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¹Estimation of Shear Wave Velocity of Darul Imarah District, Aceh Besar, Indonesia by Using 1D HVSr Inversion

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⁴**Abstract.** A total of 19 locations of Horizontal to Vertical Spectral Ratio (HVSr) measurements was conducted in Darul I⁵marah District, Aceh Besar, Indonesia. The objective of the research is to investigate the shear wave velocity (V_s) structure. This survey is important to analyze a structural characteristic through a V_s , considering the measurement points intersect to Aceh Segment Fault. One of the methods to obtain V_s is 1D HVSr inversion. In this paper, we analyzed only four of 19 measurement points of HVSr data to estimate V_s , they are AB03, AB08, AB09 and AB19 points. The inversion results show that the four points have four layers with different V_s . The average of V_s 30 of AB03, AB08, AB09 and AB19 were calculated, they are 150.90 m/s, 197.16 m/s, 150.45 m/s and 316.80 m/s, respectively. The AB09 has the lowest average of V_s 30 (highest amplification) than the other points and has soft soil composition. Furthermore, based on the average of V_s 30 and amplification, the subsurface of AB03, AB08 and AB19 may have combination soft soil and stiff soil in 30 m depth. The complete analysis of average of V_s 30 structure will be conducted at all sites including a 3D velocity structure will be derived from the interpolation of 1D velocity.

Keywords: V_s structure, HVSr inversion, Microtremor

1. Introduction

Since 1999 to 2019, as many as 697 earthquakes with magnitude in range M3.6-M6.5 were recorded¹⁰ by United States Geological Survey (USGS) around Aceh Besar, as shown Figure 1a. Aceh Besar is one of the most earthquake prone areas in the world where earthquakes could occur along the Sumatran Fault (Aceh segment), and Seulimeum Fault, as well as the Indo-Australian and Eurasian plate convergence. Therefore, the impact of the earthquake hazards of the area should be studied in



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detail. The study of the impact of earthquake hazard can be derived from the microtremor data. Microtremor data make use of natural vibration (non-earthquake) of earth surface that always in motion at seismic frequency to analyze a structure characteristics of a site [1].

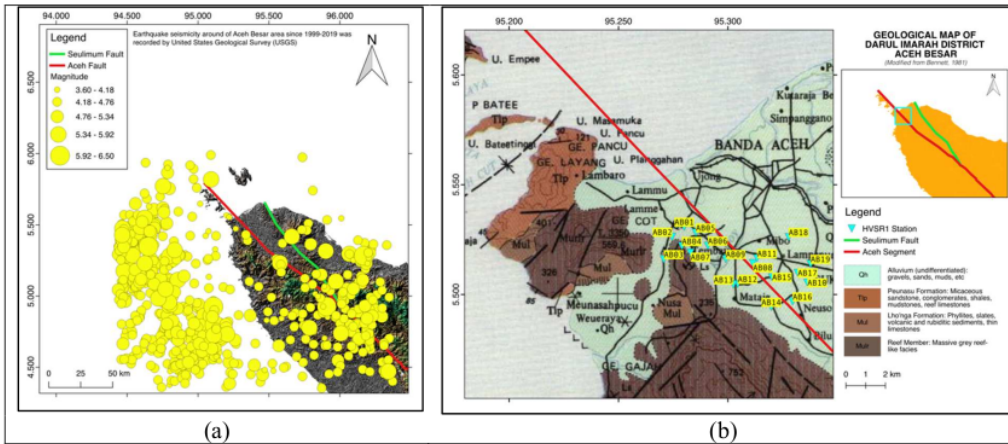


Figure 1. (a) Since 1999-2019, as many as 697 earthquakes in range M3.6-M6.5 around Aceh Besar were recorded by United States Geological Survey (USGS). (b) Geological map around Darul Imarah District, Aceh Besar Indonesia (modified from Bennett, 1981)

One of the parameters that can be used to explain a structure characteristic is shear wave velocity. The shear wave velocity is very important to seismic hazard evaluation of an area [2], [3]. A low shear wave velocity (less than 200 m/s) indicates high amplification, in other words, a ground is vulnerable to shaking [4]-[6]. The shear wave velocity can be obtained from 1D Horizontal to Vertical Spectral Ratio (HVSRI) inversion method of microtremor data. Therefore, the objectives of the research are to estimate of shear wave velocity (V_s), in particularly to estimate an average of shear wave velocity in 30 m depth (V_{s30}) of Darul Imarah District, Aceh Besar, Indonesia, where only four points microtremor data are used to analyze in this research.

2. Geological Settings

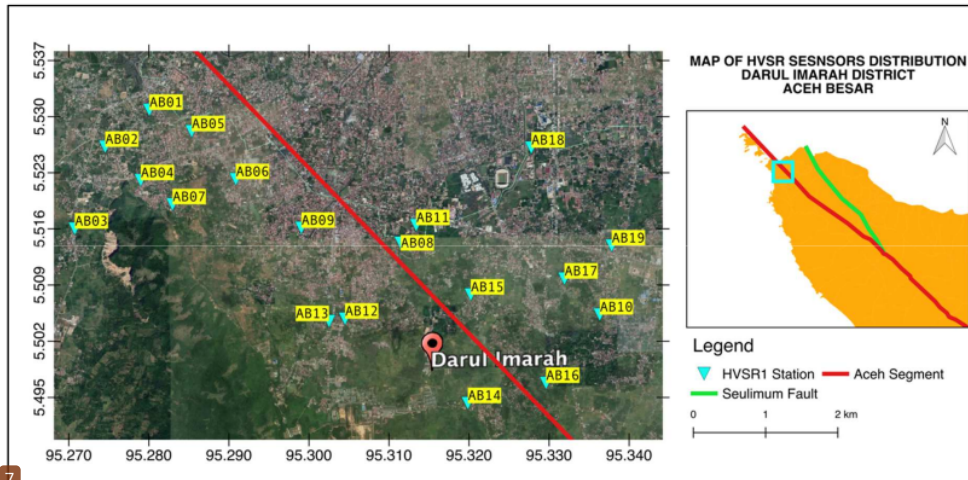
Geological settings around Darul Imarah District, Aceh Besar has been well explained and mapped by [7], as shown in Figure 1b. The lithology around these areas is composed by Qh (alluvium), Tlp (conglomerates, shales, mudstones, reef limestones), Mul (phyllites, volcanic and turbiditic sediments, thin limestones), and Mulr (reef-like facies). Specifically, the lithology around of the HVSRI survey points (inverted cyan triangle in Figure 1b) is dominated by alluvium.

3. Methodology

3.1 Data

A total of 19 HVSRI measurements points (Figure 2) was conducted in Darul Imarah District, Aceh Besar, Indonesia, considering the survey area is near to Aceh Segment Fault (red line in Figure 2). In this research, we only use four measurement points to analyze of shear wave velocity, there are AB03, AB08, AB09, and AB19 points. The locations of AB03, AB08, AB09 and AB19 intersect to the Aceh Segment, where the AB03 and AB09 are in west-side of Aceh Segment (both points are separated by hill), the AB08 and AB19 are in east-side of Aceh Segment. The HVSRI was recorded for 30 minutes by using short-period seismometer Model L-4-3D and data logger of DATA-CUE³ext. Furthermore, the data processing of HVSRI is conducted by setting several parameters, such as bandpass filter 0.5-10

Hz, window length of 25 s, STA window of 1 s, LTA window of 30 s, minimum threshold of 0.2, maximum threshold of 2.0, and Konno-Ohmachi smoothing bandwidth of 40.



7 **Figure 2.** Distribution of 19 HVSR measurement points (AB01-AB19) around Darul Imarah District, Aceh Besar, Indonesia.

9 **3.2. Horizontal to Vertical Spectral Ratio (HVSR) Method**

The HVSR is a method to estimate the dominant frequency (f_0) and high amplification from three components (two horizontal components and one vertical component) of microtremor data. The method was introduced by Nogoshi and Igarashi in 1971 to identify the dominant frequency and amplitude characteristic of microtremor data through the Rayleigh wave [8]. However, HVSR method was re-popularized by Nakamura (1989) who mentioned that the microtremor data can be explained by vertical incident SH wave [9]. The Nakamura statement was supported by explanation of Sungkono and Santosa through numerical modelling of HVSR [10]. The HVSR is calculated by using equation 1.

$$\frac{H}{V} = \frac{\sqrt{NS^2 + EW^2}}{2V} \quad (1)$$

NS = North-South component (horizontal 1)
 EW = East-West component (horizontal 2)
 V = Vertical Component

By using the HVSR data (dominant frequency and amplification), we can estimate the structure characteristic beneath a surface, e.g. shear wave velocity (V_s) by using 1D HVSR inversion method.

3.3 1D HVSR Inversion Method

A Neighbourhood Algorithm (NA) method is the inversion method that used to obtain the 1D ground profile of shear wave velocity (V_s) in this research by using the HVSR data. NA method was introduced by [11] and improved by [12] and implemented in Geopsy software. The NA method is a direct search method that has been widely used to solves inversion problems. The basic idea of those algorithm is to find an optimal models of acceptable data fit in a multidimensional parameters space. This algorithm makes use of the geometrical constructs called Voronoi cells to derive the optimal model in parameter space from each iteration. Therefore, for each new iteration of the models are concentrated around the lowest misfit that is the optimal model in the neighbourhood algorithm [11].

4. Results

The HVSR data of AB03, AB08, AB09 and AB19 points had been analyzed to obtain the dominant frequency (f_0), amplification (A_0) and seismic vulnerability (K_g), as shown in Table 1. Furthermore, the HVSR data (dominant frequency and amplification) are inverted by using neighbourhood algorithm in Geopsy to obtain the shear wave velocity. As many as 10000 a priori velocity models were imposed to obtain reliable 1D ground profile of shear velocity model for each data from inversion. After the inversion process is complete, the solutions of the 1D shear velocity model of the AB03, AB08, AB09 and AB19 points are shown in Figure 4, respectively. The ground profile of AB03, AB08, AB09 and AB19 consists of four different layers indicated by different shear wave velocity (V_s) as shown in Table 2.

Table 1. Results of data processing of HVSR observation

| Point | F_0 (Hz) | A_0 | K_g | V_{s30} (m/s) |
|-------|------------|-------|---------|-----------------|
| AB03 | 5.524 | 0.24 | 0.01043 | 150.902 |
| AB08 | 2.076 | 0.59 | 0.16765 | 197.160 |
| AB09 | 2.739 | 1.02 | 0.38167 | 150.450 |
| AB19 | 2.809 | 0.73 | 0.19389 | 316.804 |

Table 2. The depth of shear velocity (V_s) for each layer

| Layer | Depth (m) | | | |
|---------|--------------|--------------|-------------|-------------|
| | AB03 | AB08 | AB09 | AB19 |
| Layer 1 | 0-30.96 | 0-7.92 | 0-56.81 | 0-7.17 |
| Layer 2 | 30.96-53 | 7.92-12.77 | 56.81-60.92 | 7.17-19.01 |
| Layer 3 | 53-98.25 | 12.77-98.25 | 60.92-99.23 | 19.01-92.55 |
| Layer 4 | 98.25-103.17 | 98.25-103.17 | 99.23-104.2 | 92.55-97.19 |

By using shear wave velocity (V_s) data, an average of shear wave velocity in 30 m depth (V_{s30}) had been calculated to identify a structure characteristic by using equation 2. The AB03 has V_{s30} of 150.902 m/s, AB08 has V_{s30} of 197.160 m/s, AB09 has V_{s30} of 150.450 m/s and AB19 has V_{s30} of 316.804 m/s. The V_{s30} of AB03, AB08, and AB09 are categorized to low shear velocity (less than 200 m/s), while the V_{s30} of AB19 is categorized to moderate shear velocity. However, according to site classification of V_{s30} by SNI 1726-2012 [13], the AB03 and AB09 are in west-side of Aceh Segment categorized to SE class or soft soil with low shear velocity. Meanwhile, the AB08 and AB19 are in east-side of Aceh Segment categorized to SD class or medium soil with moderate shear velocity.

$$\bar{v}_s = \frac{30}{\sum_{i=1}^n \frac{d_i}{v_{si}}} \quad (2)$$

d_i = thickness for each layer between 0-30 m depth
 v_{si} = shear velocity for each layer between 0-30 m depth
 \bar{v}_s = average of shear wave velocity (m/s)
 n = a total of layer in 30 m depth

The low velocity indicates high amplification and high seismic vulnerability if a natural vibration (e.g. earthquake) occurs in an area. According to the results of V_{s30} in Table 1, the AB09 has lowest of V_{s30} (highest amplification) than the other points. Furthermore, the AB03 has second lowest V_{s30} after AB09 and lower than V_{s30} of AB08 and AB19. However, the amplification of AB03 is lower than amplification of AB08 and AB19. The same problems apply to AB08 compared with AB19.

The low V_{s30} and low amplification of AB03 may be affected by natural vibration that coming from the hill (east-side of AB03 point) that has high frequency, because the observation point of AB03 is close to the hill. The AB03 may be due to combination of soft soil and stiff soil. Furthermore, the V_{s30} of AB08 is higher than AB03, that means the subsurface of AB08 may has a composition

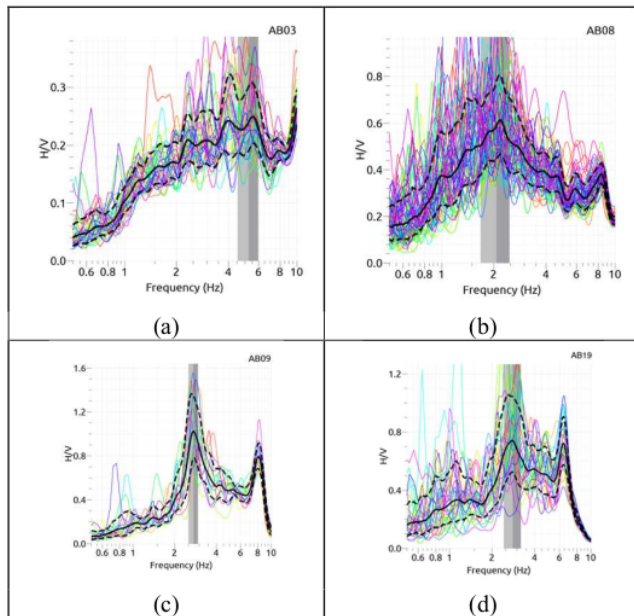


Figure 3. The amplification curve of (a) AB03, (b) AB08, (c) AB09, and (d) AB19

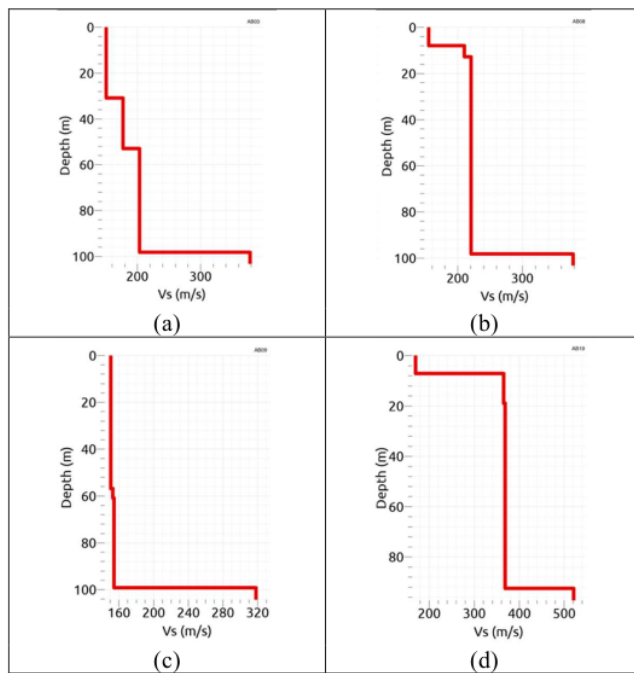


Figure 4. 1D shear velocity (V_s) models of (a). AB03, (b). AB08, (c) AB09 and (d) AB19.

between soft soil and stiff soil with high amplification than the AB03. The AB19 has the highest V_s30 than other points. In this condition, the AB19 has more stiff soil than the other points with the high amplification after AB09. However, the amplification of AB19 is higher than amplification of AB03 and AB08. It means, the AB19 may has a composition between soft soil and stiff soil. To ensure these results, boreholes survey have to be carried out. The complete analysis all of HVSR data of this research will be reviewed in the next article.

5. Conclusion

By using the HVSR inversion of four points (AB03, AB08, AB09 and AB19) the velocity structure, V_s , consists of four layers by different shear wave velocity. The average of V_s30 of AB03, AB08, AB09 and AB19 are 150.90 m/s, 197.16 m/s, 150.45 m/s, and 316.80 m/s, respectively. According to site classification of V_s30 by SNI 1726-2012, the AB03 and AB09 are in west-side of Aceh Segment categorized to SE class or soft soil and the AB08 and AB19 are in east-side of Aceh Segment categorized to SD class or medium soil. The AB09 has the lowest V_s30 (highest amplification) than the other points and has soft soil composition. Furthermore, based on the V_s30 and amplification, the subsurface of AB03, AB08 and AB19 may have combination soft soil and stiff soil in 30 m depth. To ensure these results, boreholes survey have to be carried out.

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