Regional Site Characterization by HVSR Technique Using the Archived Strong Motion Data of Earthquake Prone Areas

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Abstract- In order to monitor the ongoing seismicity in different seismically active regions of India, 300 state of the art digital strong ground motion accelerographs have been installed. To estimate site effects HVSR technique is used for 27 strong motion stations of Himachal Pradesh. In the present study, The Fourier response spectra are calculated for each component (North-South, East-West and Vertical). The horizontal to vertical spectral ratio curve (H/V ratio) was estimated using Nakamura formula. The data is processed by using "SeismoSignal" 2016 software. Along with H/V ratio the parameters can be estimated like Maximum Acceleration, Maximum Velocity and Maximum displacement. The Software gives the results based on PGA, PGV, PGD and results of ground motion parameters is obtained by considering maximum value and then by using a correction window of 5.12 seconds and then plotting it on elastic/inelastic curves by considering 5% damping. Maximum H/V spectra value is obtained for each strong motion stations. The Predominant frequency and Amplification factor for each strong motion station is obtained from H/V curve.

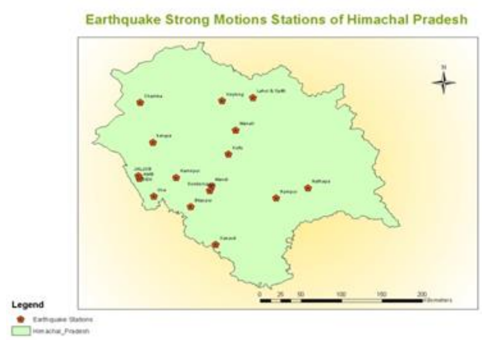
Indexed Terms- HVSR, Seismosignal, Predominant frequency, Amplification factor.

I. INTRODUCTION

Earthquake usually occurs whenever there is movement of tectonic plates place below the ground surface and a large amount of energy is released from the Earth's lithosphere that creates seismic waves which may even cause various Tsunamis and landslides. These cause extensive disaster that lead to extensive damage to the living creatures and habitat to various structures. Earthquakes are the major responsible for killing of the thousands of people. Some of the few examples of the major earthquakes with magnitude Large earthquakes have occurred in all parts of Himachal Pradesh, the biggest being the Kangra Earthquake of 1905 with a Magnitude of 7.8 on Richter Scale. M>7, 1906 San Francisco earthquake of magnitude, Mw7.9, 1923 Kanto earthquake of magnitude M7.9, Santa Barbara 1925 and Large Beach earthquake of 1933 of magnitude M 6.3, 1960 Chili earthquake of MW 9.5, 1964 Prince William Sound Alaska earthquake of MW 8.3, 1964 Niigata earthquake of magnitude M 7.5, 1985 Mexico earthquake of magnitude M 7.9, 1988 Armenia earthquake of magnitude M 7, 1989 Loma Prieta earthquake of MW 7.1, 1994 North-Ridge earthquake of MW 6.7, 1999 Turkey earthquake of MW 7.4, 1999 Taiwan earthquake of MW 7.5, 2001 Bhuj earthquake of MW 7.7, are few examples from the Indian subcontinents where severe damage was observed at sites far from the epicenter. The Indian subcontinent has experienced five major EQs in the past 100 years. As per the Bureau of Indian Standards (BIS 2002), most of the parts of the Himalayas comprising of North and North eastern parts of India fall within high to very high seismic zone. The Himalayan region is close to the most densely populated regions of the Indo-Gangetic Basin (IGB). Many strong motion recording stations are installed in IGB under a Government of India project entitled "National Strong Motion Instrumentation Network" to understand the ongoing seismicity of the area. PESMOS (www.pesmos.in) is the website which provides EQ records since 2004. Along with the ground motion records, SC of a particular station is also given by PESMOS. However, it has to be highlighted here that the site classification provided by PESMOS is purely based on the physical description of local geology. The SEISAT (2000) and Geological Maps of India, an approximate value of average shear wave velocity for 30m (Vs30) was assigned to each PESMOS recording station following Borcherdt (1994) classification scheme (Mittal et al.2012). Thus, the SC given by PESMOS is not based on in-situ field tests, rather, it is indirectly correlated with the geology (Pandey et al. 2016). The strong motion data from these stations are useful in many EQ engineering studies such advanced structural analyses, seismic hazard evaluation and development of regional ground motion prediction relationships (Kumar et al.2012). Nakamura (1989) proposed methodology for determining the site characteristics in terms of fpeak and Apeak using horizontal to vertical ratio of Fourier spectrum of microtremor records at the site of interest. While developing the methodology, Nakamura (1989) assumed that only the horizontal component retains the local site characteristics, whereas the source and the propagation path characteristics are retained in both vertical as well as horizontal components of ground motion. Thus, the ratio of horizontal component to vertical components for record reflects the local soil condition. This methodology provided a cost effective and simpler way to assess the site characteristics in terms of the fpeak value across the globe. Zhao et al. (2006) extended Nakamura (1989) technique to strong motion data considering the ratio of horizontal and vertical spectral acceleration considering 5% damping. The objective of this paper is to provide site characterization using EQ records from 27 recording stations for the Himachal Pradesh region of India. Based on the analyses, values of fpeak and Apeak obtained from average HVSR curves from all the 12 recording stations are estimated the values of fpeak and Apeak obtained from the model HVSR.

II. STUDY AREA

The state HP is located at 33.3-36.0-degree North latitude and 75.6-79.0-degree East longitude in the Western Himalayas. The state has not only been shaken by earthquake occurring in its territory but also in the neighboring areas of J&K in the North, Tibet in the East and UP hills in the South East. Based on the concept of plate tectonic model of the earth, the Himalayan Mountains have formed due to continuous threshing of the Indian plate with Eurasian plate since cretaceous times. The present geological structure and the tectonics of the Himalayas have been formed as a result of this continued collision. There are regional-tectonic features in the Himalayas like the Main Boundary Thrust (MBT), Main Central Thrust (MCT) remaining parallel to the strike length of Himalayas. A part from these regional tectonic features there are lineaments running transverse to the Himalayan Trend. Slow movements result in the elastic strain build up and the sudden release of tectonic strain energy along any of these tectonic features causes the earthquake activity. Large earthquakes have occurred in all parts of Himachal Pradesh, the biggest being the Kangra Earthquake of 1905, 1906, a Mw6.4 near Kullu, Mw 6.8 in Lahual-Kinnaur Spiti in 1975 along the Indo-China Border. Chamba, Kullu, Kangra, Hamirpur, Mandi, and Bilaspur Districts lie in Zone V. The whole state is prone to severe earthquake hazard. Chamba, Kullu, Kangra, Una, Hamirpur, Mandi, and Bilaspur Districts lie in Zone V. The remaining districts of Lahaul and Spiti, Kinnaur, Shimla, Solan and Sirmaur lie in Zone IV. Some of the Border Regions like Himachal-Punjab-Hoshiarpur Border Region also lies in the Zone IV.



Study Area Map of Himachal Pradesh

III. MODEL HVSR

Realizing the need for strong motion data collection and its analysis at high seismic prone areas of the country an attempt has been made in this work to assess the regional site response of Himachal Pradesh strong motion data, using HVSR technique. There are 27 Strong motion recording stations of the state were considered for the study and the data for these stations were processed in the software ‘Seismosignal’Version 2016. Maximum(peak) ground motion parameter was obtained in terms of Predominant frequency and Amplification Factor.The program Model HVSR provides a user-friendly tool to analyze and interpret ambient noise measurements. Herak (2008) assumed that the ambient vibrations are constituted by body waves moving vertically such that the vertical and horizontal ground motion components are controlled by P and S waves amplitudes respectively. Thus, if P and S waves have the same amplitude at the bedrock, HVSR at the surface reflects the amplifications produced based on characteristics of local soil above the bedrock. This HVSR curve is calculated as the ratio between the transfer functions relative to S waves (Fs) and P waves (Fp) by the equation. (Fs/Fp). The input parameters for the model HVSR includes shear wave velocity (Vs), layer thickness (h), density (ρ) and Q-factor. The value of Vs and ρ for various h are obtained as per Pandey et al. (2016). Detailed geophysical investigations were carried out by Pandey et al. (2016) based on MASW tests and detailed seismic profiling for these 27 strong motion recording.

IV. HVSR CALCULATION

In order to determine the HVSR from EQ data, the following procedure was applied as described by Harinarayan and Kumar (2016).

1. Calculate response spectra after applying 5 % damping of north-south, east-west and vertical components.
2. The response spectra of each component is smoothened as per Konno and Ohmachi(1998).
3. The geometric mean of the two horizontal components is calculated using the equation below;
   $H= (H_{EW} \text{ X } H_{NS})^{0.5}$
4. Calculate the ratio of H to V.

Where, HEW and HNS denotes the pseudo response acceleration (PSA, 5% damped system) of the horizontal east-west and north-south components respectively and V denotes the PSA (5% damped system) of the corresponding vertical component. The HVSR at each station is then estimated as:

$$HVSR_i=\frac{\sum_{j=1}^{Ni}\frac{H}{V}}{Ni}$$

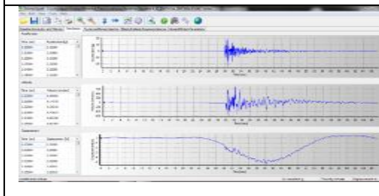
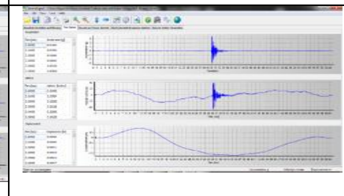
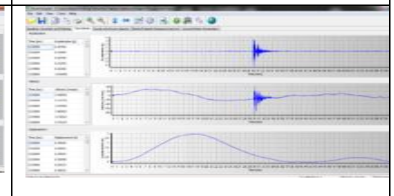
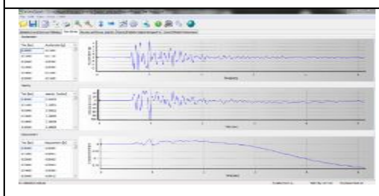
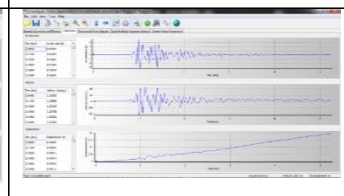
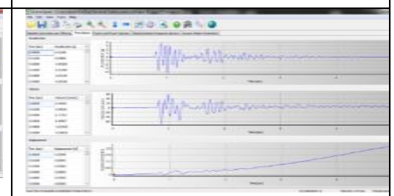
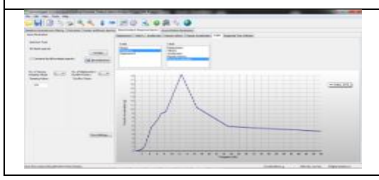
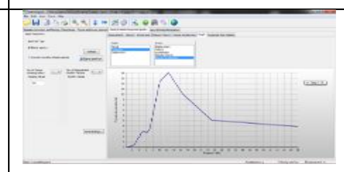
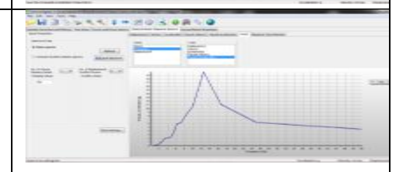
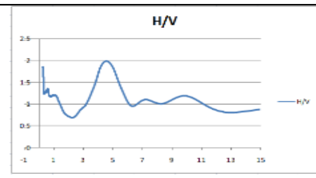
Where, Ni denotes the number of events recorded at station "i". Further, fpeak for a station is the frequency corresponding to the highest.amplitude. To estimate the Ground motion data and to calculate spectral acceleration i.ePGA,PGV and PGD. The ground motion data is downloaded from Pesmos IIT Roorkee site.

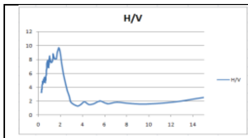
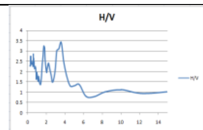
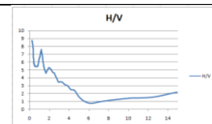
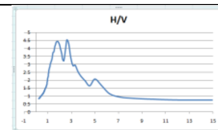
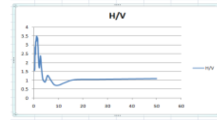
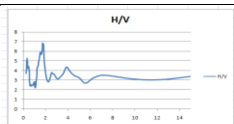
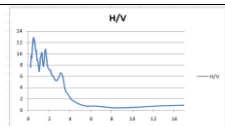
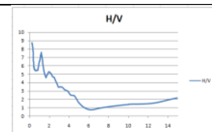
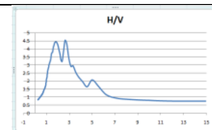
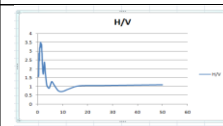
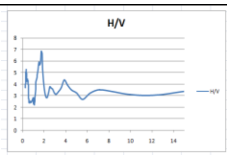
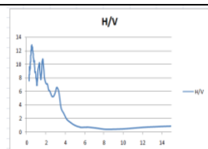
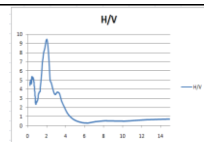
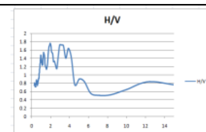
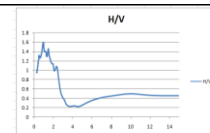
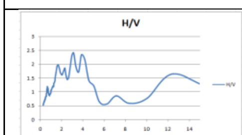
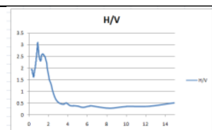
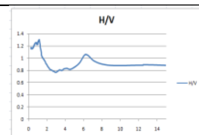
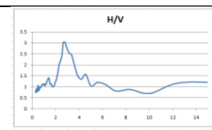
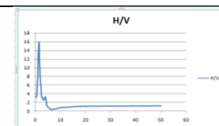
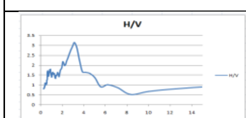
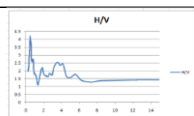
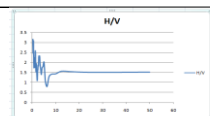
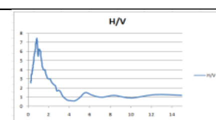
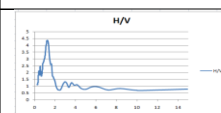
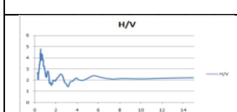
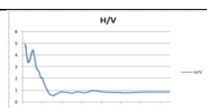
The software which is used to import the data and calculate the spectral acceleration is Seismosignal software. This software provides the following:

i. Fourier and Power spectra
ii. Elastic/Inelastic response spectra and pseudo spectra
iii. Over damped and constant-ductility inelastic response spectra
iv. Root-mean-square (RMS) of acceleration, velocity and displacement

The program is able to read accelerograms saved in in different text file formats, which may then be filtered and baseline-corrected. Polynomials of up to the 3rd order may be employed for the latter, whilst three different digital filter types are available, all of which capable of carrying out high pass, and low pass, band pass and band stop filtering. Finally, and due to its full integration with the Windows environment, Seismosignal allows for numerical and graphical results to be copied to any Windows application (MS Excel). For each station, spectral ratios between the horizontal components and the vertical component of each recording (HVSR) were computed, and then mean HVSR curves were calculated for the PGA ranges. A possible correlation between frequency and ground acceleration (peak and mean values) by examining HVSR from subsequent 5.12-s windows of a suitable recording.

Station	Station	Station
Anandpur Sahib	DEH	Lahul-Spitti
Bilaspur	JAL	Manali
Chamba	JMU	Mandi
Dasuya	JUB	Nawansahar
Dharamshala	Kangra	Nakodar
Garshankar	Kapurthal	Nathapa
Hamirpur	Keylong	Rampur
AMB	Kullu	Sundernagar
DAS	Kasuli	Una

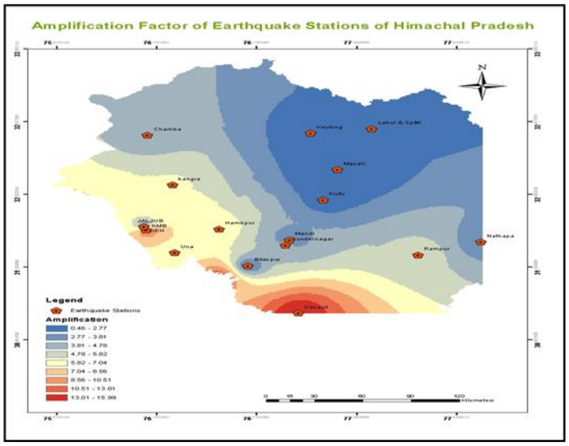
E-W	N-S	VT
		
		
		
		

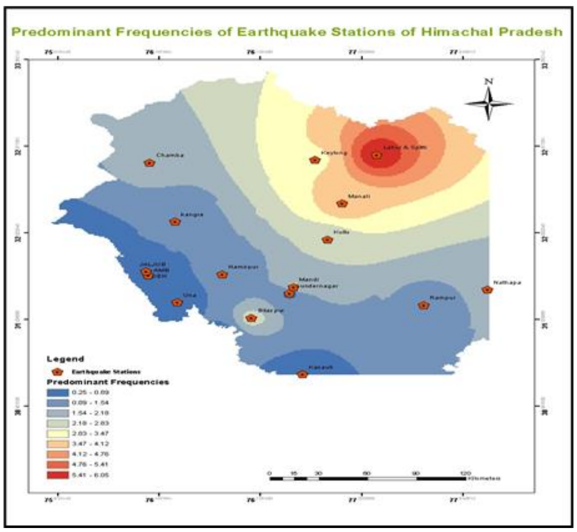
 Anandpur Sahaib	 Bilaspur	 Chamba	 Dasuya	 Dharamshala
 Garahshankar	 Hamirpur	 AMB	 DAS	 DEH
 JAL	 JMU	 JUB	 Kangra	 Kapurthala
 Keylong	 Kullu	 Kasuli	 Lahul-spiti	 Manali
 Mandi	 Nawansahar	 Nakodar	 Nathpa	 Rampur
 Sundernagar	 Una			

Ground Motion Parameter of the Station Bilaspur.

Parameter of Ground Motions.	Corrected Accelerogram E-W	Corrected Accelerogram N-S	Corrected Accelerogram VT
Max. Acceleration (g)	3.522	2.598	2.944
Time of Max. Acceleration (sec)	33.305	32.53	34.095
Max. Velocity (cm/sec)	214.0468	183.3857	136.9035
Time of Max. Velocity (sec)	33.21	31.665	37.595
Max. Displacement (m)	7.70995	4.40173	12.66382
Time of Max. Displacement (sec)	37.21	43.98	26.87
Vmax / Amax: (sec)	0.080665	0.106065	0.07565
Acceleration RMS: (g)	0.309365	0.245145	0.231295
Velocity RMS: (cm/sec)	45.17656	33.81201	43.11293
Displacement RMS: (m)	4.2151	2.413425	7.62766
Arias Intensity: (m/sec)	113.1995	71.45276	57.74622
Characteristic Intensity (Ic)	1.487075	1.051175	0.92765
Specific Energy Density (cm2/sec)	202165.3	126775	204472.9
Cumulative Absolute Velocity (cm/sec)	10282.47	8233.268	7191.912
Acceleration Spectrum Intensity (g*sec)	1.68934	1.02908	1.135695
Velocity Spectrum Intensity (cm)	1036.751	863.9356	562.6781
Housner Intensity (m)	877.1462	756.6934	471.445
Sustained Maximum Acceleration (g)	1.4055	1.47	1.573
Sustained Maximum Velocity (cm/sec)	148.8815	122.2964	93.47459
Effective Design Acceleration (g)	3.31021	2.655885	3.00756
A95 parameter (g)	3.50073	2.57068	2.921955
Predominant Period (sec)	0.45	0.45	0.45
Mean Period (sec)	0.53709	0.50159	0.45028
H/V	2.689		
Zone	V		
Site Class	C		

Sl.no	Station	Zone	Predominant Frequency	Amplification Factor
1.	Anandpur sahib	IV	0.539	12.78
2.	Bilaspur	V	2.538	2.689
3.	Chamba	V	1.88	4.021
4.	Dasuya	IV	0.25	8.78
5.	Dharamshala	V	1.386	6.186
6.	Hamirpur	IV	1.0465	6.505
7.	DAS	IV	2	9.43
8.	DEH	IV	2	3.179
9.	AMB	IV	0.505	12.49
10.	Garshankar	IV	0.52	4.085
11.	JAL	IV	0.93	1.6
12.	JMU	IV	1.4	6.25
13.	JUB	IV	2.99	4.1025
14.	kangra	IV	1.0975	5.972
15.	Kapurthala	IV	0.973	2.165
16.	Keylong	V	3.363	1.89
17.	Kasauli	V	0.25	16
18.	Kullu	V	2.4	2.35
19.	Lahul&Spitti	IV	6.06	2.2
20.	Manali	IV	4.15	0.458
21.	Mandi	V	2.51	2.926
22.	Nakodar	IV	0.34	4.06
23.	Nathapa	IV	1.61	3.198
24.	Nawansahar	IV	0.81	7.44
25.	Rampur	IV	1.11	5.33
26.	Sundernagar	V	0.4975	4.12
27.	Una	V	0.25	6.361





V. DISCUSSION

Site characterization is very important in seismic studies, as the seismographs cannot be properly interpreted unless geotechnical properties of the material are known. The sites were divided into three categories; SC A, SC B and SC C as per PESMOS. The site classification scheme adopted by PESMOS gives a broader sense of the SC in comparison with the worldwide followed NEHRP (National Earthquake Hazards Reduction Program). The value of frequency range corresponding to Vs30 is calculated as per equation given by Kramer (1996) (f_{peak}=Vz/4H).

In this study of 27 Stations of Himachal Pradesh, Results were obtained of the Predominant frequency and Amplification factor of Earthquake Strong Motions of Himachal Pradesh. These Predominant frequencies are obtained by HVSR Method. The average predominant frequencies were taken of the particular stations in the range of 0.25 to 6.05 Hz. These Predominant frequencies range of all the stations were plotted in the ArcGis Version 10.5.The lowest peak frequency was 0.25 for the station Dasuya, Kasauli,Una, and station with frequency ranging between 1.67Hz to 3.12Hz, these station are Bilaspur,,DAS,DEH,JUB,Kullu,Mandi these station belongs to Site Class C, Soils (Alluvium, slope wash material,Aeolian) and the highest predominant frequency is ranging between 5.8-13.33 Hz that is lahul-spitti that belongs to site class A, Firm/hard rocks (Fresh and compact metamorphic e.g. gneiss, schist, migmatites, phyllites, quartzites, dolomites and igneous rocks e.g. granites, granodiorites, granitoids, basic volcanics).Some station belongs to site class B that is ranging between 3.12-5.8 Hz those stations are Keylong and Mandi this soils are having Soft to firm rocks(Sedimentary rocks e.g.,sandstone, shale, limestone).

Some of the station like Keylong and Mandi are matching with the SC C with the f_{peak} 3.3 and 4.15 Hz. Amplification factor are also taken the average of all the particular station with the events, the range of amplification factor is 0.46 to 12.49, these stations were plotted and done in the ArcGis version 10.5. The lowest amplification factor i.e A_{peak} 0.46 was obtained for the station Manali and the Highest $A_{peak}$is 12.78 is obtained for the station AMB which is a town of Una Station of Himachal Pradesh.Site classification scheme followed by PESMOS has limited SC in with the world wide followed NEHRP classification scheme. For the present study, in order to make clear understanding of SC at each of the 27 recording stations, SC are assigned based on fpeak value obtained above and following NEHRP classification. This study reflects about the regional site Classification of strong motion Earthquake Stations of Himachal Pradesh.

CONCLUSION

1) The Software gives the results based on Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Peak Ground Displacements (PGD) and results of ground motion parameters also by considering maximum value and then by using a correction window of 5.12 seconds and

then plotting it on elastic/inelastic curves by considering 5% damping. The Predominant frequency and Amplification factor for each strong motion station was obtained from H/V curve. It is been found that from the results the predominant frequency is inversely proportional to the amplification factor.

2) The hard rock sites were found with high predominant frequency and low amplification and the soil sites were identified with low frequency and high amplification. The Predominant frequencies range from 0.25 to 6.05 Hz. The lowest peak frequency is 0.25 for the station Dasuya, Kasauli, and Una. The highest peak frequency (f_{peak}) is for Lahul-Spitti. The Amplification Factor ranges from 0.46 to 12.49. The lowest amplification factor is 0.46 for the station Manali and highest amplification factor (A_{peak}) is 12.78 is obtained for the station AMB which is a town of Una Station of Himachal Pradesh.
3) The lowest peak frequency is 0.25 for the station Dasuya, Kasauli, and Una lies in the Site Classification C (Alluviam and Aeolin soils) as per PESMOS, but as per NEHRP it lies in Site Class E (Soft Soils). The highest peak frequency (F_{peak}) is for Lahul-Spitti. It lies in the Site class A (Firm/Hard Rock) as per PESMOS and as per NEHRP it lies in the Site Class A (Hard Rock).
4) These predominant frequency values can be used by Civil Engineers during construction of buildings, dams and roads. The structure frequency should not match with the ground natural frequency which causes a resonance effect.
5) The f_{peak} values, Site Classification (SC) for each of the 27 recording stations is determined. Based on the work it is found that while PESMOS gives SC A,B and C and NEHRP gives Site Classification for A, B, C, D and E.

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