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# Estimating Soil Thickness using the H/V Spectral Ratio Technique in CSIR-NGRI Campus, Hyderabad, India

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**ABSTRACT**

*This article deals with a microtremor survey, which was carried out at 42 sites of CSIR-NGRI Campus (area: ~0.65 km²), Hyderabad, India using a Tromino 3G ENGY for the measurement of 20-minute interval each with the frequency of 512 Hz. The collected data were analyzed to attain a horizontal to vertical (H/V) spectral ratio of the noise spectrum with the aid of GRILLA software. The frequency corresponding to the first dominant peak of the average H/V spectrum plot was considered as the resonant frequency of that particular site. The processing included in Fourier Transformation, smoothing (~10%) with Triangular Window, and estimating the velocity of shear wave and soil thickness based on peaks were identified on the H/V spectral ratio from the ambient noise. The results indicate that the estimated resonance frequency varies from 52.81 to 102.81 Hz, with an average of 85.36 Hz. It is comparatively high in the elevated area, implying the thinning of shallow seismic contrast layers. In the intermediate elevated area, this frequency decreases, and it gives the result of a thick overlaid layer. The soil thickness estimated is an average of 0.56 m with the shear wave velocity range of 143-190 m/s, with an average of 152 m/s. This H/V spectral ratio technique is very cost-effective for mapping the resonance frequency of any place except farmland, marshland or any place having soft soil layer.*

**KEYWORDS**: *Resonance frequency; H/V spectral ratio technique; Tromino 3G ENGY; Soil thickness; CSIR-NGRI Campus; Hyderabad.*

## INTRODUCTION

Originally, the horizontal to vertical (H / V) spectral ratio technique coined to evaluate the seismic risk in Japan (Nagoshi and Igarashi, 1971; Nakamura, 1989). It is well-known that a significance of oscillating horizontal shear waves arriving from underground at a fundamental resonant frequency of the loose sediment leads to produce shaking of the surficial sediment. At this conjecture, the horizontal oscillation is amplified with respect to the vertical oscillation because of the maximum part of the shear wave is trapped within the loose sediment at this frequency. Therefore, an average spectra of the horizontal components divided to the vertical components has been produced as a dominant peak at the fundamental resonant frequency of the sediment on a three-component seismic record, which is clearly recorded by Tromino 3G ENGY (Micromed, 2012). This Tromino is a seismometer that is useful for the resolution of ambient noise measurements (Stanko et al., 2019). The ground ambient noise measured is to detect resonance frequency of sub-soil in a passive, fast and inexpensive way. The shear wave ($V_s$) velocity is very difficult to measure in deep soil, but using the Tromino device, we can evaluate the layer of the ground and also the parameters of soil. Of course, this soil thickness could be estimated using electrical method (Singh et al. 2009; Mondal et al., 2008, 2013, 2016-18, 2020).

We have in mind everything is noise, which is created from different sources such as tides, sea waves, water flow in streams, rain and wind, etc. So it is difficult to define those vibrations, which have natural or anthropogenic characters. The ambient noise sources are classified using their frequency range (Gutenberg, 1958), as an example, frequency < 0.5 Hz caused by large scales meteorological and oceanic conditions. Frequency ~ 1.0 Hz is caused from wind effect and regional meteorological condition, whereas the frequency >1.0 Hz caused by human activity (Ibs-von Seht and Wohlenberg, 1999). Uses of the ambient noise are mainly focused on seismic micro-zonation of any places/ cities using the H/V Spectral ratio. This ratio has found a wide application (Parolai et al., 2001; D'Amico et al., 2004; Gueguen et al., 2007; Biswas et al., 2015; Chabane et al., 2017; Picotti et al., 2017; Anthiraikili, 2020).

It is noted that the relationships in between the H/V ratios and thickness of sediments were well-established, and the results were appreciable when it was correlated with nearby borehole lithology (Parolai et al., 2001). The thickness of Quaternary sediments covering carbonate and terrigenous bedrock in Le Piane basin in Italy was estimated from the resonance frequency and then compared with the results of S-wave velocity profile (D'Amico et al., 2004). The sediment thickness (> 900 m) estimated by a micro-gravimetric survey at the edges of Grenoble Valley (France) was compared with the resonance frequencies (Gueguen et al., 2007). It was also estimated the shear wave velocity ranges of 200 to 550 m/s in the sediment thickness of 10 to 80 m in Shillong of Meghalaya state in North-East India with the aid of H/V ratio technique (Biswas et al., 2015). Further, the H/V ambient vibration had strengthened the electric resistivity tomography to mapping the sub-surface structures in Algiers city (Chabane et al., 2017). It was applied in several glaciers in Italy, Switzerland, and West Antarctica for estimating ice thickness (Picotti et al., 2017). The H/V ratios were well-correlated with the estimated ice thickness up to the maximum thickness of 800 m. In Indo-Ganetic Plain, an empirical relation had also been established between resonant frequency obtained from the H/V ratio and the thickness of sediment observed nearby the exiting drilled borehole lithology (Anthiraikili, 2020). Mostly the application of the H/V spectral ratios recorded in the frequency range of 0.1 to 512 Hz, which are largely caused by the cultural activities (Bonnefoy-Claudet et al., 2006). Thus the objectives of this article are to (1) calculate resonance frequency, (2) estimating soil thickness, and (3) shear wave velocity in CSIR-NGRI Campus, which is located in a largely cultural noise and capital city Hyderabad, Southern India.

**Brief of the Experimental Site**

The experimental site located in Hyderabad city, the capital of Telangana State in Southern India, is the Campus of CSIR-National Geophysical Research Institute (NGRI) (Figure 1). It is spread over an area about 0.65 km$^2$ is located in the south-east of Secunderabad at Longitude: 78º32'48" to 78º33'24"E and Latitude: 17º24'24" to 17º25'08"N. The area has undulating topography with an elevation range from 494 to 519 meters, above mean sea level (m, amsl), with an average of 508 m, amsl. The elevation map shows the gradient slope towards the south-east direction (Figure 1). In the North, the map shows comparatively higher elevation as well as in the North-West, but it is in opposite nature in the South-East direction decreasing from 519 to 494 m, amsl. In the central area, some circular yellow parts show a high elevation as compared to its surrounding area. The slope of the area is from north-west to south-east direction. Pedda Cheruvu Lake lies in the N-NE of the area. The area is mostly forest area, and there are also present some governmental constructed buildings. The dendritic drainage pattern exists in and around the study area and ultimately meets the Musi River located towards the South. Geologically, it comes under the Precambrian grey granite-gneissic complex with dolerite intrusive and many outcrops (Krishnan, 1960). Red soil of varying thicknesses forms top layer within the CSIR-NGRI Campus. This top layer is underlain by weathered granite of considerable thickness followed by massive granites which may or may not be fractured/faulted. The contact zone in granites is favorable for weathering and forming the weathered and semi-weathered layers at the shallow depths, and the fractures and joints in massive rocks, creating potential zones for groundwater development.

## MATERIALS AND METHODS

### Estimation of Resonance Frequency

In the seismically contrast layer, the fundamental resonant frequency adequately represents the H/V spectral ratio peak. It can be empirically related to the thickness of the first top layer if the stratified layers are flat with a strong acoustic impedance contrast (> 2.5) (Lane et al., 2008). The resonance frequency of a uniform stratified first layer has been derived by Nakamura (1989) as below.

$$f = \frac{Vs}{4h} \quad (1)$$

where, f is resonance peak frequency (Hz), $V_s$ is shear wave velocity (m/s), and h is thickness (m) of the top stratified (sedimentary) layer.

Mostly, the equation (1) was used for estimating soil thickness and discussed in this article.

### Instrument and Software

TROMINO 3G ENGY instrument, which allows reaching signal to noise ratios at a low frequency of interest, was used to gather the ambient noise in a passive, non-intrusive, fast, and inexpensive way. This instrument consists of 3-velocimetric channels for the measurement of seismic ambient noise recording up to 15 mm/s. In addition, it also consists of an in-built GPS receiver along with the internal and external antenna for positioning and absolute timing among other units. GRILLA software has been developed by Manufacture Company of Tromino (Micromed, 2012) in a specific way for processing and analysis of data recorded from the TROMINO 3G ENGY. This software is divided into three main modules such as (1) vibration analysis, (2) determination and modeling of H/V curves for stratigraphic, and (3) calculation of fundamental modes of structures vibration. Both Tromino 3G ENGY and GRILLA software were used in this work.

### Surface Wave Modeling

The Grilla software needs the input parameters of each layer such as 1) thickness of the layer in [m], 2) P-wave ($V_p$) velocity in [m/s] [input not requested to the user but calculated automatically], 3) shear-wave ($V_S$) velocity in [m/s], and 4) density in $10^3$ kg/m$^3$ for surface waves modeling. The last layer of the model was assumed to have an infinite thickness. The $V_p$ was compiled automatically on the basis of the $V_s$ values and Poisson's ratios (range: 0 to 0.5) inserted by the user. Other parameters for the synthetic model in soil used such as the frequency range of the lower (0 Hz) and upper (half sampling rate) frequency limit for the synthetic H/V curve. The frequency step was 0.1 Hz for the synthetic H/V calculation. It meant that the curve would be calculated at, e.g., 1.5, 1.6, 1.7, 1.8, etc., and it was an adequate step to model the curve down to 0.2 Hz. This same value was used for each layer by setting the box, and foundation depth allowed to calculate the H/V curve at a depth different from the free surface (0 m) (Micromed, 2012).

### Data Collection and Interpretation

Within the frame of determination of frequencies of the ground and its geometrical shape, ambient noise was recorded using the Tromino 3G ENGY instrument for 20-minute at each site. In total, 42 sites covering approximately area of 0.65 km$^2$ (Figure 1) were selected for the ambient noise recording during January, 2018. The sampling rate for recording was 512 Hz and measured the vertical and horizontal (E-W, N-S) directions vibrations of the ground. The locations of experimental sites were also taken with the help of Handheld Garmin GPS, as shown in Figure1.

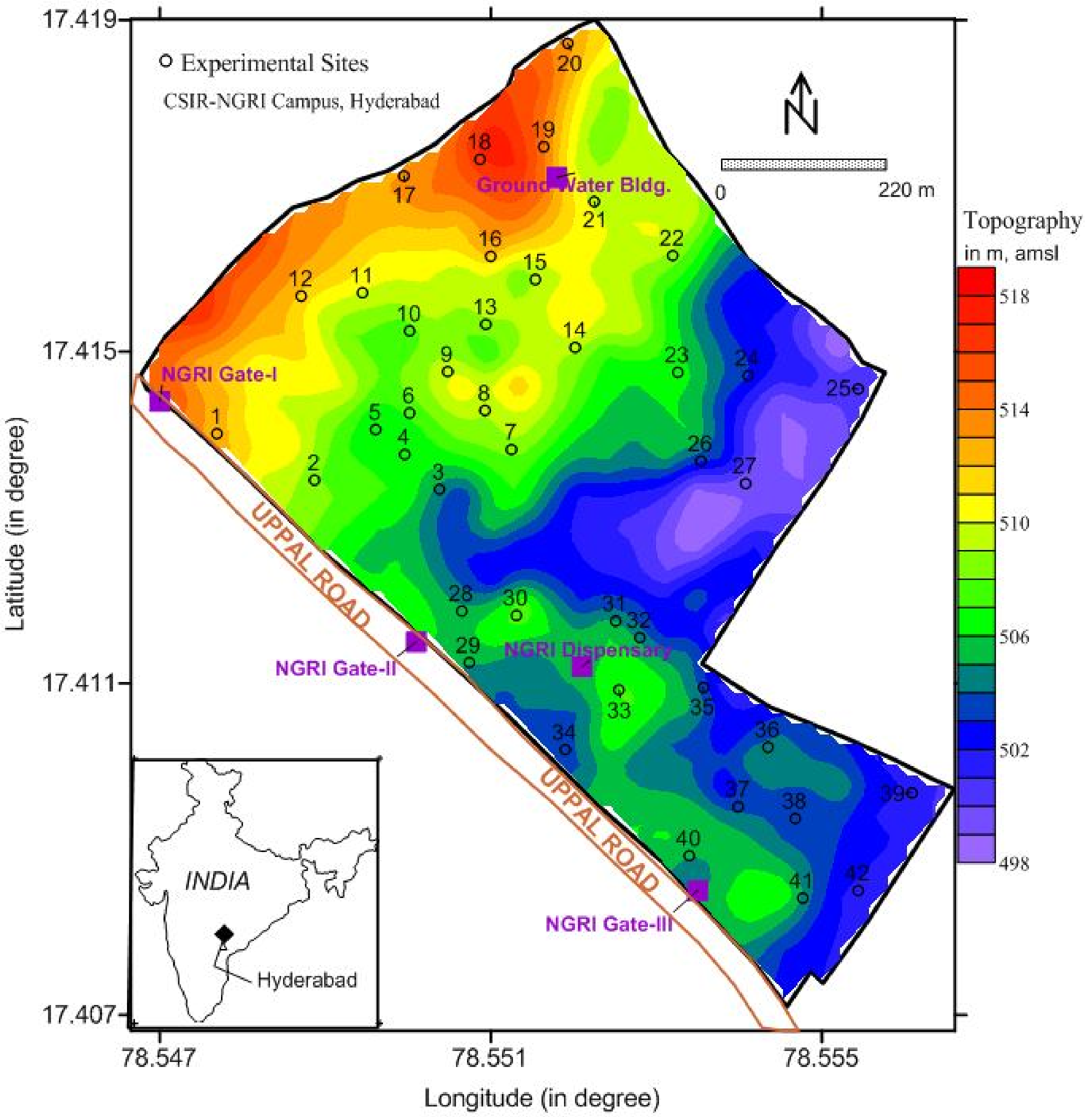


**Figure 1: Location map of CSIR-NGRI Campus, Hyderabad, India along with the TROMINO 3G experimental sites**

A Fourier Spectrum of each window was considered and then computed it. It was also analyzed and smoothed by using the GRILLA software. In some points, the measurements had shown the higher levels of noise. For this case, the triangular smoothing was used and the smoothing was taken up to 10% for getting the best result. Before interpreting the resulting curve in-terms of the sub-soil dynamical properties, the possible occurrence of spurious H/V ratio peaks were checked due to impulsive sources. For this purpose, the time stability of spectral ratios over the recording length was also investigated. For a better estimation, the graphs of frequency had been separated into three frequency classes corresponding to three depth classes.

**Table 1: Estimated resonance frequency, soil thickness and shear velocities in CSIR-NGRI Campus, Hyderabad, India using Tromino 3G ENGY instrument**

| **Site No.** | Topography (m, amsl) | Resonance Frequency (Hz) | Error (Hz) | Soil Thickness (m) | Shear velocity (Vs, in m/s) in soil | Shear velocity (Vs, in m/s) in weathered zone | **Site No.** | Topography (m, amsl) | Resonance Frequency (Hz) | Error (Hz) | Soil Thickness (m) | Shear velocity (Vs, in m/s) in soil | Shear velocity (Vs, in m/s) in weathered zone |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 511 | 90.00 | ± 0.15 | 0.56 | 145 | 378 | **22** | 507 | 100.63 | ± 0.93 | 0.45 | 190 | 374 |
| **2** | 508 | 95.00 | ± 0.50 | 0.49 | 147 | 390 | **23** | 513 | 77.81 | ± 0.05 | 0.55 | 162 | 376 |
| **3** | 500 | 72.50 | ± 0.32 | 0.72 | 145 | 375 | **24** | 506 | 79.38 | ± 0.98 | 0.53 | 156 | 375 |
| **4** | 516 | 94.69 | ± 0.16 | 0.50 | 147 | 390 | **25** | 498 | 97.44 | ± 0.73 | 0.44 | 161 | 377 |
| **5** | 516 | 98.13 | ± 0.51 | 0.50 | 146 | 379 | **26** | 504 | 75.63 | ± 0.31 | 0.60 | 148 | 378 |
| **6** | 512 | 75.94 | ±0.18 | 0.56 | 152 | 374 | **27** | 505 | 96.25 | ± 0.40 | 0.53 | 145 | 379 |
| **7** | 503 | 78.75 | ± 0.38 | 0.60 | 146 | 377 | **28** | 501 | 99.53 | ± 0.20 | 0.43 | 153 | 382 |
| **8** | 507 | 99.94 | ± 0.38 | 0.47 | 146 | 380 | **29** | 508 | 71.25 | ± 0.05 | 0.65 | 147 | 377 |
| **9** | 515 | 74.38 | ± 0.17 | 0.66 | 144 | 372 | **30** | 507 | 102.81 | ± 0.43 | 0.43 | 154 | 390 |
| **10** | 511 | 94.38 | ± 0.26 | 0.44 | 152 | 372 | **31** | 511 | 93.44 | ± 1.68 | 0.46 | 153 | 390 |
| **11** | 511 | 79.06 | ± 0.23 | 0.62 | 144 | 372 | **32** | 494 | 85.63 | ± 0.37 | 0.60 | 143 | 372 |
| **12** | 504 | 81.56 | ± 0.41 | 0.59 | 144 | 373 | **33** | 504 | 96.59 | ± 0.25 | 0.46 | 167 | 382 |
| **13** | 514 | 72.72 | ± 0.22 | 0.59 | 155 | 379 | **34** | 503 | 64.38 | ± 0.34 | 0.79 | 143 | 369 |
| **14** | 511 | 83.44 | ± 0.19 | 0.51 | 155 | 376 | **35** | 516 | 77.50 | ± 0.23 | 0.56 | 153 | 379 |
| **15** | 509 | 100.00 | ± 0.42 | 0.43 | 154 | 390 | **36** | 503 | 73.13 | ± 0.55 | 0.59 | 151 | 378 |
| **16** | 506 | 72.50 | ± 1.91 | 0.65 | 185 | 380 | **37** | 503 | 92.19 | ± 0.17 | 0.56 | 145 | 378 |
| **17** | 519 | 99.59 | ± 0.36 | 0.44 | 149 | 381 | **38** | 497 | 68.47 | ± 1.79 | 0.77 | 143 | 369 |
| **18** | 505 | 85.28 | ± 0.17 | 0.60 | 143 | 371 | **39** | 499 | 78.75 | ± 0.13 | 0.64 | 144 | 374 |
| **19** | 504 | 78.75 | ± 0.47 | 0.56 | 149 | 379 | **40** | 516 | 52.81 | ± 0.22 | 0.83 | 151 | 374 |
| **20** | 517 | 99.06 | ± 0.38 | 0.43 | 155 | 382 | **41** | 507 | 90.31 | ± 0.29 | 0.57 | 145 | 379 |
| **21** | 517 | 90.63 | ± 2.09 | 0.58 | 145 | 378 | **42** | 504 | 94.69 | ± 0.23 | 0.45 | 170 | 364 |

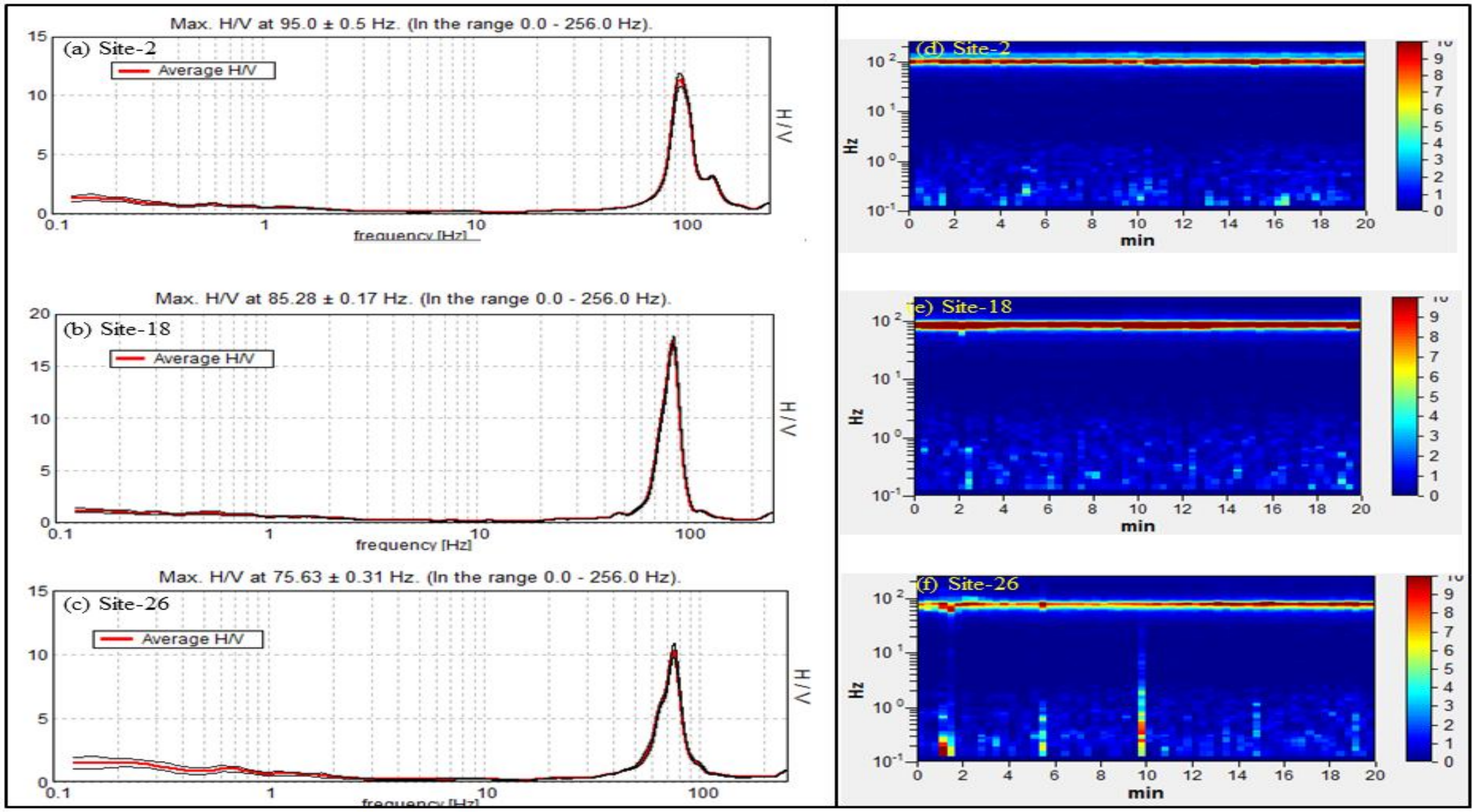


Figure 2: Showing H/V spectral ratios at the (a) site-2, (b) site-18, (c) site-26; and time stabilities at the (d) site-2, (e) site-18, and (f) site-26

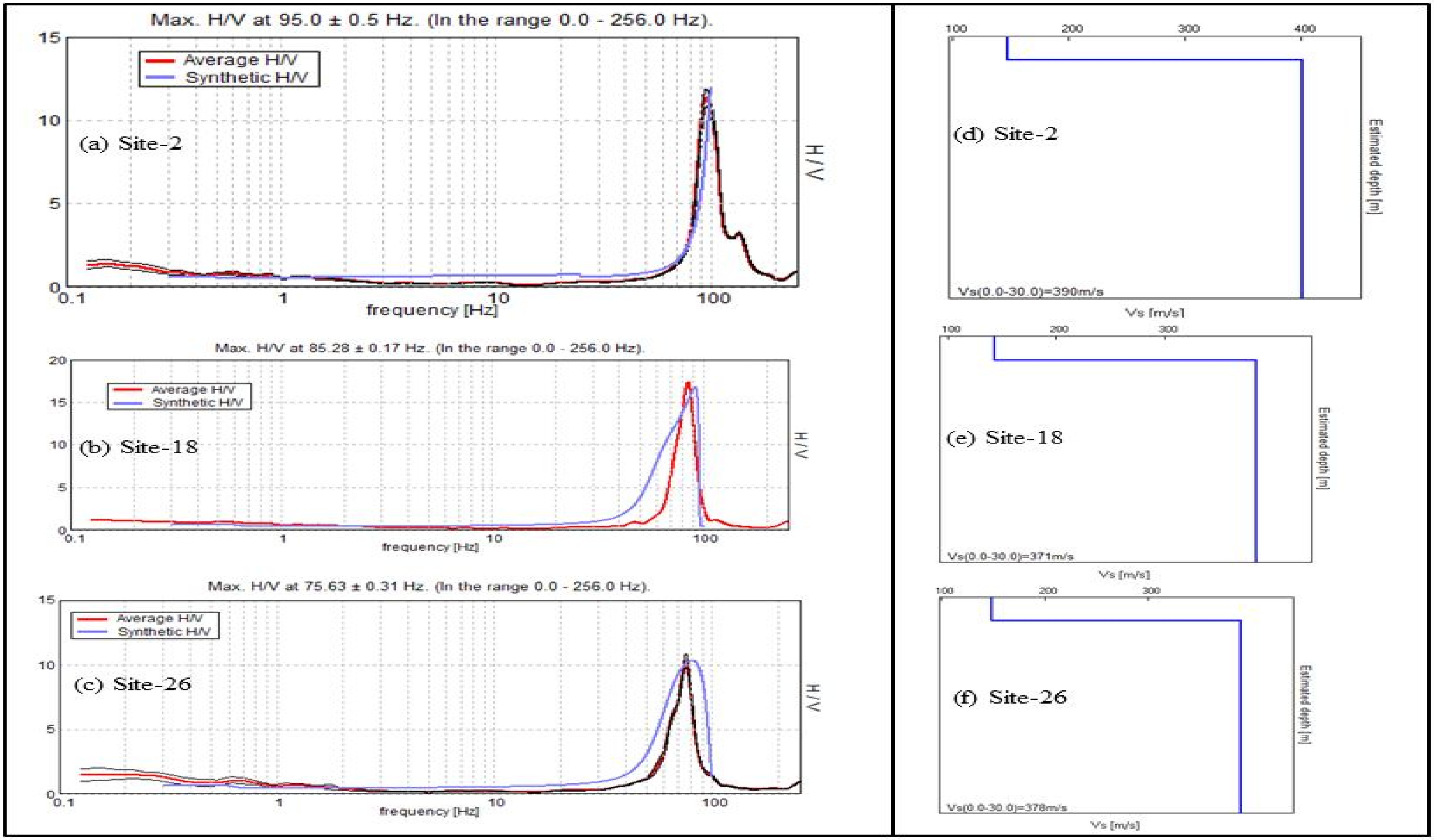


**Figure 3: Showing synthetic H/V models for the (a) site-2, (b) site-18, (c) site-26; and sub-surface models for the (d) site-2, (e) site-18, and (f) site-26**

They were for the shallow depth (10-512 Hz), (2) intermediate depth (1-10 Hz), and larger depth (0.1-1 Hz). It had been observed that there were no deeper seismic contrast layers for the frequency ranges of 0.1-10 Hz. The stability of the layer had been seen very clearly in most of the sites, but also in some places, it was a blur. The approach was used to estimate the resonance frequency using the H/V peak of the curve, as shown in Figure 2. The H/V ratio was obtained as 95.00 Hz with an error of ± 0.50 Hz at the site-2 (Figure 2a) whereas the ratios were 85.28 and 75.63 Hz at the sites-18 and 26, respectively (Figures 2b, c) corresponding to the time stabilities shown in Figures 2d-f. After completion of the analysis, the resonance frequencies obtained from the measurements are presented in Table 1. It was observed that most of the H/V curves shown within ± 1.00 Hz error, but in some cases, it had exceeded ± 1.00 Hz. It might have happened because of the local noise that comes from vehicles, under construction area or due to the wind flow and cultural noise, etc. The estimated H/V ratios have indicated that the resonance frequency ranges between 52.81 to 102.81 Hz, with an average of 85.36 Hz.

For the estimating soil thickness, we used the synthetic subsoil model for getting shear wave velocity, and from that thickness of that site. The recommended parameters of topsoil and weathered zone (Sunil et al., 2016) were initially utilized in the synthetic sub-soil model preparation. Typically, the densities in the range of 1.6-2.2 g m/cc and $V_p$ depending on $V_s$ according to the Poisson's ratio (range, μ=0.33-0.40), were used. In natural materials, being $V_p > V_s$, the Poisson's ratio was included in the range of 0 to 0.5, and in the shallow sub-stratum, it varied between 0.30 and 0.49 (Micromed, 2012). The velocities of soil and weathered rock were used initially as 150 m/s and 400 m/s, respectively. Whereas the densities were assigned as 1.8 and 1.9 gm/cc, and Poisson's ratios as 0.33 and 0.40, respectively, for the topsoil and weathered zone (Sunil et al., 2016), to generate a synthetic curve and match with the resonance curve by using the trial and error approaches. The best match between the synthetic and resonance curves had provided the most plausible shear wave velocity and thickness of soil for the site under consideration. The typical synthetic H/V models had been developed and are presented for the sites-2,18, and 26 in Figures 3a-c. Corresponding to the subsurface models are shown in Figures 3d-f. The soil thicknesses were estimated as 0.49, 0.60, and 0.60 m at the site-2, 18, and 26, respectively, whereas the shear wave velocities were 147, 143 and 148 m/s, respectively. Similarly, the soil thicknesses, and velocities in topsoil and weathered zones were estimated at other sites, and also presented in Table 1.

## RESULTS AND DISCUSSION

The H/V ratio method is very fast and inexpensive as compared to others, and also it helps to determine the seismic contrast of layers (Pazzi et al., 2017). In total 42 Tromino measurements were carried out at CSIR-NGRI Campus, Hyderabad in January, 2018. Then it had been analyzed using GRILLA software for getting a reliable peak of resonance frequency (f). All the measurements had given good peak frequency except in some cases where it had given rise to errors due to the local disturbance. But it had been tackled with the 10% Triangular smoothing for getting well- defined curves.

The H/V ratio spectra had shown that nearly all sites were giving the frequency range between 52.81 to 102.81 Hz. As at the site-40 (located at the playground in NGRI School), the H/V ratio was given near to 52.81 Hz, in time stability spectra we could see the stable layer showing against the time. At the site-34 (located in the front of Research Scholar Hostel), the H/V ratio was 64.38 Hz, and the time stability had shown the unstable layer of top layer. Similarly, a few sites had shown the stability of top layer and some of them were unstable. But the resonance frequency was estimated in the range of 52.81 to 102.81 Hz. It means that the thin soil layer exists at all the experimental sites. As frequency increases, the thickness of soil layer decreases (Figures 4, 5d). It means that the thick of soil zone had shown the low frequency because they were stable, and the thin layers given the high frequencies.

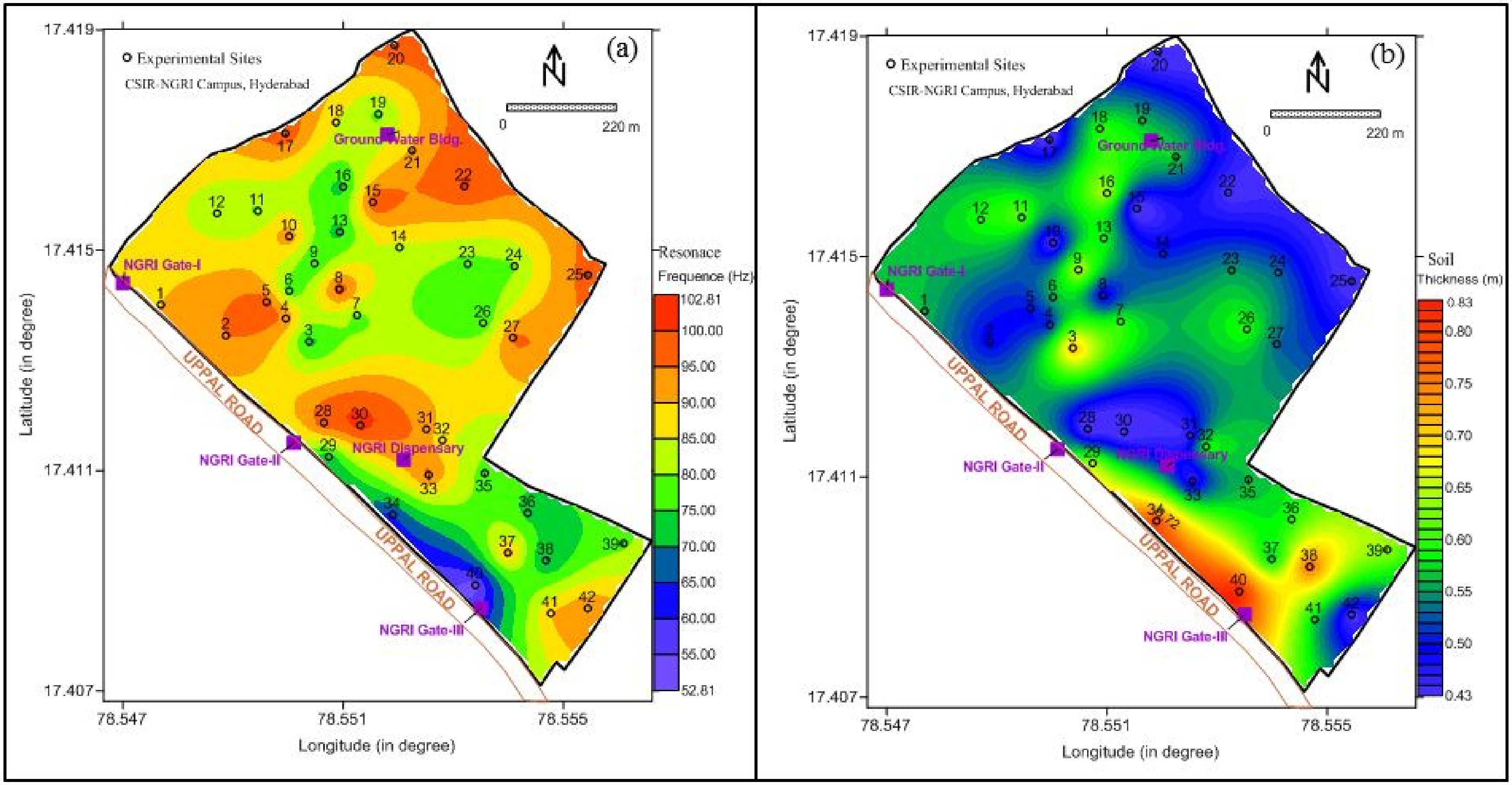


**Figure 4: Showing the contour maps of the estimated (a) resonance frequency, and (b) soil thickness in CSIR-Campus, Hyderabad**

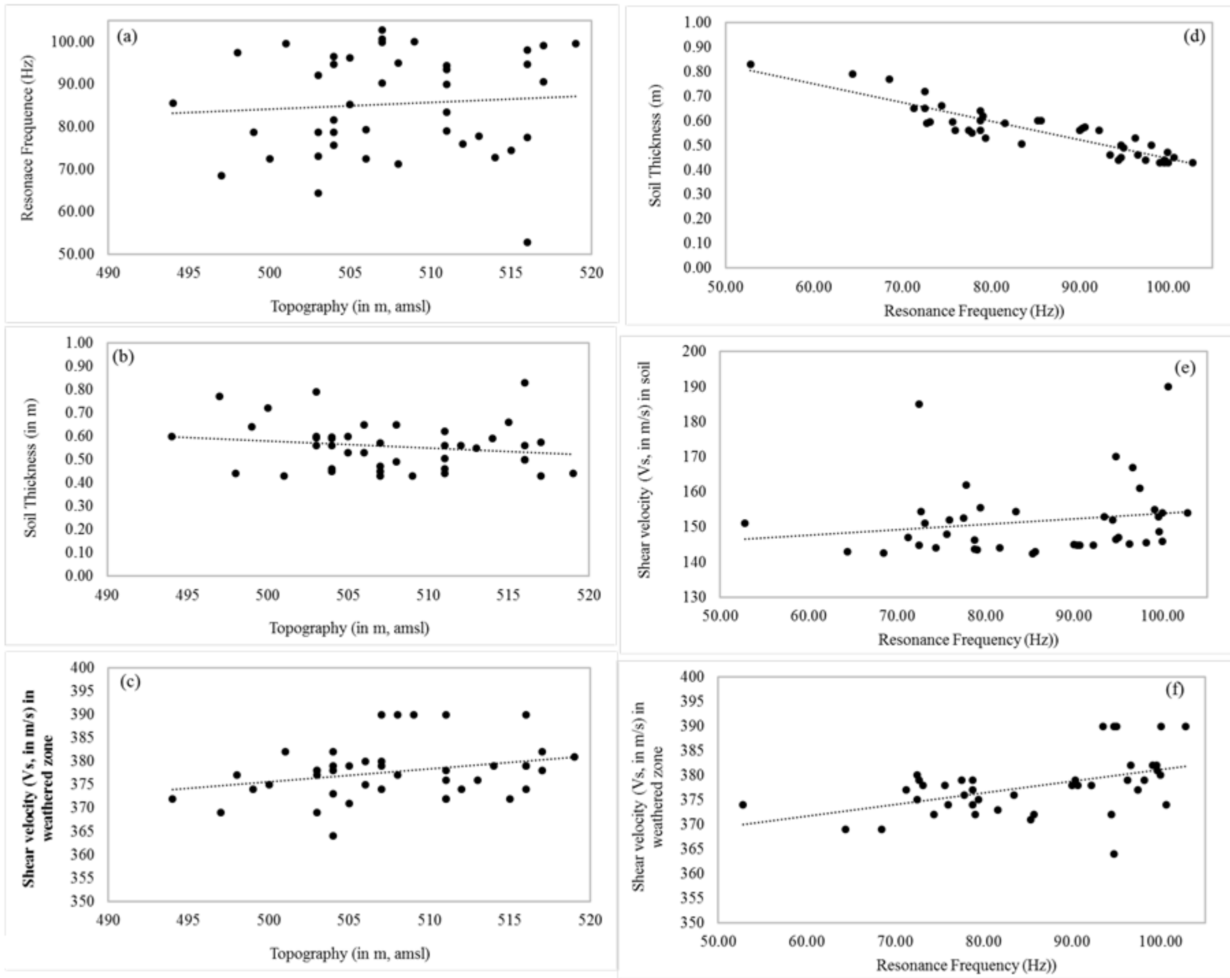


**Figure 5: Cross plots among topography vs (a) resonance frequency (Hz), (b) soil thickness (m), (c) shear velocity ($V_s$, in m/s) in weathered zone; and resonance frequency vs (d) soil thickness (m), (e) shear velocity ($V_s$, in m/s) in soil, and (f) shear velocity ($V_s$, in m/s) in weathered zone in CSIR-NGRI Campus, Hyderabad, Southern India**

By the interpretation with the help of GRILLA software, the resonance frequencies were obtained for each site. The contours of resonance frequencies were compared with the topography map of the study area, as shown in Figures1, 4a. It implies that the resonance frequency in the central part was low as compared to the boundary line of the Campus area. If it was compared with the elevation, the result was shown that the green part range between 506-511 m, amsl having less frequency as compared to the red part range of 514-519 m, amsl, and also in the blue part range of 498-503 m, amsl having less resonance frequency. It indicates that the green part of the map had a thick soil layer where the more weathered deposition was taken place. The elevated part was shown by the thin layer of the weathered zone as marked by red color (Figure1), and in the blue zone, it had shown intermediate deposition as compared to other areas. To get a clear understanding of resonance frequency distribution in the Campus area, a contour map of resonance frequency had been prepared as shown in Figure 4a. Also using the synthetic curve model, we had estimated the soil thickness. From this, a contour map of thickness had been prepared, as shown in Figure 4b. Both were inversely related to each other (Figures 4, 5d).

The contour maps of shear wave velocities in soil, and weathered zone were made available. It indicates that the shear wave velocity in soil ranges from 143 to 190 m/s, with an average of 152 m/s. It had ranged from 169-190 m/s in a few patches in the Northern and Southern parts of the area where the shear wave velocity encountered in the range of 364-382 m/s in the weathered zone. The shear velocity of > 382 m/s in the weathered zone was encountered in between NGRI-I & II Gates, where the resonance frequency was encountered comparatively high, and the estimated soil thickness was low. We had made the cross plots among topography versus resonance frequency (Hz), soil thickness (m), and shear velocity ($V_s$, in m/s) in the weathered zone. It was found that the topography is directly proportional to the estimated resonance frequency and shear velocity of the weathered zone (Figures 5a, c), whereas it was inversely proportional to the soil thickness (Figure 5b). A strong negative correlation was found among the resonance frequency and the estimated soil thickness with a correlation coefficient of 0.90 (Figure 5d). Whereas, it was observed a comparatively positive relationship with the shear wave velocity of the weathered zone (Figure 5f), but there was not a strong positive relationship with the shear wave velocity of soil (Figure 5e).

## CONCLUSION

The passive seismic survey has been carried out at CSIR-NGRI Campus, Hyderabad, Southern India, for estimating the resonance frequency using ambient noise measurements. During the survey, 42 Tromino 3G ENGY measurements are taken, and at each site, the well-defined frequency peak (known as resonance frequency) is obtained using the GRILLA software, and also its contour map has been prepared for getting clear results of soil thickness. From this study, it has been concluded that

- The estimated resonance frequency has ranged from 52.81 to 102.81 Hz, with an average of 85.36 Hz.
- The contour map of resonance frequency has shown that the resonance frequency is increasing in the high elevated areas where the thickness of the seismic contrast layer (soil thickness) is less. But in the low elevated areas, the resonance frequency has shown an increase, and it indirectly implies for the occurrence of thick soil deposition.
- The estimated soil thickness is on an average of 0.56 m, with the shear wave velocity range of 143-190 m/s with an average of 152 m/s.
- Further, it has been observed that in the high resonance frequency area, the estimated soil thickness is comparatively less than the low resonance frequency area. There is a strong negative correlation among the resonance frequency and the estimated soil thickness with a correlation coefficient of 0.90.
- The estimated shear wave velocities in soil and weathered zone are directly proportional to the estimated resonance frequencies in the individual layers.
- This H/V ratio technique is very useful for mapping the resonance frequency of any place except farmland, marshland or any place having soft soil layer. It is also an emerging rapid non-intrusive

tool and low cost for subsurface investigation in-term of soil thickness, groundwater and hydrocarbon exploration, and seismic micro-zonation.

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