Shear Velocity (VS) Estimation with HVSR (Horizontal to Vertical Spectrum Ratio) Curve Inversion Method of Microtremor Measurement in Bandung Basin

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Abstract. From the geological aspect, Bandung is a basin surrounded by mountain area. The stratigraphical setting of Bandung is also dominated by thick and soft sediment which makes Bandung needs a mitigation plans needed to reduce the risk of ground motion. Horizontal to Vertical Spectrum Ratio (HVSR) is a popular method developed by (Nakamura, 1989) in microtremor study to use for seismic characterization which is used in this research. This method is used to determine the seismic characteristic in Bandung Basin. The seismic characterization estimated in this research are amplification and dominant frequency. Those values are obtained from HVSR curves which then used to determine the shear wave velocity and depth of Bandung Basin with inversion method. Amplification value in Bandung Basin and its surrounding area is between 2-11.5 with its highest value is in the south-eastern part of observation area. The segmented amplification values based on natural period of building are varies in values based on the range of period and location points. The other seismic characteristic in this research is dominant frequency which value is between 0.1-8 Hz with the highest values are in the north and south part of observation area, while the middle part has the lowest value. Bandung Basin has low shear wave velocity underneath it which less than 800 m/s within depth more than 200 m of depth. There is also a high velocity structure which divide Bandung Basing into two major parts: west part and east part. Those seismic characteristics can be used as a guide to carry-on mitigation procedures to minimize the risk if any disasters happen.

Keywords: amplification, dominant frequency, HVSR, inversion method, and shear wave velocity
1. Introduction

Bandung is the capital city of West Java with 12,713 population per km$^2$ and the most populated city in this province according to the BPS report in 2014. According to the historical notes, Bandung is located in a basin where laid a prehistoric lake on it before and Bandung is also located near geological hazards. These conditions, make Bandung has similarity as Mexico City.

From the geographical aspects, Bandung is a part of West Java physiography which characterized by alluvial layers on top, fault zones, and volcanoes. In the geological hazard aspects, Bandung is affected by local faults and subduction zones in the eastern of Java Island. These local faults near Bandung area are Lembang Fault, Baribis Fault, and Cimandiri Fault. Cimandiri Fault can produce earthquake with maximum magnitude of 7.2, and Lembang Fault can produce earthquake with maximum magnitude of 6.6[1]. According to the geological and geomorphological configuration, Bandung has sediment layer’s depth up to 100 meters consists of volcanic and lake deposit from the drilling core [2]. Those conditions make Bandung vulnerable to earthquake hazard, so Bandung needs infrastructure regulation to save the people and to minimize the damage from earthquake.

According to the infractions above, we need to know the structure and dynamic response of the subsurface layer of Bandung area as an effort for hazard mitigation. In this research, we would like do subsurface seismic characterization with HVSR method (Horizontal to Vertical Spectrum Ratio) which then the HVSR curve result will be inversed to estimate the shear wave velocity bellow Bandung area.

2. Geological Setting

![Figure 1. Bandung vertical section across from north to the south part [2].](image)

Bandung Basin spans from Nagreg in east to Padalarang in west with distance about 60 km and is surrounded by active Quaternary volcanoes in north, east, and south side [3]. Figure 1 shows Bandung Basin geology, the central part of West Java which part of Sunda Arc subduction has characteristics of basaltic-andesitic active volcanic [2]. In this region, there are two mountains formed in Quaternary era in its north and south side. The southern part mountains have its center Malabar Mountain while the northern part mountain is called Tangkuban Perahu Complex. The height of center part of Bandung Basin is about 660 m.

Bandung is a large intramountain basin which developed by tectonic subsidence, paroxysmal eruptions, volcanism-induced faulting/riifting, drainage system adaptations, and intramontane lacustrine sedimentation processes with rock configuration of layering clay, sand, silt, and conglomerate rock up to 104 meters [2].

Lembang Fault has shallow creeping with slip rate about 6 mm/yr and deeper locking at 3-15 km [4]. Region around Cimandiri Fault has dominated M>3 seismic activity which probably associated
with seismic activity in fault zone [5]. Baribis Fault is active with a slow relative motion between Java and Sunda Block at about 5±0.2 mm/yr [6].

3. Data and Method

Data used in this research is microtremor data which recorded by three-component seismometer velocity ground motion in 60 locations with frequency sampling 250s. The data are recorded between March 17th and October 6th, 2014 and (Figure 2) shows the station distribution of this research.

HVSR method has been developed for seismic characterization since 1990s. The peak of H/V curve cannot be explained with Rayleigh wave because the energy of Rayleigh wave does not appear on the peak or almost equal to zero [7]. The horizontal tremor is amplified through multi-reflection of S wave, the vertical tremor is amplified through multi-reflection of P wave, while the effect of Rayleigh wave which appear in the vertical tremor has value effect nearly zero when the ratio of H/V is approximately 1 [8]. So, the wave affects the peak of H/V curve is shear wave. Estimated ratio of H/V in bedrock is close to 1 because no amplitude in specific direction prevails and the tremors occur in this layer is even, so the H/V curve amplitude value is the amplification of the basement in the sediment layer [8].

We used Geopsy software to compute the HVSR curves with frequency range from 0.1 to 10 Hz. To minimize narrow modulations and spikes which will lead to extreme values of HVSR, we used [9] smoothing operator. To select the signal from the transient signal, we used the ratio between the average level of signal amplitude over a short period time (STA) and long-term average (LTA). The STA and LTA values are set at 60s and 1800s or 3600s respectively, and the STA/LTA ratio value is set between 0.5 and 1.2 to select the stationer windows.

![Figure 2](image-url)
The result of H/V curve then used to estimate the ground shear wave velocity using inversion method with Monte Carlo algorithm. This inversion is done in Matlab software using script which is developed by [10]. We do the inversion cycle of each curve three different perturbation value which is smaller for the next cycle (75%, 50%, and 25%). The perturbation value in the first cycle is 75% because we want to make a wide searching range, then we make it smaller for the next cycle to make the searching range smaller to focus on searching the smaller error value. In each cycle, we do the inversion process 10000 times and we use the smoothing value in range between 100 to 800. The initial model used in this process is a random model which is estimated from the actual rock composition to estimate the $V_{s30}$ in Bandung Basin which value in Table 1.

**Table 1.** Value of initial model to do the inversion process

| Layer | Vp (m/s) | Vs (m/s) | Density (kg/m$^3$) | Thickness (m) | Qp | Qs |
|-------|----------|----------|---------------------|---------------|----|----|
| 1     | 900      | 230      | 2                   | 12            | 20 | 10 |
| 2     | 900      | 230      | 2                   | 17.5          | 25 | 15 |
| 3     | 1300     | 200      | 2                   | 29.5          | 30 | 20 |
| 4     | 2300     | 650      | 2                   | 100           | 35 | 25 |
| 5     | 2500     | 800      | 2                   | 150           | 40 | 30 |
| 6     | 2750     | 1300     | 2                   | 200           | 45 | 35 |
| 7     | 3000     | 1500     | 2                   | 250           | 50 | 40 |
| 8     | 3500     | 1800     | 2                   | 999           | 999| 999|

4. Result and Discussion

The amplification values and dominant frequencies are selected automatically by Geopsy. The amplification values are selected at the highest value of the H/V curve and their frequencies are selected as the dominant frequencies. We selected H/V spectrum result which shows clear peak and eliminate the linear spectrum in BNA02 and BNB02 stations. Figure 3 shows the amplification values of Bandung Basin and its surrounding area. The value of amplification value is mostly between 2-11.5 with the lowest value is 2.1 in the northern part and the highest value is 11.5 in the south-eastern part. The highest frequency is in the southeast part of the observation area consistent with the result of research in Bandung region which is done by Marjiono and Afnimar in 2011 and CSAMT study in 2013 that indicate the eastern part of Bandung has sediment thickness about 1000 m [11]. This can be caused by the sediment thickness in the south-eastern part of the observation area is thicker and the sediment thickness in the northern part of the observation area and in the western part of Bandung City are thinner than the other part of the observation area. The amplification occurs by the trapping the wave then reflected in multiple times in the sediment layer, so the thicker sediment layer, the bigger amplification value.

The dominant frequency result from H/V curve is showed in Figure 3. The north and south part of observation area have higher dominant frequency value between 0.1-8 Hz than the area in the middle which the dominant frequency is between 0.1-1.7 Hz. The area with lowest frequency is in the northern part of Bandung Regency and southern part of Bandung City. This can be caused by the sediment layer in this area is thicker than the other part of the observation area. This condition is match with the geological condition of observation area which the north and south part are mountain area and the middle part is basin area. Mountain area usually has thinner sediment layer than basin area. This result also supports the amplification value in Figure 4 which the north part of Bandung Regency and southeast part of Bandung City have higher amplification value that leads to have thicker sediment layer.
Figure 3. Dominant frequency map in Bandung Basin and its surrounding area.

Figure 4. Amplification map in Bandung Basin and its surrounding area.

Figure 5 shows the shear wave velocity variance in several depths. Shear wave velocity in 30 m to 50 m are mostly low, less than 200 m/s which this part is dominated by sedimentary rocks and there is high shear wave velocity anomaly in the north part which is dominated by igneous rock. There is a high velocity anomaly on 250 m of depth in the north part of Bandung City. This anomaly then merged the north and south high velocity anomaly which separated the low velocity zone in the Bandung City and north part of Bandung Regency. These low velocity zones are the part of Bandung Basin which have thick sediment layer and separated by a high named Ujung Berung High [12].
Figure 5. Horizontal section of shear wave velocity for several depth 30 m (a), 50 m (b), 100 m (c), 250 m (d), 500 m (e), 1000 m. In a) there are three cross section line with South-North (green line) and three cross section line with West-East orientation (purple line).

Figure 6 shows the shear wave velocity in cross section with south-north orientation (left figure) which there is low shear wave velocity zone (less than 800 m/s) in the depth about 200 m. In those three cross sections the sediment layer in the south part is thicker than in the north part. This is caused by the south part of observatory area is the basin part while the north part is the mountains area which is dominated by andesitic rocks. The cross section of shear wave velocity with west-east orientation
(right figure) shows that Bandung Basin is divided into two part (west and east) by a high shear wave velocity which is above 1000 m/s that shown clearly in cross section CC-CC’. The sediment layer in Bandung Basin is quite thick which reaches about 200-300 m of depth. This is because Bandung is an ancient lake which made it as an area of sediment deposition.

![Cross section of shear wave velocity](image)

**Figure 6.** Cross section of shear wave velocity in three south-north cross section (left) and three west-east cross section (right).

5. Conclusion

Amplification value in Bandung Basin and its surrounding area is between 2-11.5 with its highest value is in the south-eastern part of observation area, while the segmented amplification values based on natural period of building are varies in values based on the range of period and location points. The dominant frequency in Bandung Basin and its surrounding area is between 0.1-8 Hz with the highest values are in the tip north and tip south part of observation area, while the southern to middle part has the lowest value. Bandung Basin has low shear wave velocity (less than 800 m/s) reaches to 200-300 m of depth and there is also a high structure divides Bandung Basin into east and west part.
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