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A Comprehensive Comparative Study on Various Parameters by Using Microtremor Data

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Abstract. To perform the microzonation, site characterization and site response analysis play a crucial role. The sites can be efficiently characterized only when the basic parameters are correctly estimated. In this study, the microtremor data is recorded at 5 sites of the Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand, India and the efforts are made to delineate the variations in the physical parameter of the soil for the summer and monsoonseasons of the year (2021). The data recording at each site was done in such a way that less amount of anthropogenic noise is recorded at each site. The analysis has been done for 5 seismic parameters like predominant frequency, H/V ratio, the phase velocity of Rayleigh waves, shear wave velocity (V_s), compressional wave velocity (V_p), and Poisson's ratio for both the seasons of the year. From the results, it is observed that these parameters majorly vary drastically for the upper layers of soil, which in turn may affect the amplification ratios and probability of exceedance obtained from seismic hazard studies. The Horizontal-Vertical Spectral Ratio (HVSR) peak is higher in monsoon with a shift in predominantfrequency as compared to the summer season of the year 2021. Also, the drastic reduction in shear wave velocity (up to ~10 m) of approximately 7%-15% is also perceived during the monsoon period with a slight decrease in compressional wave velocity, and the increase in the Poisson ratios is found to have higher values during Monsoon in comparison to the summer period. This study may be very beneficial to various agricultural and geotechnical engineering projects.

Keywords: HVSR, Shear wave velocity profile, Poisson ratio profile.

1. Introduction

The site amplification or site response plays a crucial role in the assessment of the exact prediction of ground acceleration of unexpected future earthquakes. It is mainly deduced from historical earthquake events according to their damage characteristics. However, for the low-to-moderate seismic regions, the higher magnitude historical events are not available. So, in order to rectify the problems associated with the unavailability of past data, microtremor data is used for site response analysis already adopted by the National Earthquake Hazards Reduction Program (NEHRP), Standards New Zealand, Standards Australia, and European Standards.

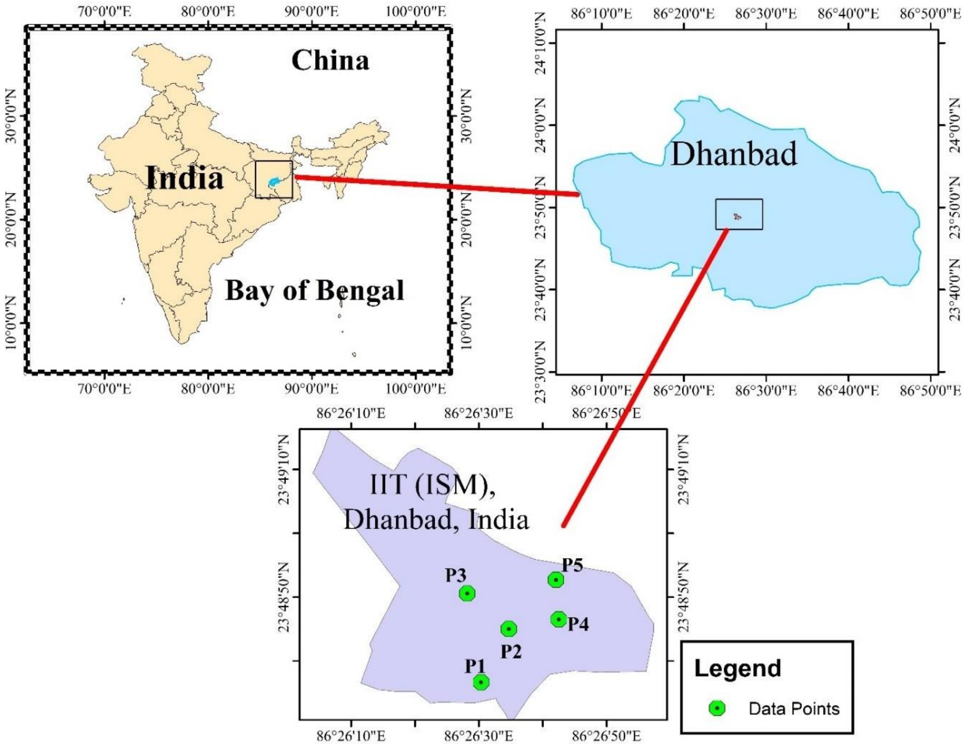
The lithological variations and subsurface material strength are directly related to shear wave velocity, which is the main parameter for the estimation of soil stiffness of building foundations [1]. The shear wave velocity can be estimated in the laboratory directly through the tri-axial test of soil mass [2]. But it can also be estimated indirectly through geophysical methods, which are comparatively less tedious, economically feasible, and can relatively cover a larger area in less interval of time. These methods mainly use the computational simulation of surface waves (i.e. Rayleigh waves), because its parameters like amplitude, frequency,and shape are used for constraining the variations of lithological and geological buried features ([3]; [4]; [5]; [6]).Thus the accurate estimation of shear wave velocity plays a key role in site assessment and site characterization.

In this study, efforts have been made to prepare a comparative study on results of various parameters in summer and monsoon. During the monsoon period, there is the presence of rainfall throughout, which increases the presence of water content or saturation value, which in turn also increases the pore water pressure in the soil. So this may cause the wrong estimation of various parameters involved in the analysis of seismic hazards. Till now, there are some published literatures that report the variation of P and S wave velocity, and Poisson ratio, but still there is no model, which shows the clear variation of these parameters seasonally. Almost all the studies based on the analysis assume the constant values of some parameters without considering their variations. On thepractical and theoretical basis, it can be very beneficial if we consider their variation as well.

2. Data collection and Methodology

The data is collected from five different sites in the Indian Institute of Technology (Indian School of Mines), Dhanbad namely UGC garden (P1), Lower ground (P2), Oval garden (P3), Eco-Vatika (P4), and behind Rosaline hostel ((P5) using microtremor active and passive data as shown in fig. 1. The passive data have been collected from all 5 different points and the active one was taken from 3 points (i.e. P1, P2, and P5). The recording of ambient noise was done for 30 minutes at each site in both the season's summer and monsoon. This data extraction is done on Grilla software and has been converted to SAF format. Then the final processing is done on Geopsy ([7]). The second- order bandpass Butterworth filter (2 Hz ≤ Frequency ≤ 15 Hz) is used for the 3 components of the recording. Also, the mean HVSR curve is estimated between 2 Hz to 15 Hz using microtremors. Numerous studies have strongly suggested that the HVSR curves are very similar considering microtremors or earthquake event recordings both for the characterization of the site and for basin structure. Since at lower frequencies (< 2Hz), curves were noisier, which may be due to the corner frequency of the sensor or some disturbances. So, we have considered the data from the frequency greater or equal to 2 Hz.

Fig. 1. It represents the study area. The green dots represent the Sites where the recording has been done.



The algorithm which was proposed by [8] and later implemented by [7], is employed for obtaining shear wave velocity profiles and inversion of surface wave dispersion curves. For the computation of theoreticaldispersion curves from random velocity models, the above-mentioned technique is used. And for the justification of this theoretical model with the measured one, the computation of misfit is done as follows:

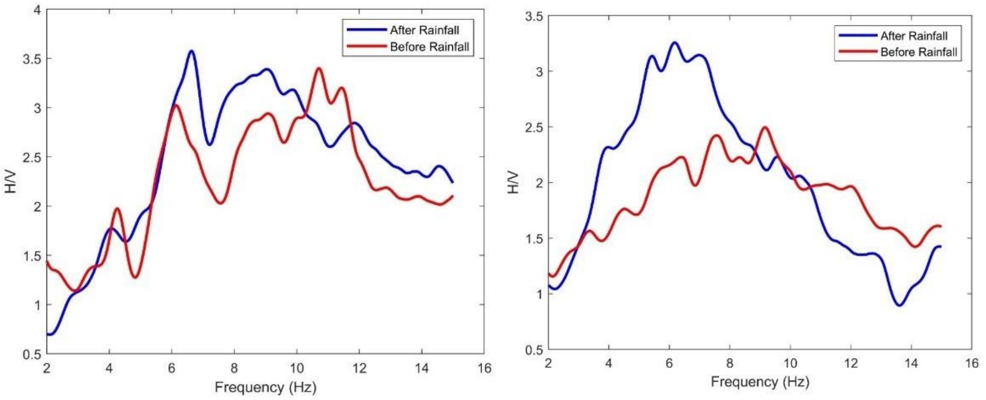
$$Misfit = \left(\sum_{j=1}^{n} \frac{(Xe-Xt)^2}{n*\sigma j^2} \right)^{0.5}$$

Where 'Xe' and 'Xt' are the experimental and theoretical velocity at frequency 'f_i'; 'σj' is the uncertainty of frequency; 'n' is the number of samples. The inversion or shear wave velocity model should be selected such that the value of the misfit is the lowest.

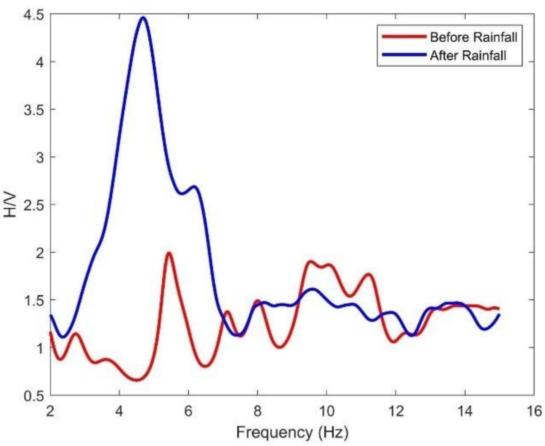
The input parameters which are involved in the inversion procedures are P and S wave velocities, density, and Poisson's ratio. In our study, the main aim was to compare the results of monsoon and summer, so these parameters are constrained to the fixed thickness of soil layers. The Dinver code which is an integral part of the Geopsy software is used. After choosing the initial models, at least 10000 models are explored in each iteration, repeated 5 times. The best model with the lowest misfit and the inversion is carried out based on the mean observed HVSR curve for each site.

3. Results and Discussion

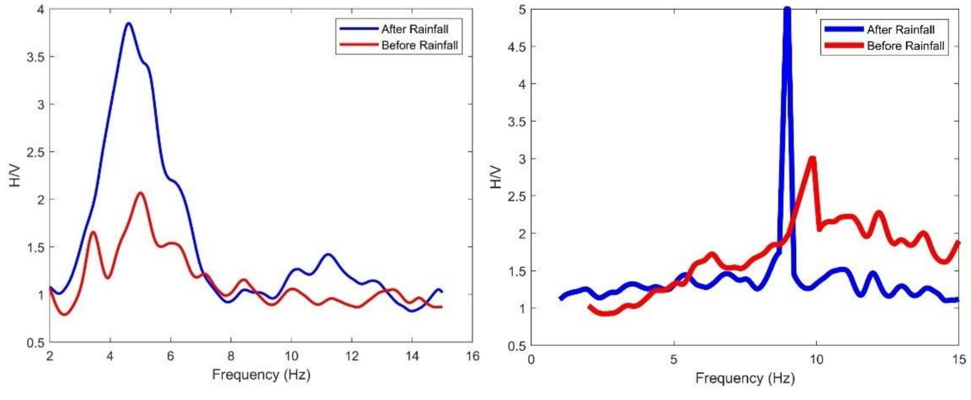
As discussed in section 2, the analysis of data is mostly performed on Geopsy (www.geopsy.org) software individually at each point. The data is extracted and plotted in MATLAB. Finally, the results have been overlapped for comparison purposes. Fig. 2 represents the variation of H/V at each point in both summer and monsoon seasons. For generalizing our results, we have considered the passive and active data of 5 and 3 different locations in the Indian Institute of Technology (ISM), respectively. From fig. 3, various things are observed. Firstly, the H/V ratio ishigher in monsoon than that in summer. The second thing is that the shift of predominant frequency towards backward takes place. The third thing is that the predominant frequency varies from 4.2 Hz to 9 Hz in the monsoon season and 5.5 Hz to 11 Hz in summer and the amplification peaks varyfrom 3.4-5 in monsoon and 2 -3.5 in summer.



(a) (b)



(c)

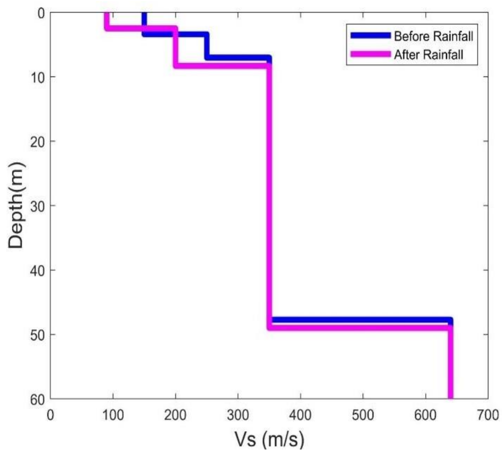


(d)(e)

Fig. 2. Variation of H/V ratio with frequency before and after the rainfall. The Red line and the blueline represent the curve of data before (i.e. summer) and after (monsoon) rainfall. (a), (b), (c), (d), and (e) are the results for data points taken at UGC garden (P1), lower ground (P2), Oval garden (P3), Eco-Vatika (P4), and behind Rosaline hostel (P5) as discussed in section 2.

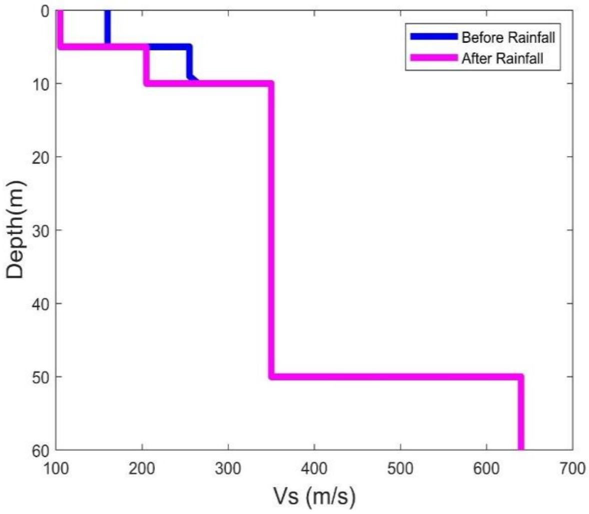
For the estimation of shear wave velocity, the surface wave method is majorly used. Itrequires the Rayleigh wave field to be accurately analyzed for the inversion of the dispersion curve, which involves the variation of phase velocity with frequency.

Fig. 3 presents the comparison of variation of shear wave velocity with depth for two seasons of year i.e. summer and monsoon. For obtaining the shear wave velocity profiles, the Dinver code which is part of the Geopsy software is used. For each curve, 10,000 models are generated in each run, repeated 5 times. From these profiles, we observe various things. Firstly, the shear wave velocity varies slightly at these sites in the same season of the year as the sites are not larger distances apart from each other. This slight variation may be due to the presence of different moisture content in thesoil at each site. Secondly, the velocity varies for almost 10m depth at each site in the two seasons and the reduction of shear wave velocity is observed up to 10m in depth due to the presence of water in the monsoon period, which will automatically affect the $V_{s,30}$, $V_{s,20}$, and $V_{s,10}$ calculations and there must exist a relationship between shear wave velocity and amplification factor (H/V) as both the parameters are dependent on the degree of saturation of the soil mass. When thereis the presence of water content in the soil mass (saturation of soil mass), the time taken by thewave from source to receiver varies. The P and S waves have to propagate via. water phase and inter-particle contacts, hence the time to reach the receiver and velocity varies. Fig 4 represents P-wave velocity profile and Fig. 5 represents the Poisson ratio profile.



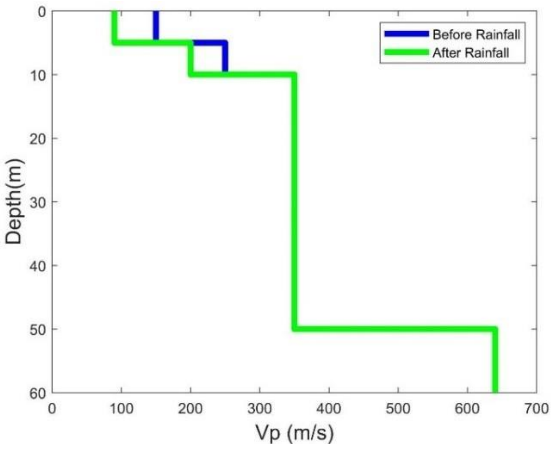
(a). $V_{s,30}$ for Site P1 is 250 m/s (monsoon) and 300 m/s (summer)

(3b). $V_{s,30}$ for Site P is 290 m/s (monsoon) and 305 m/s (summer)

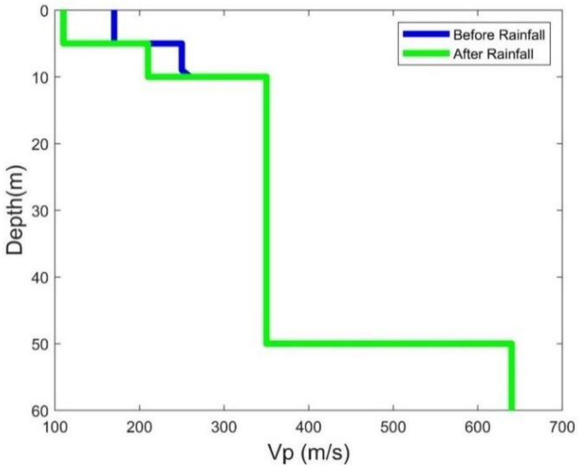


(3c). $V_{s,30}$ for Site P5 is 285 m/s (monsoon) and 302 m/s (summer).

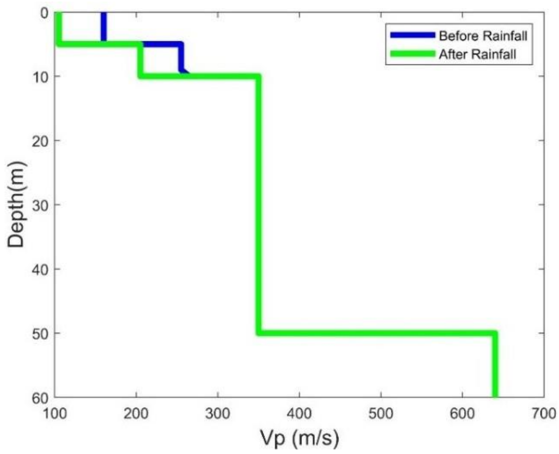
Fig. 3. This represents the comparison of variation of shear wave velocity with depth in summer(before rainfall) and monsoon (after rainfall).



(4a). Site P1



(4b). Site P2



(4c). Site P3

Fig. 4. This represents the comparison of variation of P-wave velocity with depth in monsoon(after rainfall) and summer (before rainfall).

Fig. 3 compares the shear wave velocity models for summer and monsoon. From these profiles, we observe various things. Firstly, the shear wave velocity varies slightly at these sites in the same season of the year as the sites are not larger distances apart from each other. This slight variation may be due to the presence of different moisture content in the soil at each site and the velocity varies for almost 10m depth at each site in the two seasons and there is the reduction of shear wave velocity is observed up to 10m in depth due to the presence of water in the monsoon period, which will automatically affect the $V_{s,\,30}$, $V_{s,20}$, and $V_{s,10}$ calculations. And finally, there must exist a relationship between shear wave velocity and amplification factor (H/V) as both the parameters are dependent on the degree of saturation of the soil mass. When there is the presence of water content in the soil mass (saturation of soil mass), the time taken by the wave from source to receiver varies. The P and S waves have to propagate via. Water phase and inter-particle contacts, hence the time to reach the receiver increases and velocity varies. The Shear wave velocity relationship is given below:

$$V_s = \varphi\left(\frac{(0.115*(\sigma')^{0.33}}{\rho*p}\right)^{0.5}$$

Where V_s are the shear wave velocity; φ factor depends on the type of soil; p represents porosity of soil; σ' represents effective pressure; ρ is the bulk density; during the monsoon period, there is a decrease in effective pressure of the soil mass, leads to reduce the shear wave velocity. This decrease in shear wave velocity would underestimate the standard value of shear wave velocity at 30 m depth ($V_{s,\,30)}$ if estimated in monsoon season.

Fig. 4 represents the compressional wave or primary wave or P-wave velocity profile. This shows the variation of P-wave velocity with depth. The relationship of this wave velocity inside soil mass is given below:

$$V_c = \varphi\left(\frac{(0.306*(\sigma')^{0.33}*Z}{\rho*p}\right)^{0.5}$$

Thus,

$$V_s = V_c / (1.63*(Z)^{0.5})$$

V_c represents P-wave velocity; the Z parameter is already discussed above. Thus the variation of P-wave velocity can be considered linear, nonlinear, or exponential depending on the degree of saturation and type of soil [9]. The main reason for its variation should be Z-factor. Z-factor describes the effect of fluids present in the soil mass. The Z-factor increases non-linearly if the degree of saturation in the soil mass increases [9]. Thus the primary wave velocity should decrease non-linearly, which is quite obvious from our results.

Fig. 5 represents the comparison of Poisson’s ratio profile in summer and monsoon. The Poisson’s ratio is considered an elastic property that acts as an input to various civil engineering projects/applications. Many research works have already been published on the variation of Poisson’s ratio with the degree of saturation. It is the ratio of elastic strain and longitudinal strain under uniaxial loading. The relationship of Poisson’s ratio can be derived from elastic constants and wave velocities. Let’s assume the material is elastic, isotropic, and homogenous in nature [10].

$$G = \rho * V_s^2$$

$$M = \rho * V_c^2$$

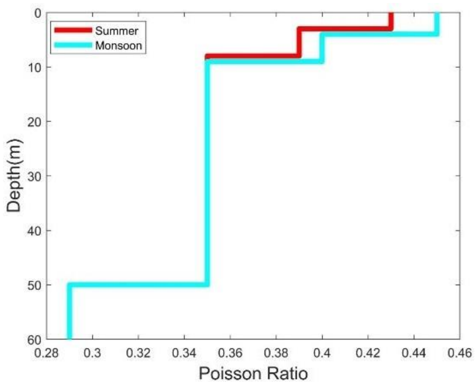
And $$E = 2*G*(1+\mu)$$

And $$E = \frac{M*((1+\mu)*(1-2*\mu)}{(1-\mu)}$$

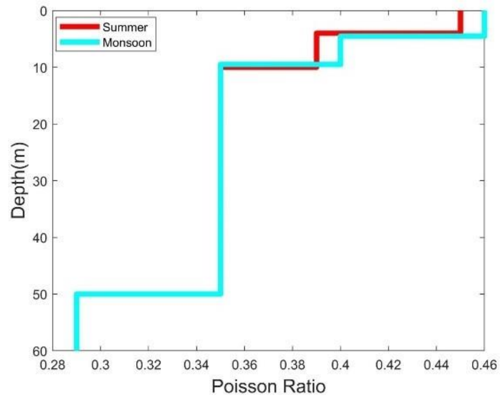
Substituting equations (9) and (10) in equations (11) and (12), we have

$$\mu = \frac{0.5*(\frac{Vc}{Vs})^2-1}{(\frac{Vc}{Vs})^2-1}$$

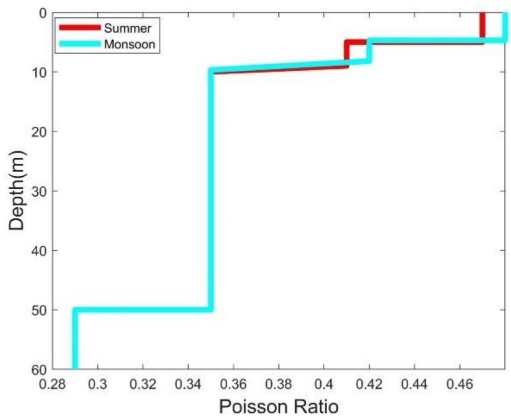
Where E, M, and G are Young's modulus, constrained, and shear modulus respectively. V_c and v_s are primary and secondary wave velocities. μ is the Poisson's ratio. It increases with the increase in the degree of saturation in the soil mass for all soil types [11]. From our results, it is quite obvious that the value of the Poisson ratio increases in the monsoon season up to a depth of 10 m. The reason may be, during the monsoon season the degree of saturation in the upper layer of soil increases, which increases the mobilization of pore water in the soil mass, consequently decreasing the compressibility (i.e. ability to decrease its volume), and in turn, decreases the Poisson's ratio. With the variation in Poisson's ratio for the soil mass at the same site, many other things also vary like Young's modulus, shear modulus, temperature, density, soil pressures, or soil stresses. Thus our study may be very beneficial to various agricultural and geotechnical engineering projects.



(5a). Site P1



(5b). Site P2



(5c). Site P5

Fig. 5. Presents the variation of comparison of Poisson's ratio profile for 3 different sites.

From the above discussion, all these parameters seem to be interlinked with each other. When the amplitude or H/V ratio of waves increases, there is a decrease in shear wave velocity, which in turn, leads to an increase in the Poisson ratio. During the summer season, the water content or the moisture in the upper layer of soil is low, and the ability of soil mass to amplifythe waves is also low, the soil mass is very compact, which leads to the increase in shear wave velocity, thus reduces the Poisson ratio for the upper layer of soil. And during the monsoon period, the rainfall fills the pores of soil mass, which leads to an increase in pore water pressure, which in turn, decreases the cohesive force between the soil particles and travel downwards, leading to the reduction in shear wave velocity, consequently increasing the Poisson ratio for the soil mass.

4. Conclusion

In this paper, the main efforts are made to present the variation of different seismic parameters in two seasonsof the year (i.e. summer and monsoon). For the validation of our results, we have performed the analysis for 5 different sites in the Indian Institute of Technology (ISM), Dhanbad, India. The microtremor HVSR data recorded for the 30-minute duration at each site in both the above-mentioned seasons of the year is used for the analysis of different seismic parameters. The data extraction, processing, and analysis have been done in grilla, geopsy, and MATLAB software. The present study can be concluded as:

1. The shift in predominant frequency of the HVSR curve is observed in two seasons.
2. The predominant frequency decreases during the monsoon period.
3. The amplitude or H/V ratio decreases during the monsoon period.
4. The shear wave velocity decreases drastically in the upper layers of soil, leading to reduce the value of standard shear wave velocity at 30 m depth (i.e. $V_{s,\ 30}$) during the monsoon period.
5. The slight decrease in compressional wave velocity is observed during the monsoon period in the upper layers of soil.
6. And finally, the Poisson ratio shows a drastic increase during the monsoon period in the upperlayers of soil.

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