response at fifteen seismic site stations. Regarding this method, some significant local site parameters such as the fundamental frequencies f_0 of soft sediments, peak amplitudes A_0 of corresponding H/V spectral ratios, spectrum amplitude, and spectrum rotation were computed over fifteen seismic stations in the study area. Microtremor data of fifteen seismic stations were utilized for site response. The fundamental frequency response varies from 0.67 to 8.10 Hz within the study area. Resulting from this analysis, the fundamental frequency response is low in and around the MUN, KLT seismic station. Similarly, the peak amplification at these seismic sites is found to be in the range of 2-4. Further, the contour map is prepared with the help of fundamental frequency response values obtained from the H/V curve to know the hazardous areas of the study region. Also, obtained H/V results were verified by comparing with SESAME guidelines condition of the study area. Spectrum rotation and spectrum amplitude analysis were carried out to know the characteristic of H/V with respect to azimuth and frequency in the sedimentary soil.

Keywords- Fundamental Frequency, Kumaun Himalaya, Seismic Hazard, Site Response

1- Introduction-

Earthquake is the most severe natural hazard which is one of the deadliest events associated with the tectonic process. The prime tectonic cause of earthquakes in the Kumaun

Himalayan is the continuous continent-continent collisions between the Indian and Eurasian plates. The regular occurrence of low to moderate magnitude earthquakes increases the seismicity in any tectonic setting, making it more vulnerable to hazard. In the recent past, several low to high magnitudes earthquakes have been experienced in the Kumaun Himalayan region. As a result, the Kumaun Himalayan has become the most tectonically active region of the Indian sub-continent in term of the impact on human lives, constructed man-made buildings, and environment. It is well known and emphasised in several earthquakes that soil site conditions can greatly affect the ground motion during an earthquake. On the other hand, the amplitude and frequency of ground motion may be significantly affected by local site motion during earthquakes. The soil type of any study region is influenced by the seismic ground motion of that region. The evaluation of site response on the characteristics of ground response is one of the most common aspects of any study region.

There are various methods for determining the characteristics of soil which have been used in the recent past for site effect assessment, including seismic reflection; multichannel analysis of surface waves, seismic refraction, uphole, downhole, and cross-hole surveys, spectral analysis of surface waves, continuous generation of surface waves, geotechnical investigations; microtremor measurement, and analysis of strong ground motion records (Choobbasti et al., 2014). Recently, the spectral ratio of Horizontal to Vertical (H/V) travelling seismic noise has become an important tool to estimate the fundamental frequency response and peak amplifications during ground motion. The long duration ambient seismic noise and recorded earthquake data have been utilized to study the H/V spectral ratio technique over soft deposits (Ohmachi et al., 1991; Field and Jacob, 1993; Lachet and Bard, 1994; Lermo and Chavez-Garcia, 1994; Lachet et al., 1996; Fäh et al., 1997; Parolai et al., 2004). This technique has advantages over other geophysical methods in that it is a simple, straight-forward, and fast non-invasive measurement of the seismic sites. In the present article, we have estimated the site response of fifteen seismic site locations along with spectrum rotation, spectrum amplitude, and probability of spectral density through a modified Nakamura technique by using the source tool Geopsy software (www.geopsy.org). These studies have led to reliable estimation of the fundamental frequency response and peak amplification of microtremor data from six seismic stations during the period of 2012-2018. These analyses are completely performed by microtremor data, but the earthquake data can be used to investigate the site response of this study region.

The primary object of this study is to quantification the relationship between the local geology and the ground motion, i.e., resonant frequencies and the peak amplification estimation of the six seismic sites for the entire Kumaun Himalayan region. The modified Nakamura technique is utilized to estimate the Horizontal to Vertical Spectral Ratio (HVSR) of fifteen seismic stations. The fundamental frequency response values were verified by using SESAME European project, which shows that the obtained results are reliable. The fundamental frequency responses of different seismic site locations show the soil characteristics. Further, the spectrum rotation and spectrum amplitude analysis has been conducted for the estimation of H/V with respect to azimuth vs frequency.

2- Geological setting-

The Kumaun Himalaya region is one of the most active orogens in the world. This region is bounded by latitude 29°N-31°N; longitude 78°E-81°E and located in the zone of greatest seismic activity in the Himalaya. The Kumaun Himalaya is also known as a lesser Himalaya. It is also divided into two parts namely as (i) the inner lesser Himalaya (ii) the outer lesser Himalaya. In addition, this region belongs to the central seismic gap and has the potential to produce great earthquakes. The underthrusting of the Indian with the Eurasian continental plate is the main reason behind it (Valdiya, 1980: Singh et al., 2012). The major tectonic features of the region include the Southern Tibetan Detachment (STD), the Main Central Thrust (MCT), the Main Boundary Thrust (MBT), and the Main Frontal Thrust (MFT) (Singh et al., 2012). The Lower

Himalaya is consisting mainly of Precambrian clastic sediments which are structurally bounded by MBT and MCT whereas the greater Himalaya is comprised of early Cambrian metasedimentary rocks and bounded by MCT and STD. Most of the earthquakes were recorded as shallow and restricted to a seismogenic zone within the upper ~25 km of the crust. The study region is experiencing regular occurrence of low to moderate earthquake in the Kumaun Himalaya. A few recent moderate earthquakes and bigger earthquakes have been experienced in and around the Kumaun Himalayan regions.

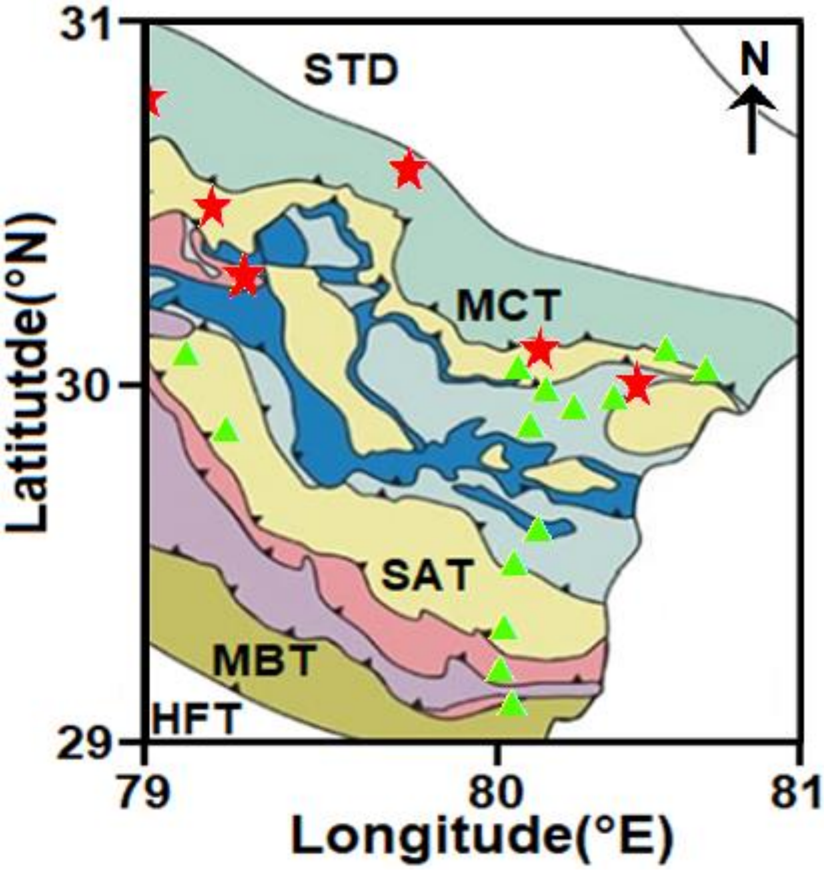


Figure-1 Tectonic map for the Kumaun Himalaya. Red stars show the historic earthquakes in the study region. Seismic site stations indicated by green colours.

3- Data and Method-

The Nakamura technique is one of the most popular techniques utilized for the investigation of seismic site response over soft deposits in any tectonic setting (Nakamura, 1989; Pandey et al., 2018; Matassoni et al., 2015). This technique was developed by Nogoshi and

Igarashi, (1971), but later modified by Nakamura, (1989). The Nakamura technique is described as the ratio of Fourier amplitude spectra of horizontal to vertical of recorded microtremor. Generally, this technique is based on impedance contrast i.e., the presence of sedimentary soil on hard bedrock. So, the horizontal component of microtremor data is amplified by the soft soil layer. The Nakamura technique has been adopted to compute the fundamental frequency response with respect to the peak amplification with the help of source tool Geopsy software for different microtremor data at six seismic site locations in this study region. Thus, we have considered only microtremor data which is recorded at all seismic stations. However, the earthquake data of three components can be used to compute the seismic site response. The Fourier spectra have been estimated by applying the Fast Fourier Transform (FFT) to all components of a particular station at each time window. Further, a cosine tapper of 5% is utilized to avoid spectral leakage. The Konno-Ohmachi algorithm has been applied for smoothing the Fourier amplitude spectra for which the smoothing constant value is 40.00 s (Konno and Ohmachi, 1998). The frequency sampling range has been selected in the range of 0.50 to 25.00 Hz for all recorded microtremor data. The short-term average (STA) and long-term average (LTA) algorithms have been used to split the recorded microtremor data in each time window. STA and LTA are set to 2 s and 30 s, respectively, for this analysis. Thus, the obtained results from the H/V analysis have been checked for the reliability and clarity of the peak by using the SESAME guidelines condition. Further, the spectrum amplitude and H/V with respect to azimuth have been performed for all recorded microtremor data in the study region. The range of rotation is kept from 0 to 180 degrees for the horizontal components of motion and also the azimuth direction is selected clockwise in the north direction.

4- Result and Discussion-

The Horizontal to vertical spectral ratio has been applied to estimate the fundamental frequency response and peak amplification of fifteen seismic site locations for the Kumaun

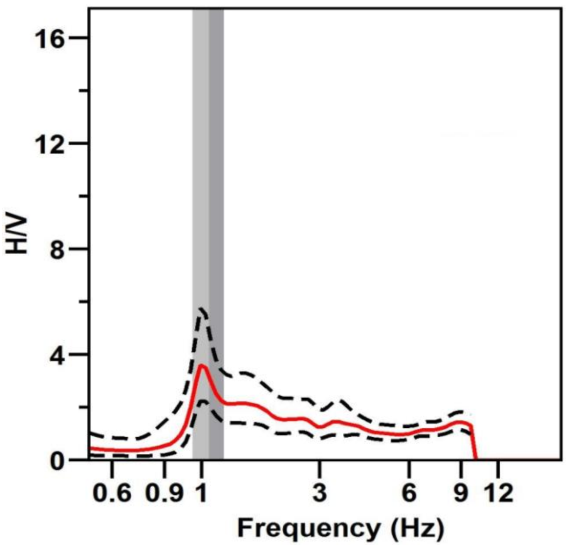
Himalayan region. Also, the spectrum rotation, and spectrum amplitude have been computed for all recorded microtremors as mentioned below in Fig. 2-5.

Fundamental Frequency Response-

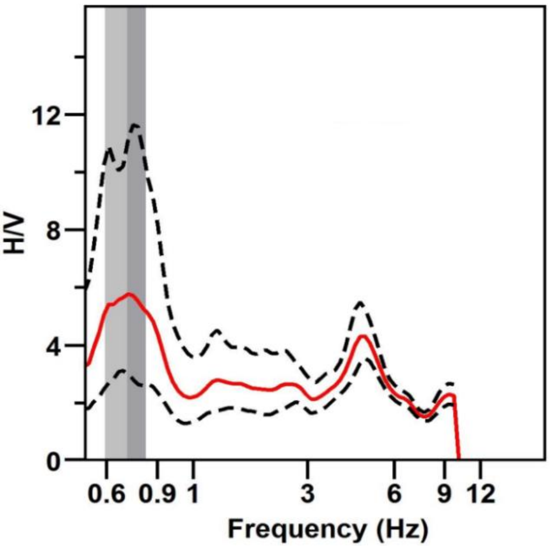
The fundamental frequency response with peak amplification has been estimated at fifteen seismic site locations in this study region as depicted in Fig. 2(a-o). Low fundamental frequency response and high amplification in the range of 0.6-2.0 Hz with a mean value of 1.3 Hz has been observed at different seismic site locations such as (KHAT, PNGL, SBLA), which represents that there is a possibility of thick sedimentary soil cover at greater depth. The moderate fundamental frequency response with moderate amplification is found to be at BSN, SKH, AMRI, BNDL, BANS, DHAM, DHAR, LGHT, and TANK seismic stations in the range of 2.0-8.0 Hz with a mean value of 5.0 Hz as shown in Fig. 2(d-i). Resulting from this, it is indicating that there is a possibility of thick sedimentary soil cover present at moderate depth. Previously it has been pointed out that the sedimentary soil is present at moderate depth in and around these seismic site locations. High fundamental frequency response with low amplification has been observed at different seismic site locations such as KLK, MUN, TOL as depicted in Fig. 2(m-o) which indicates the possibility of thin sedimentary soil cover is present at shallow depth in and around these seismic stations. However, it has been suggested by several authors such as Fnais et al., (2010); Pandey et al., (2018) low and high fundamental frequencies are obtained corresponding to greater depth and shallower depth respectively.

The liquefaction index can be achieved by using frequency response and amplification values in this analysis. Liquefaction vulnerability index (kg) is estimated by taking the square of amplitude (A_0) divided by the fundamental frequency (f_0) as shown in Table-1 (Natarajan and Rajendran 2015; Pandey et al., 2018). Resulting from this it has been observed that high kg value is present at seismic site SBLA (64.051) while low kg value is present at seismic site DHAR

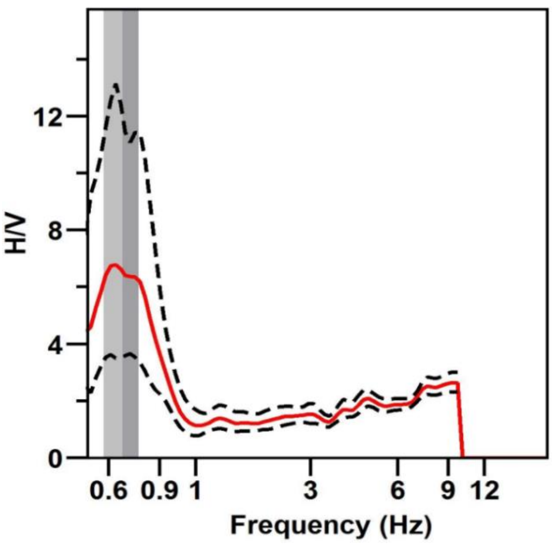
(0.354) respectively. Therefore, High kg value indicates future expected earthquake damage for SBLA seismic station is highly vulnerable.



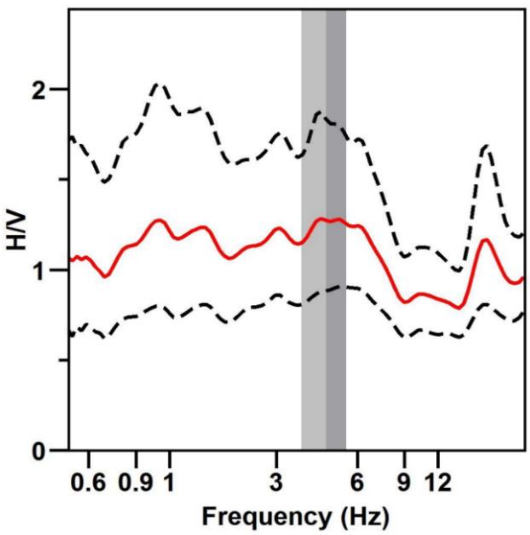
(a) KHAT

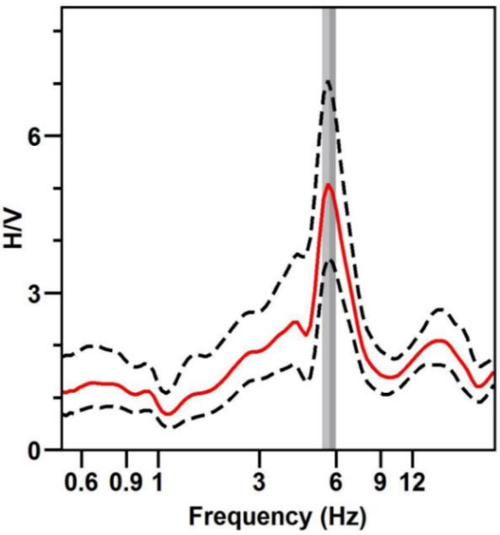


(b) PNGL

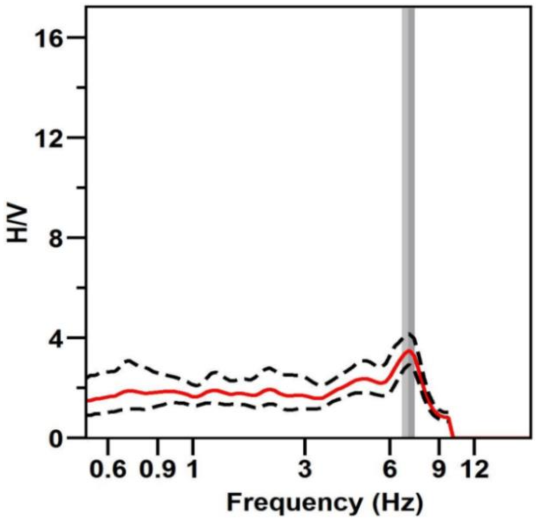


(c) SBLA

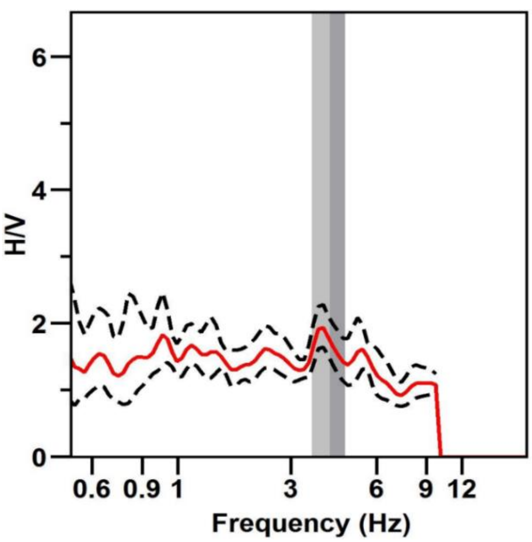


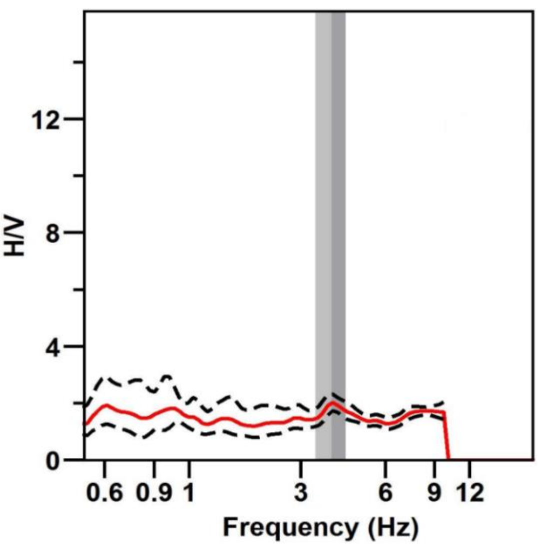


(d) BSN **(e) SKH**

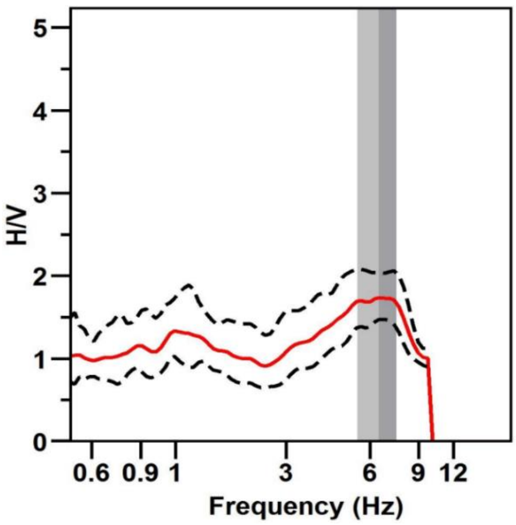


(f) AMRI

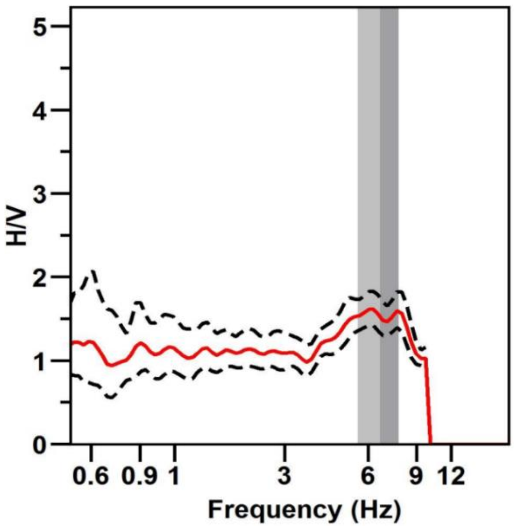




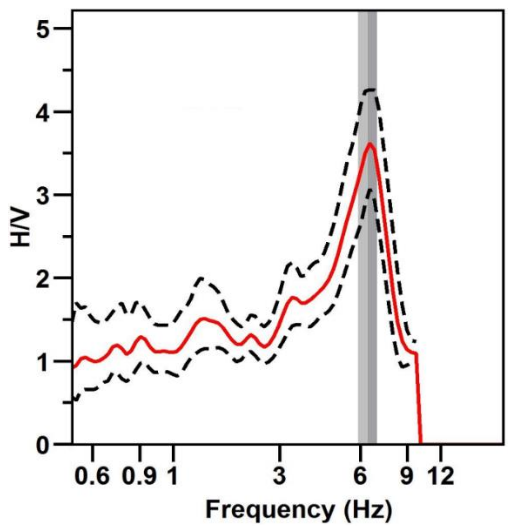
(g) BNDL



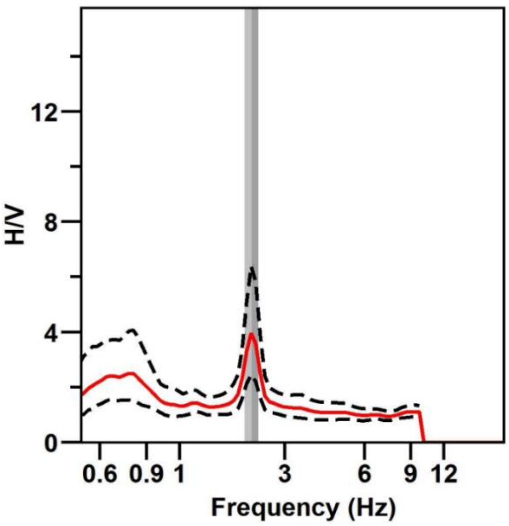
(h) BANS



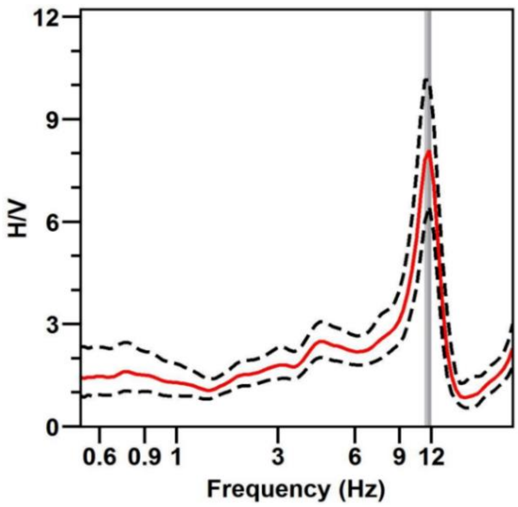
(i) DHAM



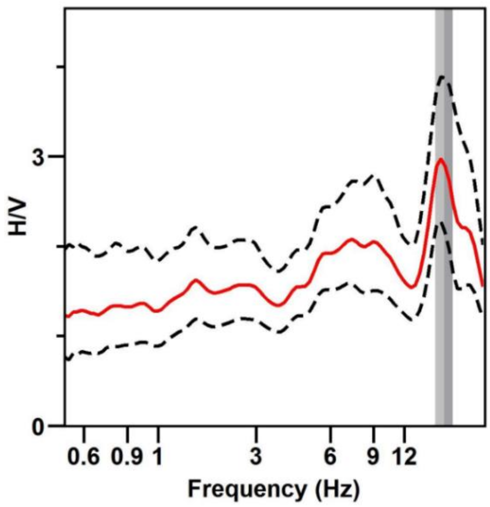
(j) DHAR



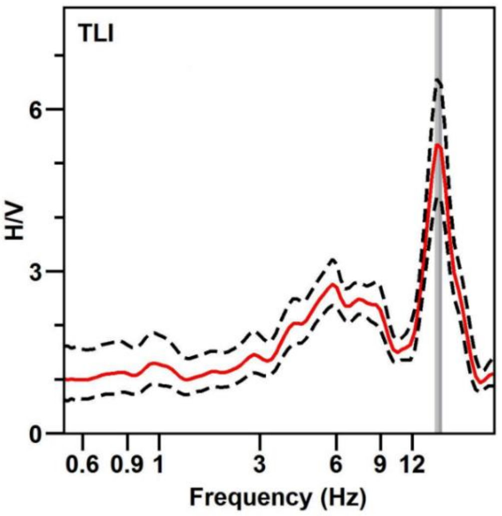
(k) LGHT



(l) TANK



(m) MUN **(n) KLK**



(o) TOL

Figure-2(a-o) Plot of fundamental frequency response of fifteen seismic site stations at different frequency range. Solid red line represents the average value H/V.

Table-1 List of the different fundamental frequency response, amplification and liquefaction index values for the fifteen seismic site stations.

S. No.	**Station Name**	**Lat(°N)**	**Long(°E)**	**Frequency**	**Amplification**	**Duration (In Min)**	**Liquefaction Index**
1	TOI	29.80	80.36	6.302(0.928)	2.679	25	1.139
2	MUN	30.06	80.25	11.540(0.589)	8.944	32	6.932
3	BSN	30.09	79.26	3.194(0.561)	1.352	30	0.572
4	SKH	29.32	80.04	5.639(0.334)	4.618	25	3.782
5	KLKT	29.59	79.35	10.032(1.214)	1.929	40	0.371
6	AMRI	29.22	80.04	6.994(0.361)	3.463	30	1.715
7	KHAT	28.94	79.98	1.271(0.154)	3.179	30	7.951
8	BNDL	29.74	80.27	4.106(0.555)	1.749	50	0.745
9	BANS	29.93	80.31	3.856(0.479)	1.979	15	1.016
10	DHAR	29.85	80.54	6.623(1.118)	1.532	18	0.354
11	DHAM	29.56	80.20	6.440(1.025)	1.733	18	0.466
12	LGHT	29.42	80.08	6.394(0.524)	3.559	18	2.003
13	TANK	29.12	80.08	2.248(0.131)	3.936	40	6.892
14	SBLA	30.05	80.58	0.669(0.930)	6.546	40	64.051
15	PNGL	29.98	80.68	0.706(0.114)	5.736	40	46.603

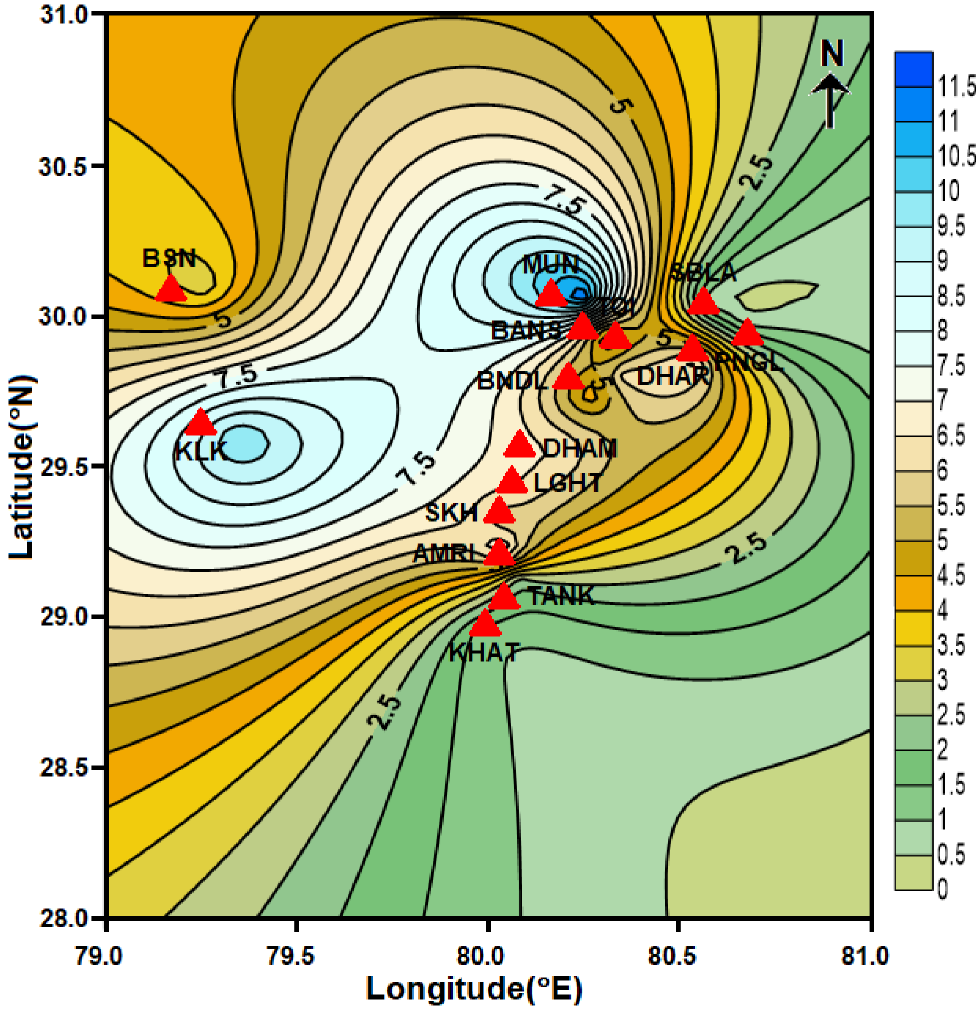


Figure-3 Contour map of fundamental frequency response for the Kumaun Himalaya region.

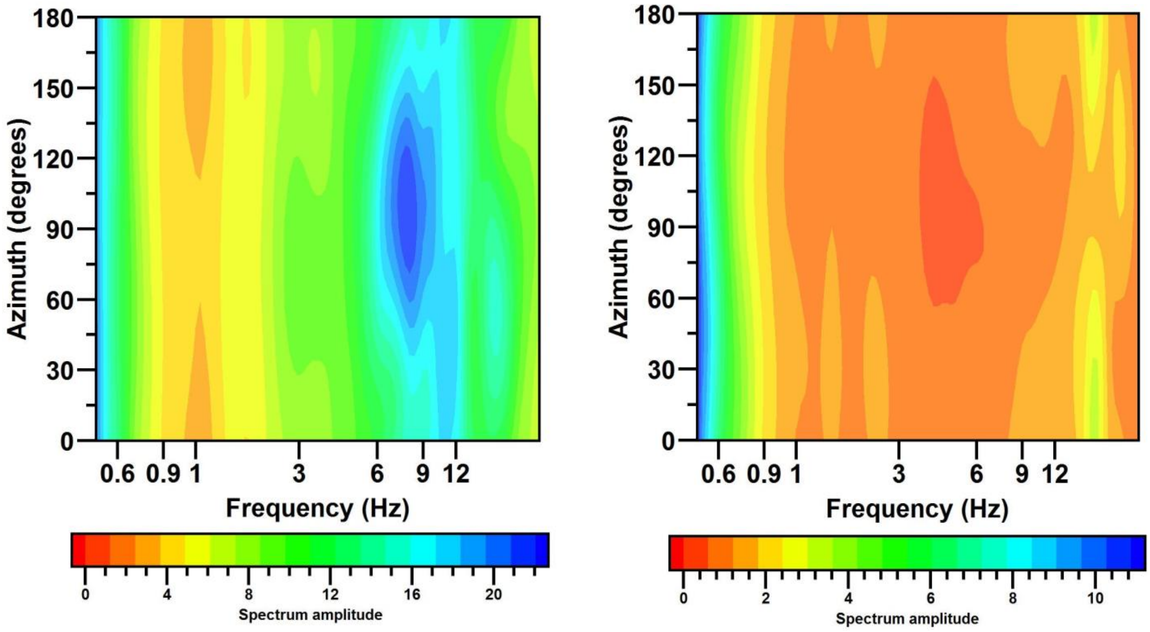
The contour map is prepared with the help of fundamental frequencies response values obtained from fifteen seismic site locations as depicted in Fig. 3. This contour map is helpful to understand the sedimentary disparity by the combination of fundamental frequency response results to the sedimentary thickness (Surve and Mohan, 2010; Pandey et al., 2018). From Fig. 3, it has been observed that the high fundamental frequency is present in and around the TOL, MUN seismic site locations whereas low frequency is present at different seismic site locations such as PNGL, SBLA. However, the moderate fundamental frequency response values are to be found in the rest of the study region. From this analysis, it has been observed that high fundamental frequency response with low amplification value at shallow depth vicinity of any seismic site location represent the hazardous areas in this study region. After that, these obtained results were verified by applying the conditions of the SESAME guidelines project. Thus, the criteria and reliability parameters have been taken from SESAME, (2004) guidelines which show the obtained fundamental frequency response results are reliable as shown in Table-2. But, at seismic site stations such as PNGL and SBLA obtained result of fundamental frequency response is not reliable as per SESAME guidelines condition.

Table-2 Represents the criteria and reliability parameters values of SESAME, (2004) guidelines for the fundamental frequency response results of all fifteen seismic site stations. f_0 is the fundamental frequency response, A_0 is the amplitude, N_W is defined as number of windows selected for the average H/V curve, L_W is window length and n_c is number of significant cycles.

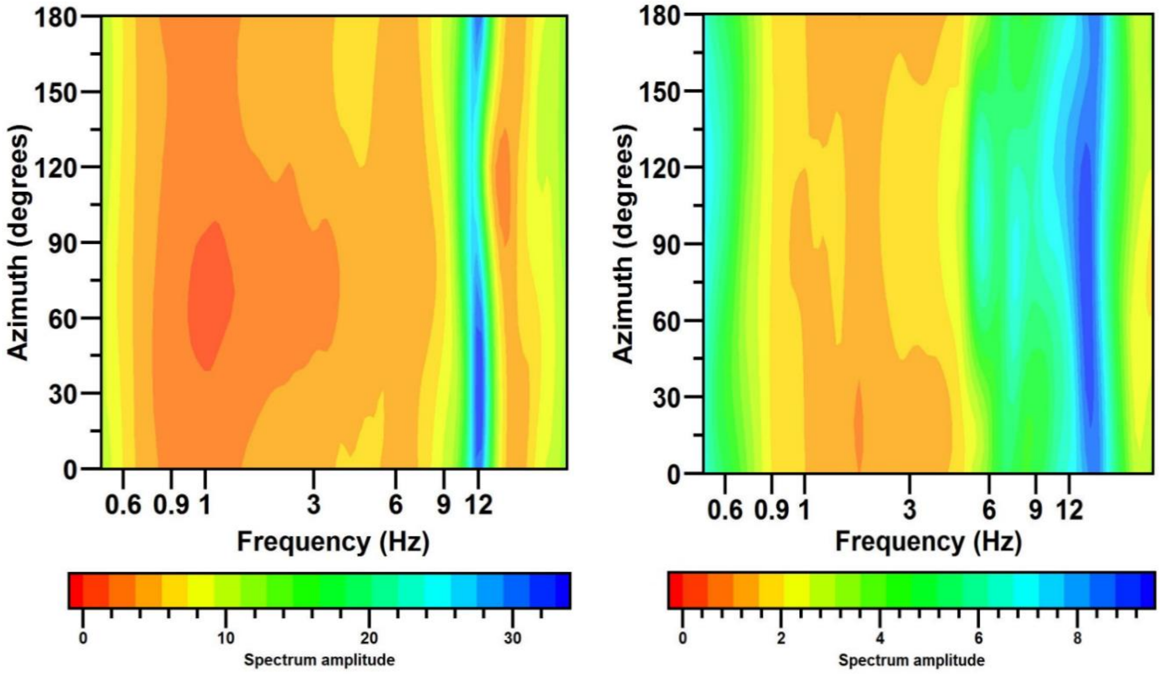
S. No.	**Station Name**	**Lat(°N)**	**Long(°E)**	**f_0 (Hz)**	**$A_0 > 2$**	**$f_0 > 10/L_w$**	**N_w**	**$n_c = n_w \times L_w$**	**nc (f_0) > 200**	**Comment**
1	TOI	29.80	80.36	6.302	2.679	0.40	22	550	3465	Reliable
2	MUN	30.06	80.25	11.540	8.944	0.31	18	576	6647	Reliable
3	BSN	30.09	79.26	3.194	1.352	0.33	25	750	2392	Reliable
4	SKH	29.32	80.04	5.639	4.618	0.40	19	475	2674	Reliable
5	KLKT	29.59	79.35	10.032	1.929	0.25	17	680	6820	Reliable
6	AMRI	29.22	80.04	6.994	3.463	0.33	21	630	4403	Reliable
7	KHAT	28.94	79.98	1.271	3.179	0.33	25	750	952	Reliable
8	BNDL	29.74	80.27	4.106	1.749	0.02	24	1200	4920	Reliable
9	BANS	29.93	80.31	3.856	1.979	0.66	18	270	1039	Reliable
10	DHAR	29.85	80.54	6.623	1.532	0.56	17	306	2026	Reliable
11	DHAM	29.56	80.20	6.440	1.733	0.56	20	360	23.18	Reliable
12	LGHT	29.42	80.08	6.394	3.559	0.56	21	378	2415	Reliable
13	TANK	29.12	80.08	2.248	3.936	0.25	18	720	1612	Reliable
14	SBLA	30.05	80.58	0.669	6.546	0.25	23	920	615	Not Reliable
15	PNGL	29.98	80.68	0.706	5.736	0.25	20	800	564	Not Reliable

Spectrum Amplitude-

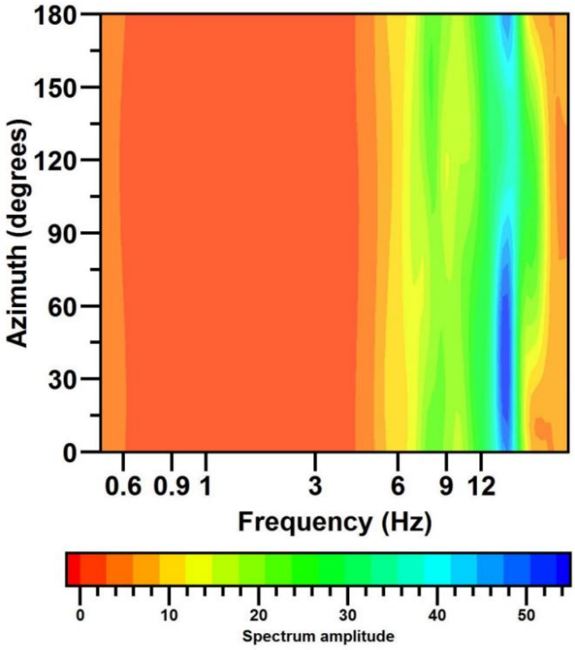
The presence of strong sources is revealed by direction analysis of the H/V curve. In this analysis, the H/V curve of fifteen seismic site stations has been performed for directional analysis. Thus, the horizontal component of motions is rotated in the range of 0°-180°. This analysis may be very suitable to check the site dimension, whether the site is 1D or not. An azimuth direction is always counted in the clockwise direction to the north. Therefore, spectrum amplitude has been observed at the seismic site stations such as BSN, MUN, SKH, TOL, KHAT, SBLA, and PNGL, which indicate the presence of strong sources in 1D.



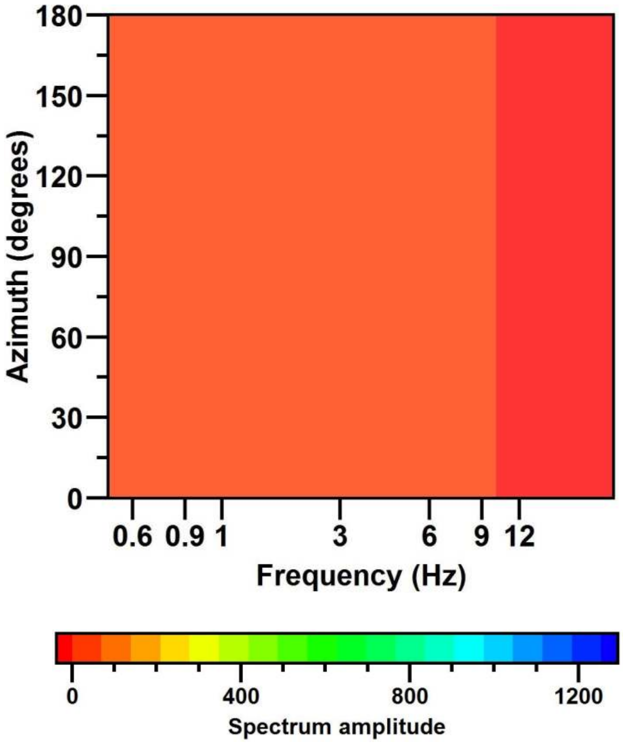
(a) BSN **(b) KLK**

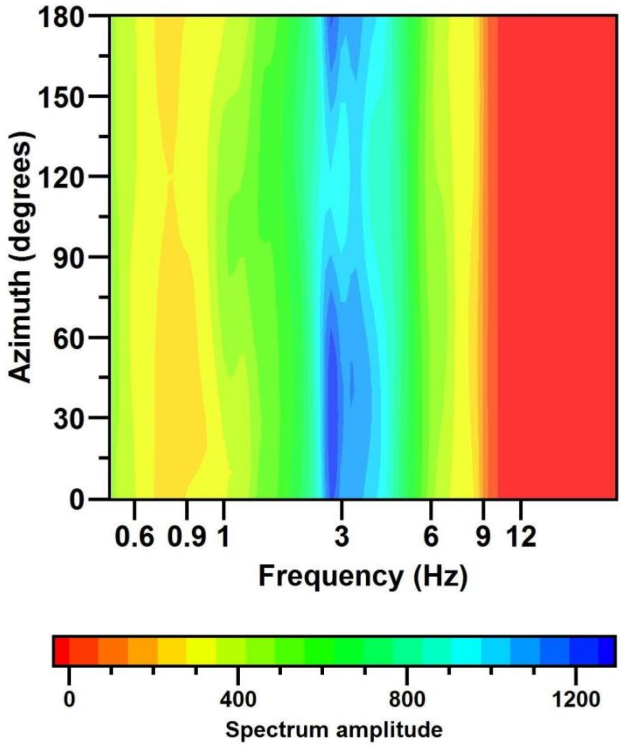


(c) MUN **(d) SKH**

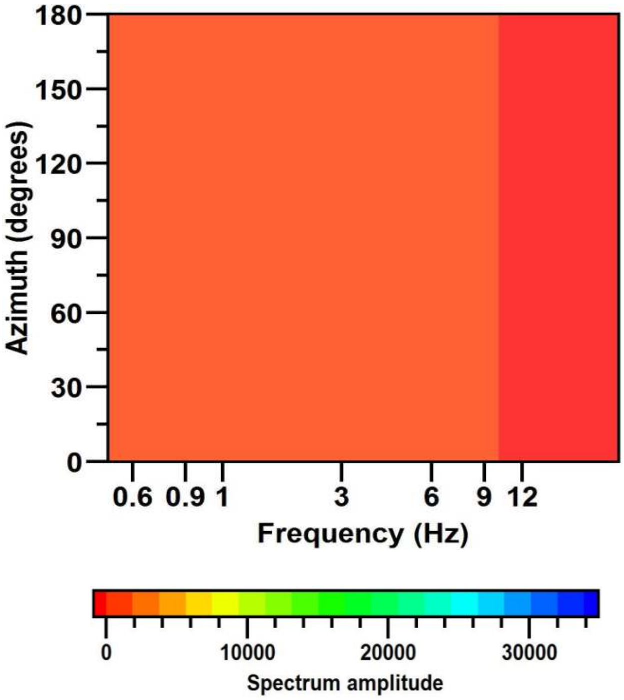


(e) TOL

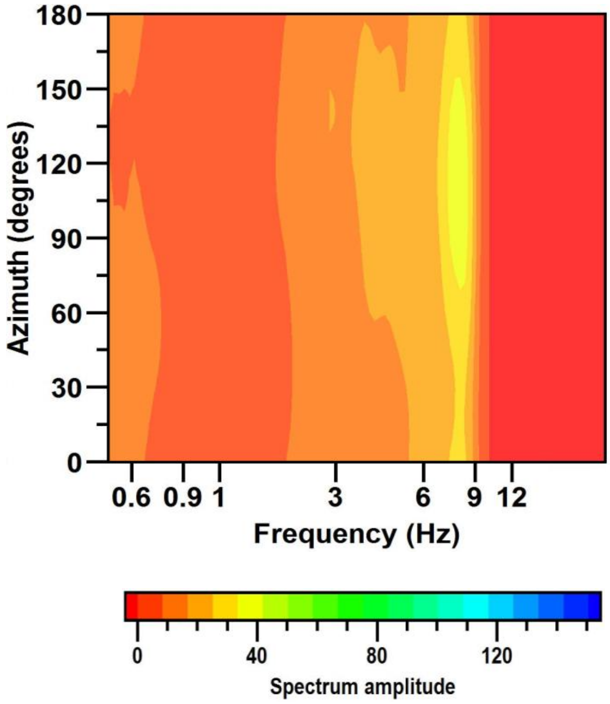




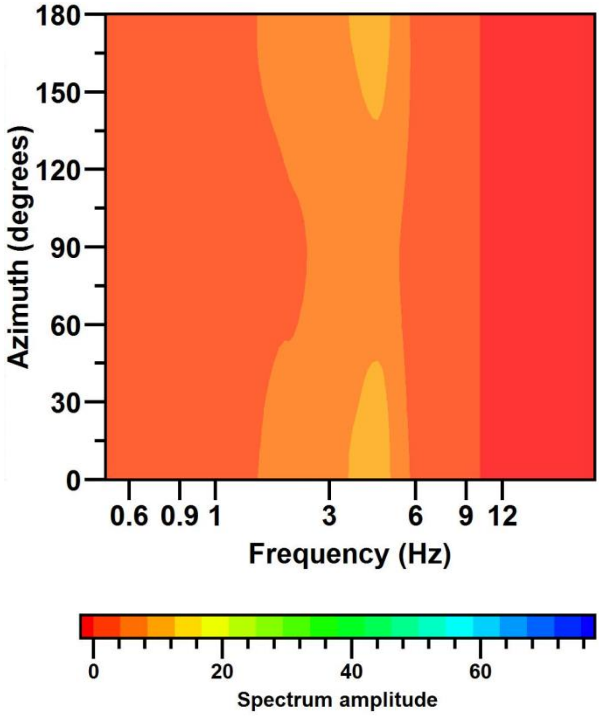
(f) AMRI **(g) KHAT**



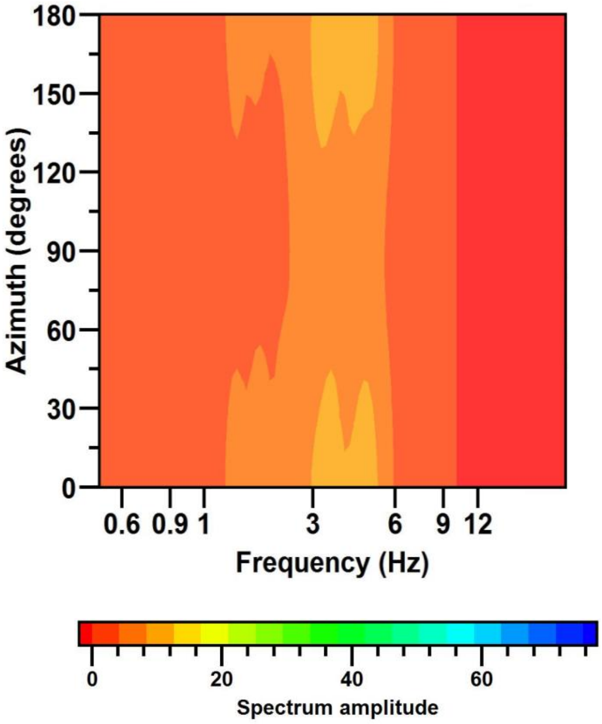
(h) BNDL



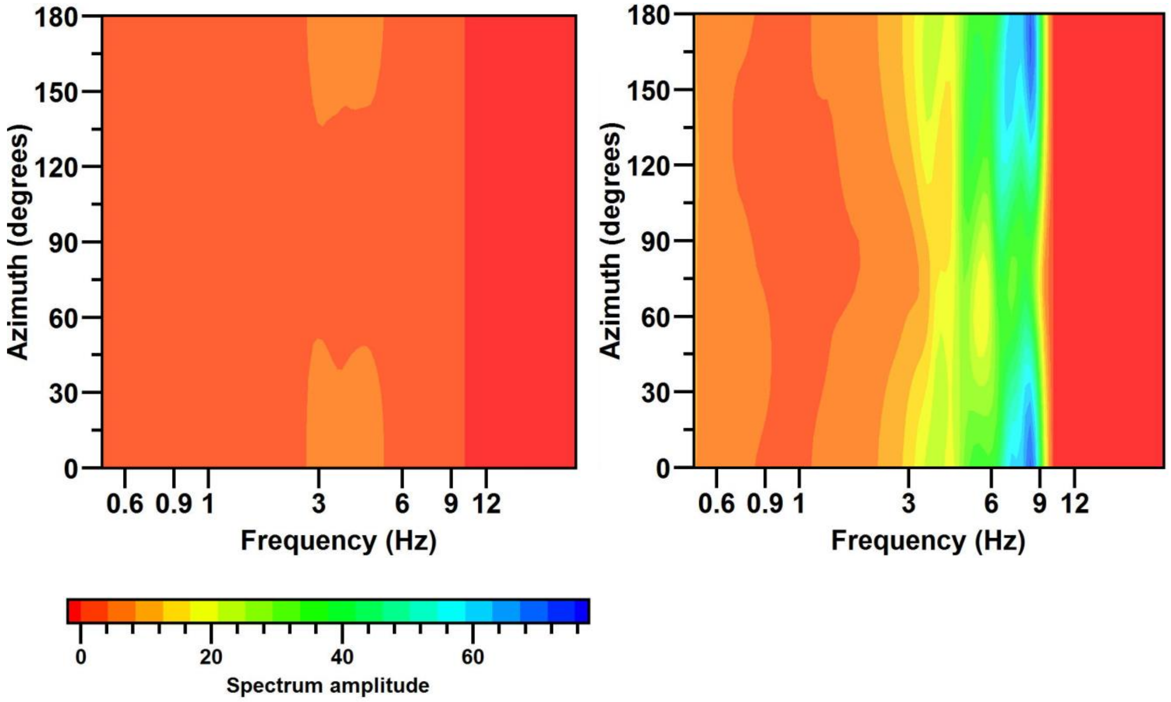
(i) BANS



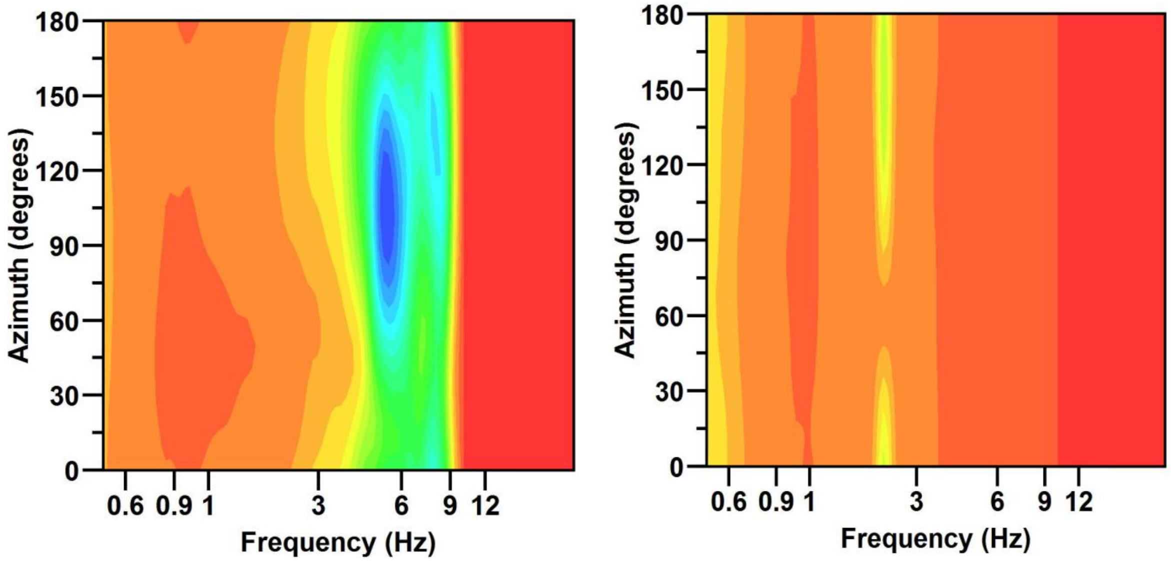
(j) DHAM



(k) DHAR



(l) LGHT **(m) SBLA**

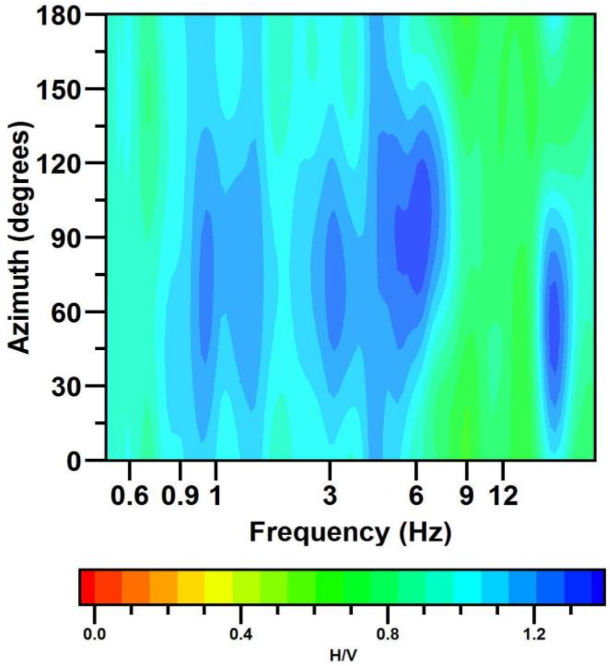


(n) PNGL **(o) TANK**

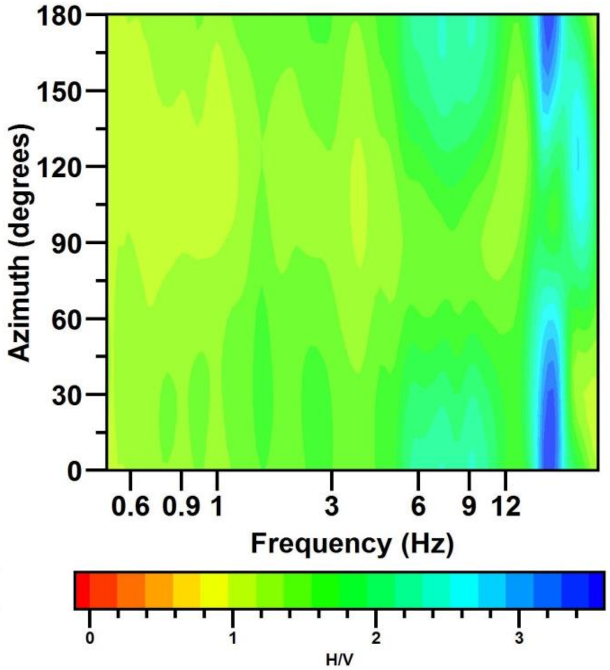
Figure-4(a-o) Plot of the spectrum amplitude with respect to azimuth for fifteen seismic site stations at different frequency.

Spectrum Rotation-

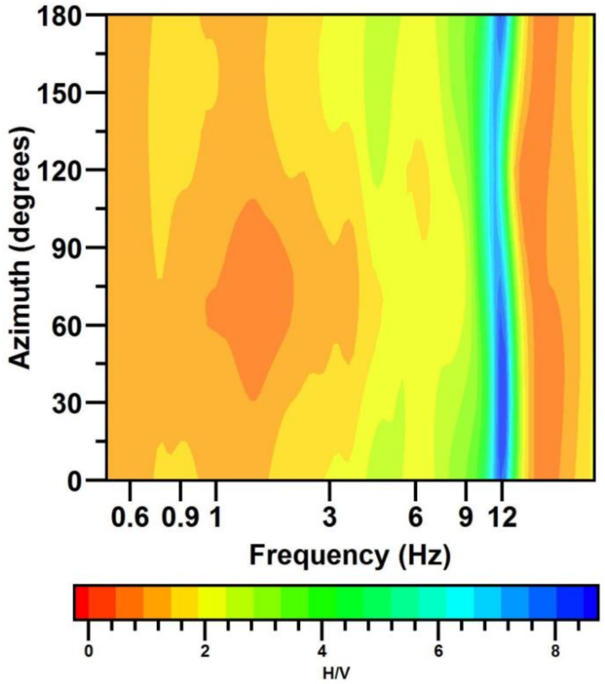
The variation of fundamental frequency with azimuth can be obtained with the help of H/V rotate analysis. Fig. 5(a-o) depicts the H/V rotate analysis of fifteen site stations. The H/V rotate amplitude has been observed for BSN, KLK, MUN, SKH, TOL, AMRI, KHAT, LGHT, PNGL, and TANK seismic site stations in the range of 0.6 to 12 over 0°-180°. It is indicated that maximum energy release occurs over this part of the study region. Furthermore, as shown in Fig. 5(b-h), other seismic site stations such as BANS, BNDL, DHAM, DHAR, and SBLA did not provide any significant observations during the H/V rotate analysis.

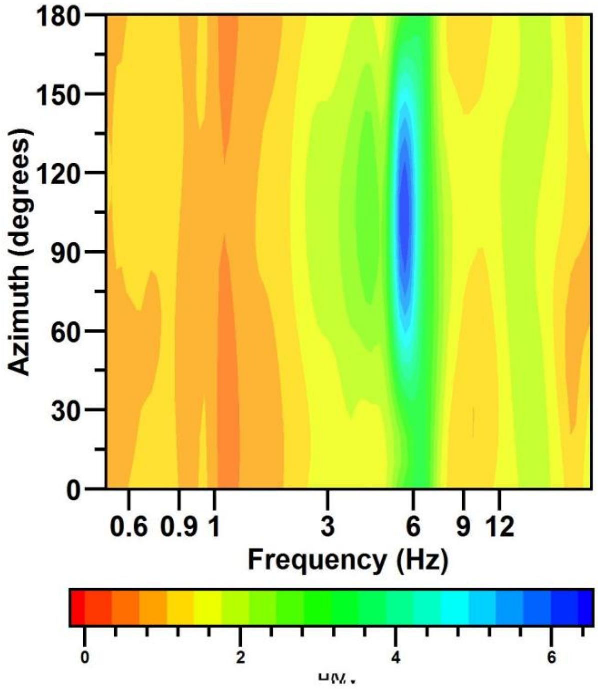


(a) BSN

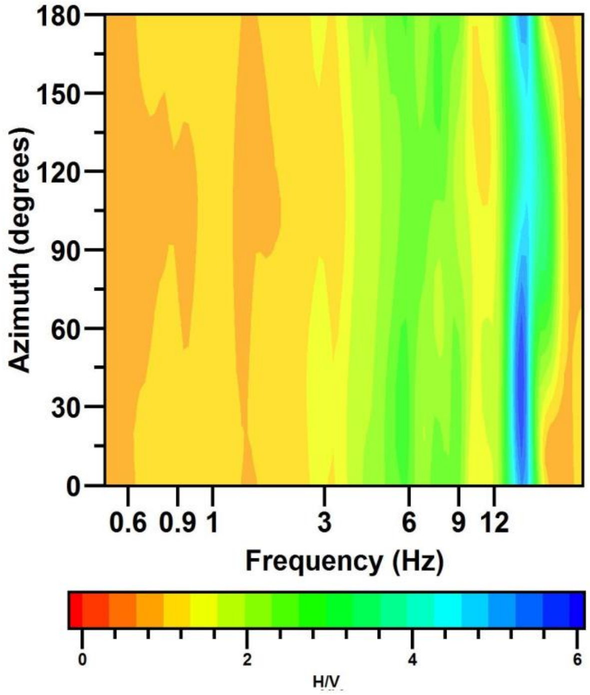


(b) KLK

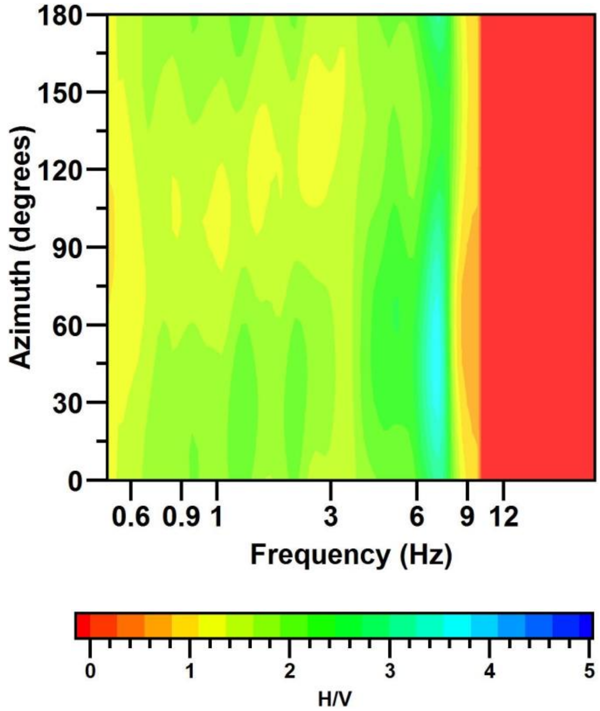


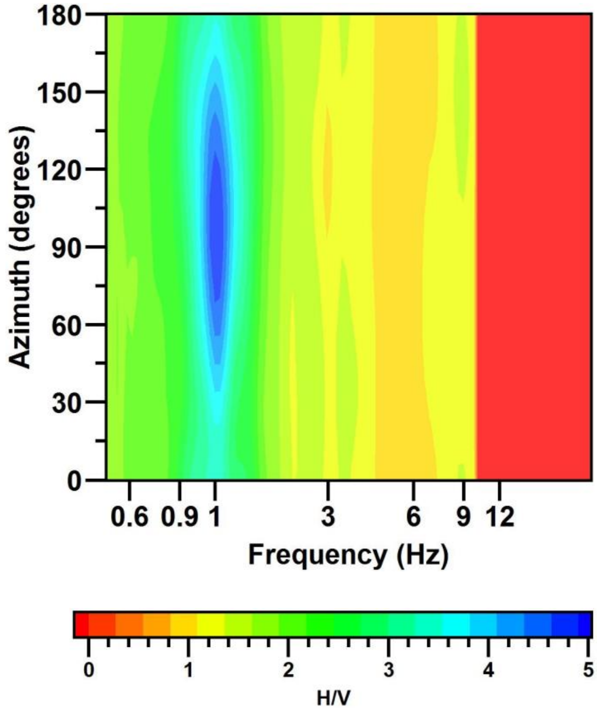


(c) MUN **(d) SKH**

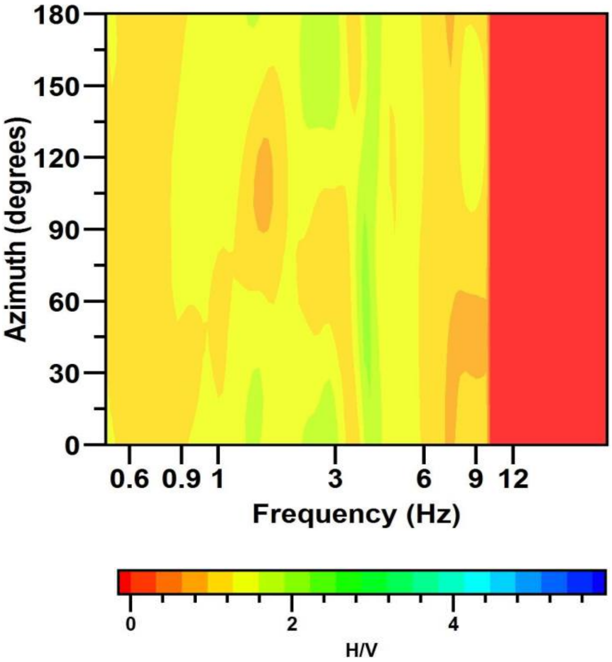


(e) TOL

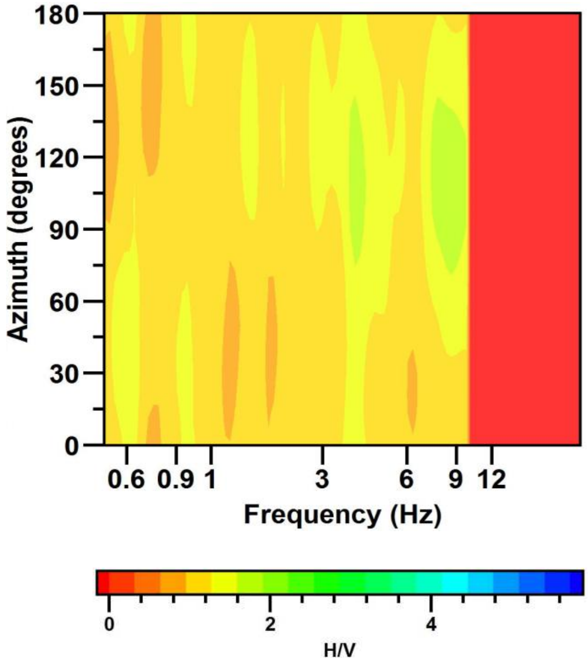




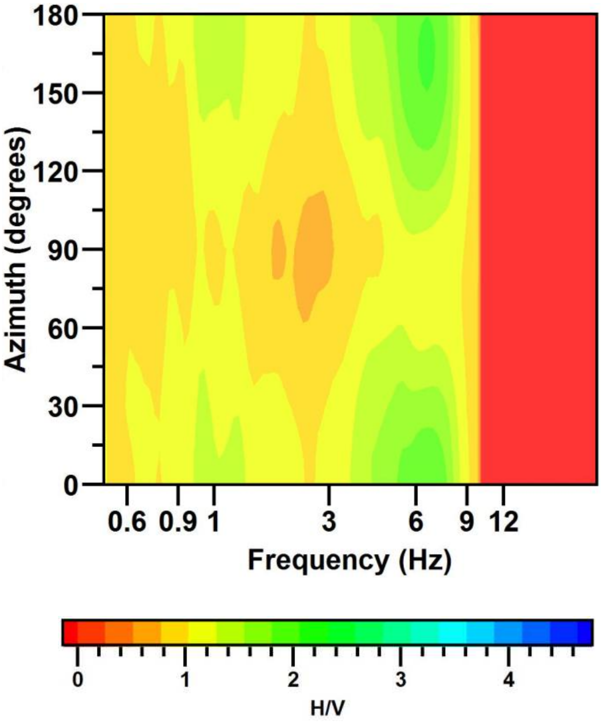
(f) AMRI **(g) KHAT**



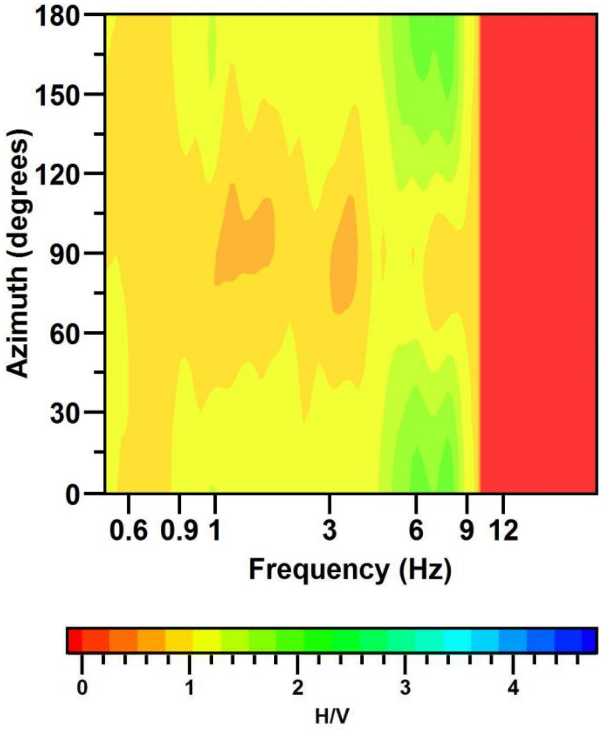
(h) BNDL



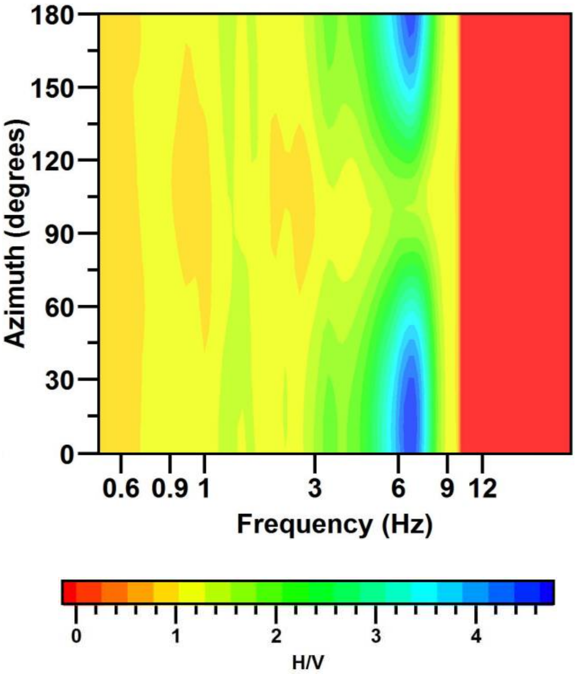
(i) BANS

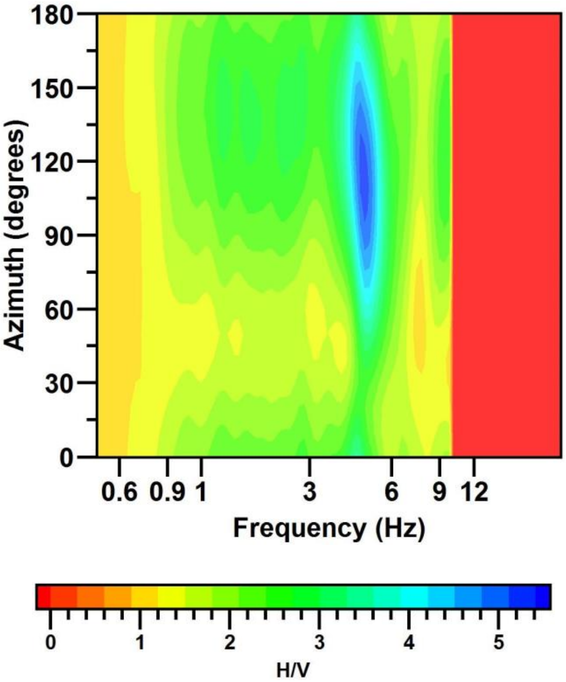


(j) DHAM

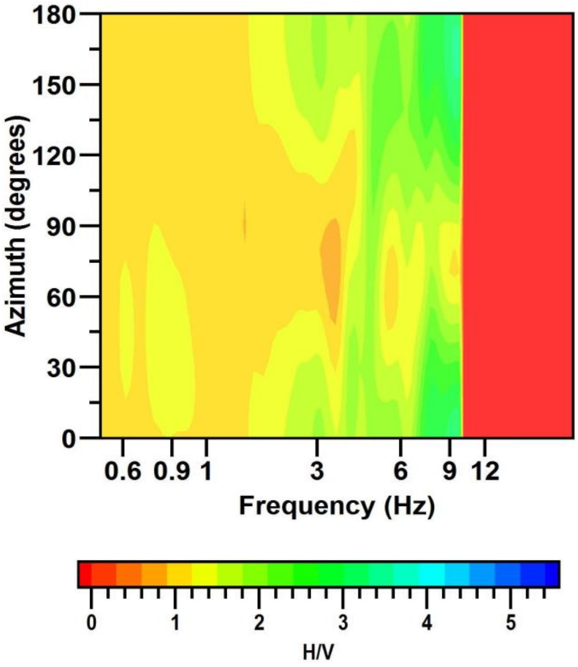


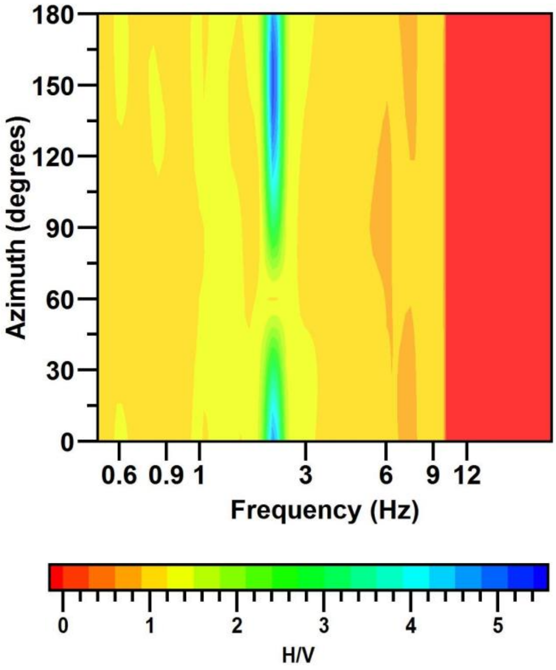
(k) DHAR





(l) LGHT **(m) PNGL**





(m) SBLA **(o) TANK**

Figure-5(a-o) Plot of the H/V rotation with respect to azimuth for different fifteen seismic site stations at different frequency.

5- Conclusion-

This article presents an approach using Nakamura technique measurements to govern the site response at fifteen seismic site stations. Microtremor data were analysed by employing the H/V method. Nakamura technique is a valuable tool to determine peak frequency and amplification factor of shallow soft soils. The study area reflects a high variability in terms of fundamental frequency (f_0) and amplification (A_0). High values of fundamental frequency (f_0) and corresponding lower values of amplification reflect at some seismic site locations, thus indicating a greater seismic risk triggered by soil amplification in the study area. The fundamental frequency response is found to be in the range of 0.7 to 22.0 for the fifteen seismic site locations. Also, SESAME guidelines have been followed to check the accuracy of the measurements, reliability, and clarity of the peak in the H/V curve. Spectrum rotate and amplitude investigation shows in some seismic site stations the energy is released corresponding to certain azimuth and frequency windows, it is indicating that measurement of these local site responses was highly significant to assess the seismic risk in the study area.

6-Acknowledgement-

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7- Declaration of Interest-

In this work no financial interests were requirement and no personal relationship. So, all these things will not influence the present work in this article.

8- References-

Choobbasti, A. J., Rezaei, S., Farrokhzad, F., 2013, Evaluation of site response characteristics using microtremors. Gradevinar 65:731-741.

Fah, D., Ruttener, E., Noack, T., Kruspan, P., 1997, Microzonation of the City of Basel. Journal of Seismology, 1, 87-102.

Field, E., Jacob, K., 1993, The theoretical response of sedimentary layers to ambient seismic noise. Geophys. Res. Lett, 20, 2925-2928.

Matassoni, L., Fiaschi, A., Silengo, M. C., Lotti, A., Saccorotti, G., 2015 Preliminary seismic microzonation in a mountain municipality of Tuscany (Italy). Open Geosci 7:559-571.

Nakamura, Y., 1989, A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface Q. Rep. Railw. Tech. Res. Inst. 30, 25-33.

Nogoshi, M., Igarashi, T., 1971, On the amplitude characteristics of microtremor (part 2). J Seismol Soc Japan 24:26-40.

Konno, K., Ohmachi, T., 1998, Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. Bull Seism Soc Am, 88, 228-241.

Lachet, C., Bard, P.Y., 1994, Numerical and Theoretical Investigations on the Possibilities and Limitations of Nakamura's Technique. J. Phys. Earth, 42, 377-397.

Lachet, C., Hatzfeld, D., Bard, P. Y., Theodulidis, N., Papaioannou, C., Savvaidis A., 1996, Site effects and microzonation in the city of Thessaloniki (Greece) comparison of different approaches. Bull Seismol Soc Am 86:1692-1703.

Lermo, J., Chavez-Garcia, F. J., 1994, Are microtremors useful in site response evaluation?. Bulletin of the Seismological Society of America, 84, 1350-1364.

Natarajan, T., Rajendran, K., 2015, Estimation of site response based on spectral ratio between horizontal and vertical components of ambient vibrations in the source zone of 2001 Bhuj earthquake. J Asian Earth Sci, 98, 85-97.

Ohmachi, T., Nakamura, Y., Toshinawa, T., 1991, Ground motion characteristics of the san Francisco Bay area detected by microtremor measurements. Proceedings of the second International Conference on recent advances in geotechnical earthquake engineering and soil dynamics. Missouri, LP08, 1643-1648.

Pandey. A. K., Roy, P. N. S., Baidya, P.R., Gupta, A. K., 2018, Estimation of Current seismic hazard using Nakamura technique for the northeast India. Journal of Natural Hazards, 93 (2), 1013-1027.

Parolai, S., Richwalski, S. M., Milkereit, C., Bormann, P., 2004, Assessment of the stability of H/V spectral ratios from ambient noise and comparison with earthquake data in the Cologne area (Germany). Tectonophysics, 390, 57-73.

Surve, G., Mohan, G., 2010, Site response studies in Mumbai using (H/V) Nakamura technique. Nat Hazard, 54, 783-795.