Journal of Soil, Environment & Agroecology

Journal homepage:
https://karyailham.com.my/index.php/sea/index
ISSN: 3030-5497

Assessment of Subsurface Soil Properties using Horizontal-to-Vertical Spectral Ratio (HVSR) and Multichannel Analysis of Surface Waves (MASW) in Cheras, Malaysia

Lee Hong Shen[1,*], Hoh Kai Sheng[1], Muhammad Noor Hisyam[1], Sapitri[2], Salihah Surol[1]

[1] Civil Engineering Department, Faculty of Engineering, Technology and Built Environment (FETBE), UCSI University, 56000, Cheras, Kuala Lumpur, Malaysia
[2] Teknik Sipil, Universitas Islam Riau, Pekanbaru, Indonesia

ARTICLE INFO

Article history:
Received 28 February 2025
Received in revised form 16 May 2025
Accepted 25 May 2025
Available online 15 June 2025

ABSTRACT

This study employs the HVSR method to evaluate subsurface conditions and infer soil properties at Cheras area. The HVSR technique identifies the fundamental resonance frequency (F_0) and peak amplitude (A_0), which are critical for differentiating soil types. Results indicate that F_0 values between 2–5 Hz correspond to fine-grained soils, while values between 5–10 Hz suggest coarse-grained or compacted materials. Complemented by MASW, the study provides further insights into shear wave velocity (Vs) distribution and corresponding Standard Penetration Test (SPT-N) values. The MASW analysis identified four key zones: soft to firm soil (Vs = 0–200 m/s, SPT-N = 0–8), stiff to very stiff soil (Vs = 200–300 m/s, SPT-N = 8–25), hard/dense soil (Vs = 300–400 m/s, SPT-N = 25–35), and weathered rock (Vs > 400 m/s, SPT-N > 35). The undulating nature of the rock profile suggests differential weathering and potential instability zones, consistent with findings from other studies in granite terrains. The correlation between HVSR and MASW results confirms a complex subsurface with significant lithological and structural variations, including weak zones characterized by lower shear wave velocities. These weak zones highlight potential geotechnical challenges that may require further validation through borehole investigations. These findings indirectly contribute to evaluating soil stability and load-bearing capacity, demonstrating the utility of HVSR and MASW as cost-effective, non-invasive tools for preliminary soil investigations, particularly in urban areas.

Keywords:
HVSR; MASW; peak amplitude (A_0); resonance frequency; shear wave velocity

1. Introduction

Over the past decade, landslides in Malaysia have caused over 50 fatalities in addition to large economic losses, so it matters that there is pre-assessment so that soil characteristics can be

* *Corresponding author.*
E-mail address: 1002058441@ucsiuniversity.edu.my

https://doi.org/10.37934/sea.5.1.5972

identified as well as geotechnical hazards prevented. Although having relatively flat land, landslides are quite prevalent in Malaysia, usually due to heavy rainfalls, erosion, as well as earthquakes, that may cause soil structure content as well as destabilize the slope. Malaysia is well known for its diverse soil types, and this presents distinct challenges in geotechnical work, highlighting the importance of considering variations in soil properties during excavation and construction [1].

Urban landslides, frequently caused by poor slope design and inadequate maintenance, highlight the need for rigorous slope assessments to ensure safe and cost-effective development [2]. Traditional soil exploration methods, that is, inclinometer and piezometer-based drillings, are restricted due to their expense and intricacy. In response, Horizontal-To-Vertical Spectral Ratio (HVSR) has emerged as an inexpensive alternative as well as an uncomplicated approach for preliminary soil explorations [3]. This study seeks to apply HVSR in the evaluation of underground structures and establishing true facts regarding soil parameters such as shear-wave velocity and bearing capacity, this study contributes towards improved project planning and structural reliability in Malaysia. Although HVSR and MASW are established geophysical techniques for subsurface characterization, their combined application in the Cheras region remains limited. The lack of localized studies comparing and validating these methods under varying subsurface conditions represents a significant research gap. This study aims to fill that gap by assessing the effectiveness and complementarity of HVSR and MASW in delineating subsurface profiles in Cheras, Malaysia.

2. Literature Review

2.1 Type of Landslides

Landslides are usually caused by particular types of soil debris movement, depending on the area on which they are occurring. Though most landslides occur in inaccessible mountains and hills away from human settlements, landslides are no less significant threat and can adversely affect local economics. Landslides are a generic term for mass movement where unstable area debris is sliding away from an unbroken base surface, encompassing numerous forms such as translational slides, rotational slides, and rockfalls. A notable example is the 2022 landslide in Batang Kali, Malaysia, which resulted in 31 fatalities. Initially manifesting as a rotational failure, it transitioned into a debris flow during the secondary failure (Figure 1). Rotational landslides are characterized by a curved soil surface, driven by the downward movement of materials like clay, soil, and sometimes rock along a curved failure plane [4]. These events are often precipitated by subsurface weaknesses, heavy rainfall altering groundwater levels, and human activities such as excavation, construction, and deforestation. The landslide in question involved a mass of moving soil, loose mud, and rocks, exacerbated by high pore water pressure from heavy rainfall and subsequent seepage, culminating in a debris flow. Debris flows are distinguished by their rapid movement of cohesive masses of mud, soil, and rocks down slopes, making them faster and more destructive than creep and earthflows due to their speed and destructive power [5].

Fig. 1. Aerial view of the Batang Kali landslide in Malaysia

Furthermore, one of the common types of landslides is also known as translational landslides which can be characterized by the gently movement of landslide mass along the planer surface and it will accompany by some rotation or backward tilting [5]. On the other hand, there are also some types of landslides that rarely occur in Malaysia including rockfall, earthflow and creep. Rockfall can be characterized by the free fall, rolling or dropping of rocks down to the slope when a certain area is affected by bad weather, earthquakes or some seismic activity.

Based on the Figure 2 by JKR, a map for showing the landslide hazard of Selangor and Penang for constructed road slopes besides the federal roads in Peninsular Malaysia was made for the purpose of slope monitoring. From the JKR statement, there are around 57% of landslides occurred between 2004 to 2007 which is mainly caused by human factors and most of them are the man-made slopes including the area of Cameron Highland [6]. Since the landslide hazards are highly correlated with the human development and changing of land-use, therefore the relevant departments should limit the development in high-risk areas and enforce policies according to the branches to reduce the impact of landslide hazard.

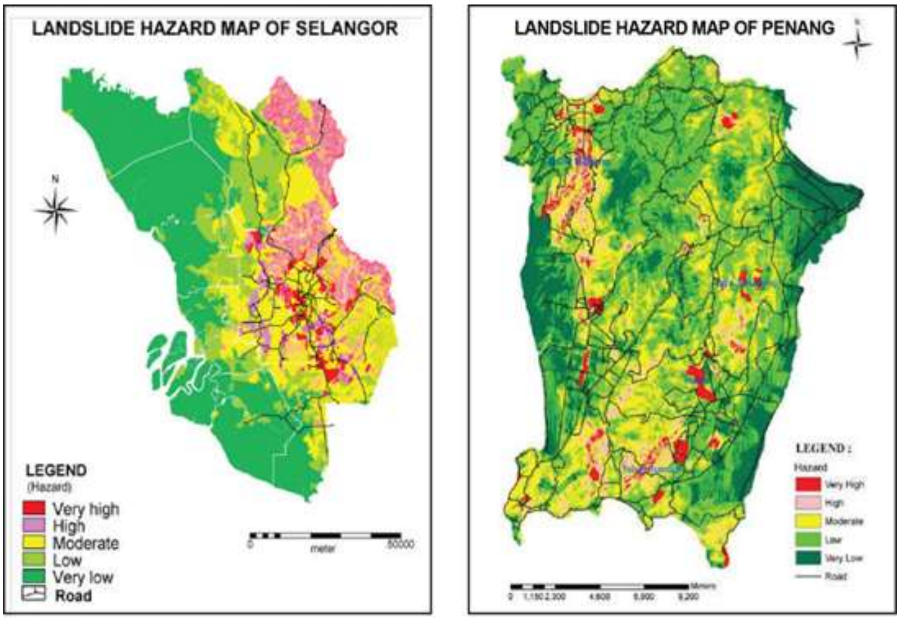

Fig. 2. Landslide hazard maps of Selangor (left) and Penang (right)

2.2 Introduction Passive Seismic

Passive seismic techniques involve the study of Earth's subsurface by detecting seismic waves with natural low frequencies, often referred to as ambient noise. This method, also known as the passive seismic method, is favoured by geotechnical engineers for its stability and non-invasive nature, as it collects data through mechanical vibrations without disrupting the subsurface layers (Figure 3). The relationship between ground resonance and the mechanical characteristics of the medium enhances the analysis within specific frequency ranges, revealing structural characteristics at the measurement site [7]. By utilizing low-frequency data, which is a complex mixture of ambient vibrations with high noise levels, engineers can accurately determine soil properties and interpret medium thickness. In contrast to active seismic methods, which are commonly used to identify new oil and gas reservoirs by releasing and reflecting waves, the passive seismic monitoring systems (PSMs) are designed to collect and analyse ambient noise from micro-seismic waves, providing important insights into subsurface properties [8].

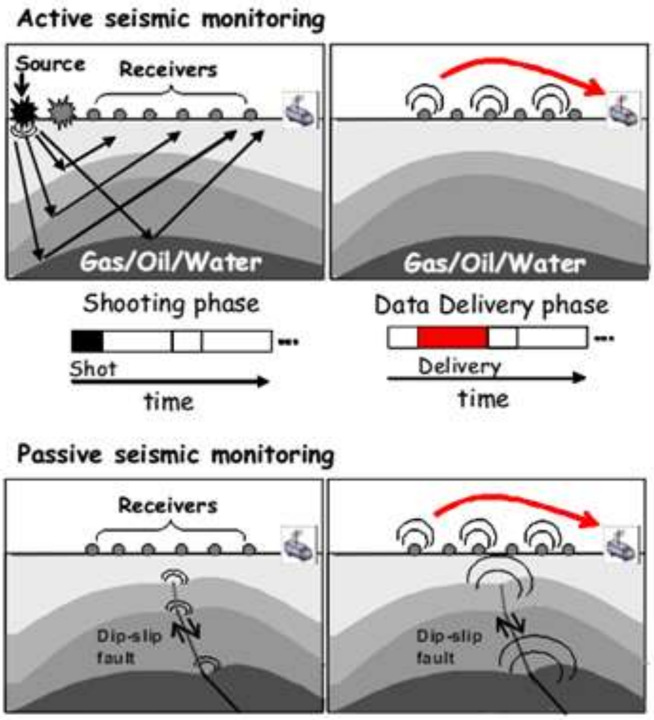

Fig. 3. Example of active and passive seismic monitoring

2.3 Horizontal Vertical Spectral Ratio (HVSR)

The Horizontal-to-Vertical Spectral Ratio (HVSR) method is a geophysical method by using passive seismic techniques for evaluating subsurface properties. HVSR investigation is used to estimate key parameters of subsurface such as the resonant frequency (f0), soil amplification, vulnerability index, and shear wave velocity (Vs). To obtain reliable data, a seismometer is typically set at a site for 10 to 30 minutes to record the fundamental resonant frequency, with longer recording times required for lower frequencies [9]. For comprehensive data collection, seismometers are installed in three directions (two horizontal and one vertical) to record ambient seismic noise in a minimum of 8 hours, ensuring reliable spectral ratios. To improve accuracy, several measurements are taken at roughly 100-meter intervals. The HVSR is calculated by dividing the average horizontal spectrum by the vertical spectrum for each time window, yielding a reliable measure of the fundamental resonance frequency (f0), which is typically indicated by the highest amplitude peak on the H/V frequency spectrum [10].

2.4 Frequency Values of Subsurface

Resonant frequency can be utilized depending on the type and physical characteristics of the waves that interact with the subsurface in detection and characterization of the different features in the subsurface through the categorization of subsurface material based on the type of waves and the physical characteristics that interact with the subsurface. The ground penetrating radar resonance, electromagnetic resonance, and seismic resonance are utilized by the engineers based on geophysics as well as the exploration of the subsurface. Seismic waves vibrate in subsurface layers with natural frequency is also known as resonant frequency. As the information is collected, the frequency will provide the characteristics of soils layer including the density, elastic properties and thickness. Due to lack of understanding soil-structure interaction mechanisms, it is always a complicated issue to comprehend the seismic resonance for structural of soil.

In geophysics, the resonance frequency (fo) for layered medium is found with the thickness of soil (h) and certain shear wave velocity (Vs). The fundamental resonance frequency is used to identify the subsurface layer properties and evaluate the sediment layer [11]. The formula can be expressed as:

$$f_0 = Vs/4h \tag{1}$$

where fo is fundamental resonant frequency of a specific layered medium, Vs is the shear wave velocity in the layer (m/s), and h is the thickness of the layer (m).

As shown in Table 1, the subsurface explanation for every range and condition. Different types of subsurface with different characteristics will perform a different value of resonance frequency. The frequency ranges of soil are linked to particular soil composition, condition, and thickness [12]. It is helpful to identify soil types and subsurface characteristics based on the resonance frequencies collected from passive seismic methods like Horizontal-to-Vertical Spectral Ratio (HVSR) and Multichannel Analysis of Surface Waves (MASW). In short, a lower frequency generally indicates a thicker and softer soil, and a higher frequency shows shallow, dense or rocky layers of soil.

Table 1
Frequency ranges and their underlying subsurface conditions

Frequency range	Subsurface description
Less than 1.0 Hz	Soil layer is soft with a large thickness. A group of loose and unconsolidated sediments.
1.0 Hz to 2.0 Hz	Thick and fine alluvial deposits. Normally formed by loose and unconsolidated sand and clay.
Less than 4.0 Hz	Fine-grained soils with relatively thinner layer.
More than 5.0 Hz	Formed by coarse-grained soils, volcanic ash deposits, and artificial deposits. A thin layer of consolidated and well compacted subsurface.
More than 10.0 Hz, below 12 Hz	Hard rocks, basement.

2.5 Amplification Index of Soil Condition

The amplification index (AI) is a crucial parameter in geological investigations, particularly for identifying subsurface conditions and assessing how soil types amplify earthquake waves relative to reference rock sites. It plays a vital role in understanding subsurface motion, differentiating between soil types, and evaluating seismic risk for structural design in earthquake-prone areas. Research by Zahoor *et al.,* [13] in Los Angeles highlights that moderate amplification is influenced by factors such as soil density, shear wave velocity (Vs), soil depth, water table depth, and the intensity and frequency of seismic input. To mitigate seismic wave amplification at low frequencies, techniques like softening soil materials and increasing damping are employed, based on shear modulus reduction, which can filter high frequencies as damping increases. For instance, softer embayment soils experience greater duration as well as higher amplitudes of low-frequency ground motions as opposed to harder soils due to an effect referred to as the waveguide effect [13]. Site response further depends on soil depth, soil type, geologic age, as well as the size of the earthquake. Soil properties such as cohesion, friction angle, and bulk density are critical parameters that influence structures' stability and load-bearing capacity [14]. Therefore, methods such as spectral inversion, involving multiple strong-motion stations, are appropriate in determining amplification factors in an area based on earthquake ground motion analysis [15].

2.6 Shear Wave Velocity of Soil Condition

Shear wave velocity (Vs), or S-wave velocity, is a critical parameter in geotechnical engineering, used to evaluate soil behaviour in seismic site reactions, potential liquefaction, and vibrations from machine foundations [16]. A key parameter, Vs measures the velocity of seismic shear waves in soil profiles and is controlled through parameters such as soil type, void ratio, effective confining stress, density, and compaction. Soil type is of particular relevance as composition, density, and water content significantly impact Vs values; stiffer soils like gravel and sand are higher in velocity than softer soils like clay and silt [17]. Understanding soil type is essential for accurately analysing Vs results and assessing seismic properties. Studies, such as those by Nazri *et al.,* [17] have demonstrated the importance of evaluating soil type and seismic hazards by determining site-specific Vs profiles, which are vital for earthquake-resistant design and construction. Additionally, methods like the multichannel analysis of surface waves (MASW) are used to investigate soil properties by analysing Vs at different depths, providing critical insights for slope stability assessments and seismic risk mitigation [18].

2.7 Correlation Shear Wave Velocity with SPT-N

The Standard Penetration Test (SPT) is widely used on site testing technique in subsurface investigation although there are numerous other techniques that can be applied nowadays. It is mainly suggested for granular or hard soils or any other ground conditions where samples collection is challenging for laboratory testing. By using various seismic surveys methods, researchers tried to study the relationship between shear wave velocity (Vs) and SPT-N values. As a result, a strong correlation between the parameters has been proved by the researchers that each of the shear wave velocity values represents the soil condition corresponding to SPT-N.

From the guideline published by National Earthquake Hazards Reduction Program (NEHRP), a site classification is listed as Table 2 based on the shear wave velocity (Vs) and Standard Penetration Test N-value (SPT-N). The guideline has classified the classes of site by average shear wave velocity at 30 m depth below the surface and average SPT-N value ranges of the soil profiles. Based on the classification of NEHRP guideline, soil profiles are classified into 5 categories: hard rock, firm and hard rock, dense soil and soft rock, dense to medium soil, medium to soft soil [19].

Table 2
NEHRP site classification system

Class	Description	V_s, m/s	SPT-N
A	Hard rock	>1,500	
B	Firm and hard rock	760 - 1500	
C	Dense soil and soft rock	360–760	N > 50
D	Dense to medium soil	180–360	15 < N < 50
E	Medium to soft soil	<180	N < 15

3. Methodology
3.1 Data Acquisition

In the phase of data acquisition, the application of HVSR method is done by using a three-component seismometer to collect the natural seismic noise systematically (Figure 4). It is important to choose a location is free from the man-made noise sources just like construction sites or besides the road with heavy traffic to ensure the quality of recorded signals. Due to extremely sensitivity of seismometer, the most significant step in this phase is to set up the seismometer correctly as it will only provide data when it is set up in the right way.

By placing the seismometer on the ground, it will present a prediction of natural resonance frequency, (fo) by collecting data and these are the essential of rapid rise in popularity of the HVSR method [20]. Usually, the seismometer needed to be placed at one point for 10 minutes to an hour to capture enough representative sample of ambient seismic noise. As one of its advantages, seismometer can digitize the collected data and store for the further analysis. Therefore, this study is done by multiple recording in several points at the site and some supplementary information such as the specific location is recorded for increasing the data reliability. As shown in Figure 5, a Global Positioning System (GPS) is connected to a seismometer with power supply while it is collecting the data required for analysis.

Fig. 4. Seismometer that operating and collecting

Fig. 5. Seismometer connected with power supply and GPS

For comparing data between HVSR and Multichannel Analysis of Surface Waves (MASW), seismic MASW survey is done at the same point of HVSR data collection. MASW is a geophysical method that uses seismic waves by hitting a strike plate and collect data at every set receiver to study the subsurface. It's used to determine the shear wave velocity of the ground, which indicates the ground's stiffness and ability to support loads. The geophone array is usually either 24 or 48-channels which only require one shot. It will be laid in a straight line at regular interval as adopted in seismic refraction survey as shown as Figure 6. To generate the seismic wave, sledgehammer is used as an impulse source by hitting a striking plate for this survey and starting to collect data after setting up at the site.

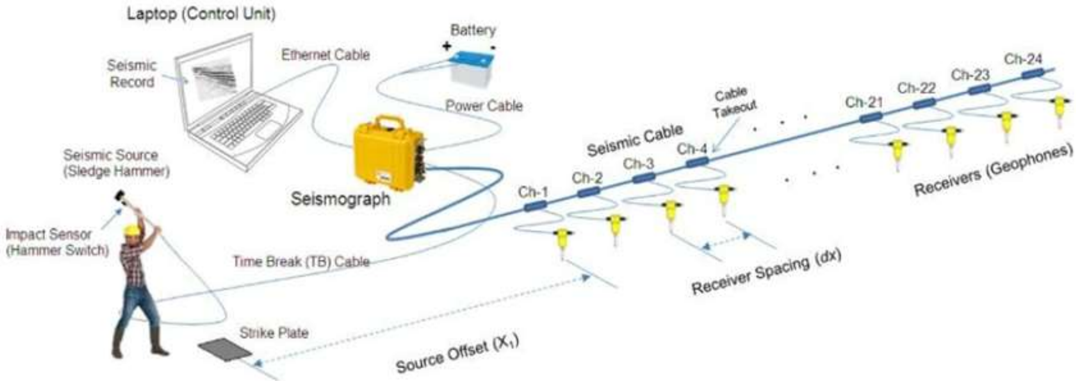

Fig. 6. Description of fieldwork setup with typical generation of seismic

3.2 Data Processing

In the data processing stage, there are few critical steps to ensure the accurate interpretation of subsurface properties. Through the experiment, it shows HVSR method can provide peak frequencies which is close to fundamental frequency at sites where there is a considerable impedance comparison between rock and soil layer [21]. With the guidelines provided for peak frequency recording at specific site, the lower peak frequency is required to have more recording time compared to the higher peak frequency. A longer time window is required for the sites with low fundamental frequencies due to the reason that length of window is inversely proportional to lowest frequency. Based on the guideline provided, every single time window length need to be greater than the approximate fundamental site period with at least 10 times [20]. A total of 9 points are done with data acquisition and marked for data processing. By importing the raw data collected into Geopsy as shown in Figure 7, it allows us to filter out the valid data for further analysis. Filtering raw data as shown in Figure 8 before HVSR analysis is importance for removing environmental and instrumental noise, eliminate transient signals, and focus on the relevant frequency range (0.1–10 Hz). It ensures stability, enhances signal quality, and improves the accuracy of spectral ratio calculations for reliable site characterization and seismic response analysis.

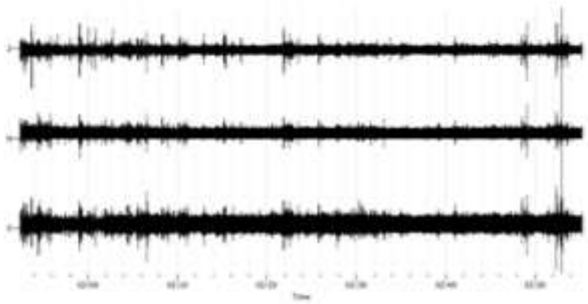

Fig. 7. Raw data in Geopsy

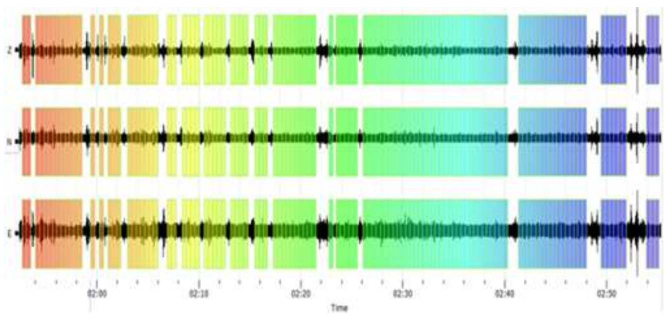

Fig. 8. Filtered data in Geopsy

After signal processing, quality evaluation will be done for the signal to obtain the reliable HVSR results. In Geopsy, signal quality is assessed and maintained through several parameters including Signal-to-Noise Ratio (SNR), Window Selection Criteria, Quality Control Parameters and so on. Signal-

Journal of Soil, Environment & Agroecology
Volume 5, Issue 1 (2025) 59-72

to-Noise Ratio (SNR) can be determined as proportion of strength of a signal with information to unwanted interference. Peak shows in H/V ratio curve corresponds to the resonance frequencies (fo) of the subsurface layers as shown in Figure 9. This plot is used to indicate the predominant frequency (Po) and peak amplitude (Vo) of the earth's movement.

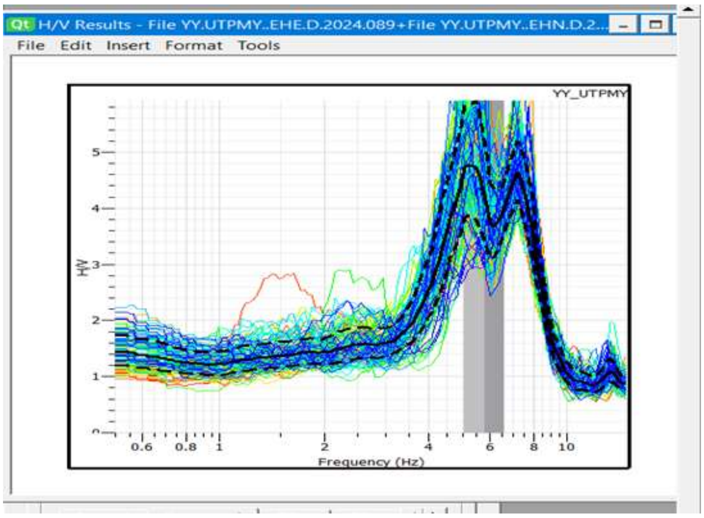

Fig. 9. H/V against frequency plot

3.3 Shear Wave Velocity (Vs) Profiling

In the application of HVSR method for soil investigation, shear wave velocity (Vs) profiling is a crucial component in estimating the parameters of subsurface motion. By determining the shear wave velocity of soil and rock deposits, material of subsurface can be characterized which is useful for assessing seismic site effects. As one of the important fundamental soil properties, shear wave velocity (Vs) is useful for geotechnical engineering to understand the variable loading conditions and renovation of unstable earthquake geoformation [22]. From the HVSR curve generated by using Geopsy, fundamental resonance frequency (fo) can be identified due to the relationship between shear wave velocity and thickness of subsurface layers. In HVSR analysis by using Dinver (a geophysical inversion tool in Geopsy), the dispersion target refers to the fundamental or higher-mode dispersion curves of surface waves, which are used to infer subsurface shear-wave velocity profiles. These targets guide the inversion process by comparing observed and theoretical dispersion curves to achieve the best-fitting model.

4. Results and Analysis

To have a cross validate results and improve the accuracy of data, shear wave velocity (Vs) is determined by using Horizontal-to-Vertical Spectral Ratio (HVSR) and Multichannel Analysis of Surface Waves (MASW) method at the same survey area. Although both the methods are non-invasive geophysical method, HVSR is useful to identify resonance effect and MASW is used to help site classification by providing complete Vs profile. Thus, a more complete and reliable estimation of shear wave velocity can be provided by using both HVSR and MASW methods.

With the HVSR curve, the resonance frequency and peak amplitude is exported from Geopsy to Dinver for further analysis. After running the model with specific parameters, a ground profile can be generated as shown in Figure 10 - 13 with different profiles including P-Wave Velocity (Vp), S-Wave

Velocity (Vs), and Density with depth, along with a misfit value bar at the bottom which use to indicate the quality of the model fit.

P-wave velocity (Vp) represents the primary wave velocity in soil layer which also known as the compressional wave velocity in subsurface of soil layer. The ground profile shows that the survey point has a low Vp in upper layer (0 – 20m), indicating loose or unconsolidated materials. Shear wave velocity (Vs) also known as S-wave which is use for assessing the seismic site classification and soil stiffness. Two layers of soil is shown in the ground profile which a low Vs values in the upper layers at 0 – 10 meter is 100 m/s, indicating soft or loose soil and 10 – 20 meter is 150 m/s, indicating loose to medium-dense sandy soils which is more compacted compared to very soft soils.

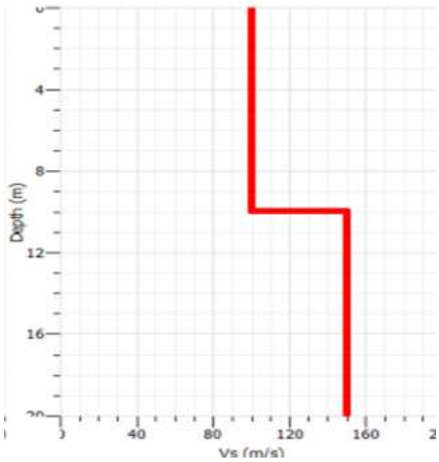

Fig. 10. HVSR inversion at point 57

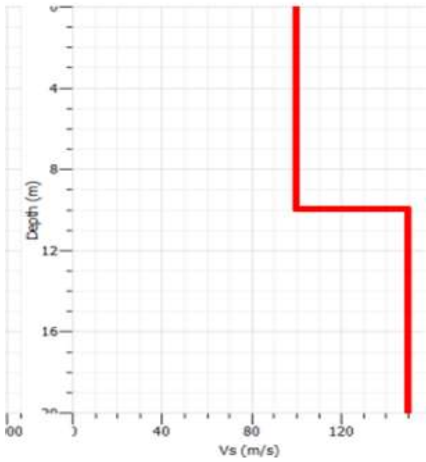

Fig. 11. HVSR inversion at point 58

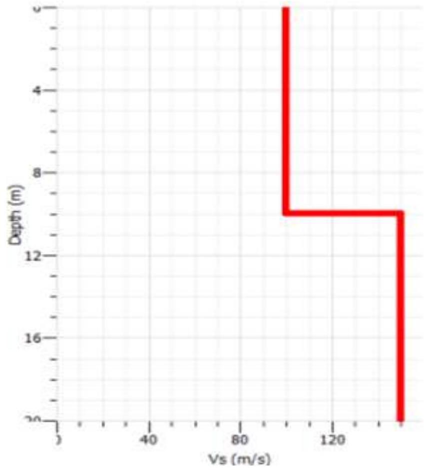

Fig. 12. HVSR inversion at point 68

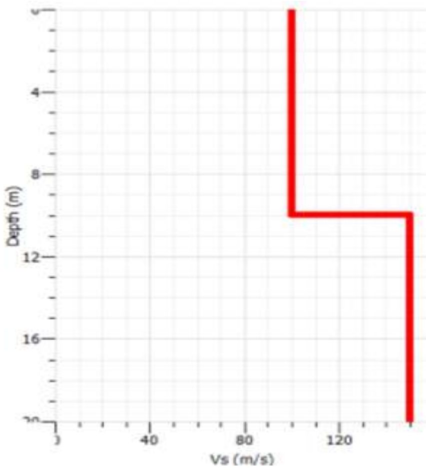

Fig. 13. HVSR inversion at point 69

Furthermore, MASW analysis is done with the results for shear wave velocity (Vs) and SPT-N values. Figure 14 visually represents the subsurface stratigraphy which correlating shear wave velocity with soil stiffness and SPT-N values. From this survey, shear wave velocity is identified as the left panel with four key zones, soft to firm soil (Vs = 0-200 m/s), stiff to very stiff soil (Vs = 200-300 m/s), hard/dense soil (Vs = 300-400 m/s), and weathered rock (Vs > 400 m/s).

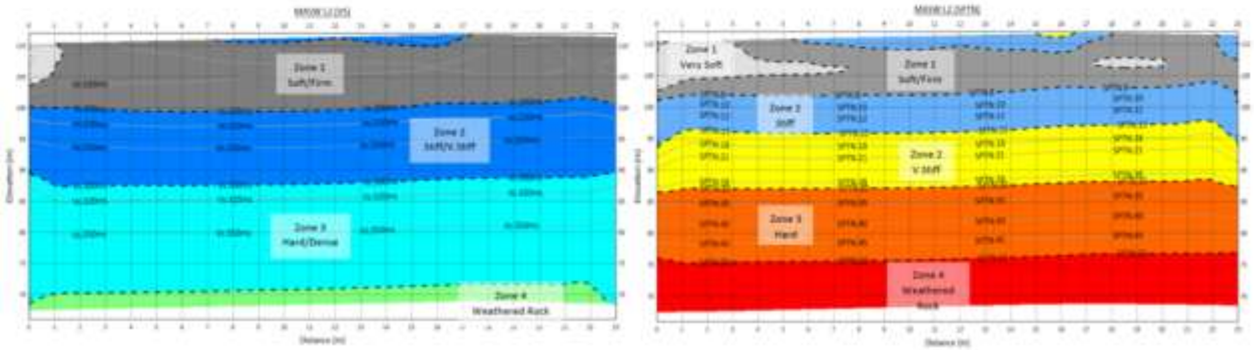

Fig. 14. Shear wave velocity and SPT-N profile from MASW

Overall, shear wave velocity (Vs) of Multichannel Analysis of Surface Waves (MASW) and Horizontal-to-Vertical Spectral Ratio (HVSR) is analysed and listed in Table 3 by presenting the Vs in different level of depth. This comparison will show the key differences between MASW and HVSR results including the variation of velocity, sensitivity to layering, and accuracy and application.

At shallow depth 0 – 5 meters, the lower bound of MASW result show a range of Vs values between 100 – 150 m/s, suggesting the presence of some variation in soil stiffness. The HVSR result has a similar value at 100 m/s, assuming a homogenous near-surface layer. Both methods agree that the shear wave velocity at this depth is around 100 m/s and MASW suggest the velocity is possible up to 150 m/s which also indicates a soft and compressible layer likely influenced by moisture content.

At depth 5 – 10 meters, shear wave velocity result from MASW increases to the range of 150 – 200 m/s, presenting a transition to a stiffer material. Besides that, HVSR result remain a same value as upper layer at 100 m/s which could assume the material of the soil subsurface remains soft. At depth 10 – 15 meters, MASW method show a significant increase of shear wave velocity at the range 200 – 250 m/s, indicating dense or stiff soil. The shear wave velocity of HVSR also increases to 150 m/s but remain much lower than the MASW upper bound. This difference could suggest that MASW has better at resolving higher-velocity layers, while HVSR may still be lagged in detecting the stiffness of soil.

At the depth of 15 – 20 meters, MASW result show the shear wave velocity values continue increasing to 250 – 300 m/s, indicating the presence of a denser subsurface material or possible bedrock. However, Vs value for HVSR method is remaining at 150 m/s, suggesting medium-dense or silty soil which also means it does not fully capture the increasing stiffness at depth. The difference between MASW and HVSR result could be related to the testing method, depth sensitivity, or data interpretation limitations. Discrepancies between HVSR and MASW shear wave velocity (Vs) results stem from methodological limitations: MASW's resolution is constrained by geophone frequency (e.g., 4.5 Hz limits shallow profiling), while HVSR's reliance on ambient noise makes it sensitive to cultural interference, leading to overestimations in urban areas [23].

In short, this study highlights HVSR for estimating shear wave velocity (Vs), with MASW method used as a comparative reference. HVSR shows that it is a cost-effective technique for preliminary subsurface characterization, especially in identifying resonance frequency and detecting impedance contrasts. However, HVSR has limitations in accurately capturing depth-wise variations in soil stiffness, often underestimating Vs in deeper layers. Despite its limitation, HVSR is still a valuable for seismic hazard assessments and preliminary soil classification. The combination of both methods may enhance the reliability of subsurface characterization and ensuring a balance between efficiency and accuracy for engineering applications. In addition, since HVSR overestimated Vs in noise-prone areas compared to MASW, highlighting the need for hybrid methods validated by borehole data to mitigate uncertainties is required.

Table 3
Shear wave velocity of MASW and HVSR

Depth (m)	Shear Wave Velocity, *Vs* (ms^{-1})	
	MASW	HVSR
0-5	100 – 150	100
5-10	150 – 200	100
10-15	200 – 250	150
15-20	250 – 300	150

5. Conclusions

Through seismic noise analysis, the study aimed at evaluating the possibility of utilizing the Horizontal-to-Vertical Spectral Ratio method as an indirect soil investigation for geotechnical site characterization. Multi-Channel Analysis of Surface Waves method is utilized for cross-validation of HVSR with MASW through conducting thorough evaluation of the state of the ground at the subsurface level. In order to estimate the shear wave velocity (Vs), the results indicate that HVSR performs well in the identified resonance frequency (fo) and peak amplitudes (Ao). However, differences are observed from the result when comparing data between the shear wave velocity (Vs) values from HVSR and MASW results, especially at deeper depths. The results of the comparison between HVSR and MASW showed that while HVSR is more effective at detecting resonance frequencies and shallow soil stiffness, and the MASW method produced a more detailed velocity profile at the deeper layers. As summarized, Vs values derived using MASW method ranged between 100 – 300 m/s in the top 20 meters, while HVSR showed lower Vs values ranging between 100 – 150 m/s. The difference in the values shows the limitation in HVSR in ability to accurately depict deep soil subsurface layer due to the inversion assumption as well as dependency on ambient noise sources of the method. Notwithstanding the limitations of HVSR method, HVSR is also endowed with numerous advantages towards geotechnical engineering such as being non-invasive, cost effective, as well as having minimal equipment as well as manpower requirement. These benefits make HVSR a useful tool for preliminary site investigation, especially in urban areas and on hills where traditional invasive methods might be difficult. Overall, this research has highlighted the important of HVSR method as an alternative soil investigation in the geotechnical field and highlights its potential as a useful instrument in future civil engineering applications. It is recommended that further studies be conducted in areas with varying geological conditions and formations to enhance the reliability and robustness of data obtained using this method. The use of conventional methods, such as borehole drilling, remains essential due to their proven relevance and reliability. These methods also serve to complement geophysical techniques by providing ground-truth data for validation and interpretation.

Acknowledgement
The authors would like to thank Ministry of Higher Education Malaysia (MOHE) for funding this research under the REIG-FETBE-2022-054 grant. This support has been instrumental in facilitating the successful completion of this study.

References

[1] Kho, Melvin Ying Fan, Daryn Ng Tee Ngi, Sim Dong Hao, Ng Yen Ying, Kok Zi Jie, Ho Cheng Jun,Muhammad Noor Hisyam Jusoh. "The Effect of Sheet Pile Used for Temporary Work Structure forExcavation Purposes," *Semarak International Journal of Civil and Structural Engineering* 4, no. 1 (2024): 1-21. https://doi.org/10.37934/sijcse.4.1.121

[2] Komoo, Ibrahim, Sarah Aziz, and Lim Choun Sian. "Incorporating the Hyogo Framework for Action into landslide disaster risk reduction in Malaysia." (2011).

[3] Alonso-Pandavenes, Olegario, Daniela Bernal, Francisco Javier Torrijo, and Julio Garzón-Roca. "A comparative analysis for defining the sliding surface and internal structure in an active landslide using the HVSR passive geophysical technique in Pujilí (Cotopaxi), ecuador." *Land* 12, no. 5 (2023): 961. https://doi.org/10.3390/land12050961

[4] Petley, Dave. "The Official Report into the 16 December 2022 Batang Kali Landslide." *The Landslide Blog*, October 23, 2023.

[5] Highland, Lynn. "Landslide types and processes." *USGS Report* (2004): 15. https://doi.org/10.3133/fs20043072

[6] Chow, Mei Mei. "What It Takes to Manage Landslides." *Macaranga*, December 24, 2021

[7] Fazriati, Evi, Muhammad Randy Azhari, Abdul Hakam, Widya Utama, and Yudi Rosandi. "Horizontal to Vertical Spectral Ratio (HVSR) Analysis of the Passive Seismic Data on Alluvial Lithology: An Example from Bandung Basin Rim." *Jurnal Penelitian Pendidikan IPA* 9, no. 1 (2023): 402-411. https://doi.org/10.29303/jppipa.v9i1.2962

[8] Savazzi, Stefano, L. Goratti, Umberto Spagnolini, and M. Latva-Aho. "Short-range wireless sensor networks for high density seismic monitoring." In *Proc. Wireless World Res. Forum*, pp. 1-5. 2009.

[9] Vantassel, Joseph P., Andrew C. Stolte, Liam M. Wotherspoon, and Brady R. Cox. "AutoHVSR: A machine-learning-supported algorithm for the fully-automated processing of horizontal-to-vertical spectral ratio measurements." *Soil Dynamics and Earthquake Engineering* 173 (2023): 108153. https://doi.org/10.1016/j.soildyn.2023.108153

[10] Arwananda, Alif Prabawa, Bagas Aryaseta, Hafidz Dezulfakar, Yosar Fatahillah, and Juan Pandu Gya Nur Rochman. "Horizontal-vertical spectral ratio method in microtremor to estimate engineering bedrock thickness at sedati mud volcano." In *IOP Conference Series: Earth and Environmental Science*, vol. 62, no. 1, p. 012010. IOP Publishing, 2017. https://doi.org/10.1088/1755-1315/62/1/012010

[11] Badrolhisham, Siti Noor Shafiqah, Amin Esmail Khalil, Wong Kian Wai, and Abdul Halim Abdul Latiff. "Evaluation of site effects using horizontal-to-vertical spectral ratio in Kuala Pilah, Negeri Sembilan." In *IOP Conference Series: Earth and Environmental Science*, vol. 1003, no. 1, p. 012036. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/1003/1/012036

[12] Zaenudin, A., and I. B. S. Yogi. "Preliminary study of HVSR forward modeling: parameters properties and non-uniqueness of subsurface models." In *Journal of Physics: Conference Series*, vol. 1816, no. 1, p. 012063. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1816/1/012063

[13] Zahoor, Falak, Neelima Satyam, and K. Seshagiri Rao. "A comprehensive review of the nonlinear response of soil deposits and its implications in ground response analysis." *Indian Geotechnical Journal* 54, no. 3 (2024): 781-799. https://doi.org/10.1007/s40098-023-00798-1

[14] Jusoh, Muhammad Noor Hisyam, Salihah Surol, Hocine Hamza, Noor Safwan Muhamad, Muhammad Azrief Azahar. "Model Prediction of Soil Parameters via Experimental Analysis for the Geotechnical Design," *Semarak International Journal of Civil and Structural Engineering* 1, no. 1 (2024): 30-41. https://doi.org/10.37934/sijcse.1.1.3041

[15] Miyakoshi, Hiroyuki, Seiji Tsuno, Kosuke Chimoto, and Hiroaki Yamanaka. "Investigation of site amplification factors for S-and P-waves from spectral inversions in the Tokyo metropolitan area, Japan—for application to earthquake early warnings." *Journal of Seismology* 23 (2019): 561-578. https://doi.org/10.1007/s10950-019-09823-4

[16] Miyakoshi, Hiroyuki, Seiji Tsuno, Kosuke Chimoto, and Hiroaki Yamanaka. "Investigation of site amplification factors for S-and P-waves from spectral inversions in the Tokyo metropolitan area, Japan—for application to earthquake early warnings." *Journal of Seismology* 23 (2019): 561-578. https://doi.org/10.1007/s10950-019-09823-4

[17] Nazri, F. M., C. G. Tan, and M. Z. Ramli. "Investigation of site-specific shear wave velocity for geotechnical engineering applications using microtremor array measurement." *Soil Mechanics and Foundation Engineering* 53 (2016): 332-335. https://doi.org/10.1007/s11204-016-9407-3

[18] Qaysi, Saleh, Kamal Abdelrahman, and Abdullah B. Saadon. "Evaluation of kinetic moduli and soil competence parameters for sustainable urban development using multichannel analysis of surface waves (MASW) technique." *All Earth* 37, no. 1 (2025): 1-34. https://doi.org/10.1080/27669645.2024.2448362

[19] Anbazhagan, P., M. Neaz Sheikh, and Aditya Parihar. "Influence of rock depth on seismic site classification for shallow bedrock regions." *Natural Hazards Review* 14, no. 2 (2013): 108-121. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000088

[20] Molnar, S., A. Sirohey, J. Assaf, P-Y. Bard, S. Castellaro, Cécile Cornou, B. Cox et al. "A review of the microtremor horizontal-to-vertical spectral ratio (MHVSR) method." *Journal of Seismology* 26, no. 4 (2022): 653-685. https://doi.org/10.1007/s10950-021-10062-9

[21] Holtrigter, M., and A. Thorp. "The use of scpt and hvsr for site period and subsoil class estimation." In *NZGS Symposium*, pp. 24-26. 2021.

[22] Tempa, Karma, Nimesh Chettri, Lily Gurung, and Dipendra Gautam. "Shear wave velocity profiling and ground response analysis in Phuentsholing, Bhutan." *Innovative Infrastructure Solutions* 6 (2021): 1-16. https://doi.org/10.1007/s41062-020-00420-w

[23] Durmuş, Hatice. "Soil characterization using HVSR and MASW techniques: a case study (Kütahya Dumlupınar University Campus)." *Pure and Applied Geophysics* 181, no. 4 (2024): 1281-1302. https://doi.org/10.1007/s00024-024-03452-w